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Drivers of Fertilizer Markets: Supply, Demand, and Prices

Angelica Williams, LaPorchia A. Collins, and Amy Boline





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Drivers of Fertilizer Markets: Supply, Demand, and Prices

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Abstract

U.S. fertilizer production and consumption—crucial for the productivity of U.S. agriculture—take place within a global fertilizer market. The fertilizer price increases of 2021–22, driven by a set of national and global market events, pushed U.S. fertilizer costs per acre for corn and wheat in 2022 to more than double their levels in 2020. This study analyzes U.S. fertilizer production, consumption, and trade from 2006 (the last full year preceding the Great Recession) to 2023. Relative to 2006, U.S. fertilizer consumption and production have declined. Over the study period, U.S. nitrogen fertilizer consumption remained higher than phosphate and potash fertilizer consumption combined. Whereas phosphate fertilizer was once the main fertilizer produced in the United States, nitrogen fertilizer now makes up the largest share of production, while potash fertilizer made up 2 percent or less of total U.S. fertilizer production throughout the period. While global production and trade in fertilizer have increased, the U.S. share of world fertilizer production, imports, and exports have each declined by 25 percent or more since 2006.

Keywords: fertilizer, nitrogen, potash, phosphate, trade

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About the Authors

Angelica Williams and Amy Boline are agricultural economists in the Market and Trade Economics Division of the Economic Research Service in the U.S. Department of Agriculture. LaPorchia A. Collins (formerly of USDA, ERS) is an assistant professor in the Tufts University Friedman School of Nutrition Science and Policy. While at USDA, ERS, she led the production of this report.

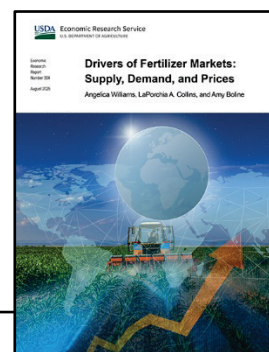
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A report summary from the Economic Research Service

Drivers of Fertilizer Markets: Supply, Demand, and Prices

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Key Points

- Global production and trade volumes in fertilizer increased by 27.4 and 18.8 percent, respectively, between 2006 and 2022. Meanwhile, the U.S. share of global production, imports, and exports each declined by 25 percent or more over the same period.
- In 2022, the United States produced 36.6 million metric tons of nutrient fertilizer, 8.4 percent of the world total by volume. Between 2006 and 2022, U.S. fertilizer production declined by 5.1 percent, driven by a 10.3 million metric ton reduction in phosphate production.
- Because fertilizer is a major cost in the U.S. production of corn and wheat, increases in fertilizer prices affect farmers' crop management decisions.
- U.S. fertilizer consumption dropped meaningfully in 2021, in part due to a rapid increase in fertilizer prices, with nitrogen, phosphate, and potash consumption declining 5.8, 12.6, and 16.2 percent between 2020 and 2021, respectively.
- In 2006–22, the composition of U.S. fertilizer production and exports shifted. In 2006, phosphate made up 64 percent of U.S. fertilizer production and 77 percent of exports, but by 2022, nitrogen made up the largest share of production at 61 percent and exports at 54 percent.
- The United States relies on imports to meet demand for potash. In 2022, U.S. potash production was less than 5 percent of that needed for domestic use.

Why Does This Matter?

Most countries rely on imports to meet domestic fertilizer demand. Between 2020 and 2021, fertilizer prices increased substantially when conflicts involving major fertilizer-producing countries (Belarus, Russia, and Ukraine) exacerbated already high fertilizer prices. Global fertilizer prices dropped between 2022 and 2023, but ongoing military conflicts introduced additional volatility in fertilizer prices. This study analyzes trends in U.S. fertilizer supply, demand, and prices and identifies factors that have contributed to changes since 2006. In 2023, U.S. fertilizer costs per acre varied by

region. For corn, fertilizer costs per acre were highest in the Southern Seaboard (\$238.57 per acre) and lowest in the Prairie Gateway (\$127.88 per acre). For wheat, fertilizer costs per acre were highest in the Heartland (\$107.42 per acre) and lowest in the Fruitful Rim (\$57.98 per acre). Relative to historical averages in 2010–19, fertilizer costs per acre for corn and wheat in 2022 were 110 percent and 141 percent higher, respectively. Fertilizer's share of total operating costs also increased in 2022, with fertilizer costs making up more than 40 percent of operating costs for corn and wheat production each.

Drivers of Fertilizer Markets: Supply, Demand, and Prices

Introduction

Between 2020 and 2021, U.S. fertilizer prices increased substantially, driven in part by the Coronavirus (COVID-19) pandemic, rising energy prices, and trade restrictions (Outlaw et al., 2022; Wongpiyabovorn et al., 2022; Fedorinova & Albery, 2021; Outlaw et al., 2021; Wongpiyabovorn, 2021). In 2022, conflicts involving fertilizer-producing countries (i.e., Belarus, Russia, and Ukraine) exacerbated already high fertilizer prices (Kee et al., 2023). Recent conflicts involving Israel, a major potash-producing country, have sparked renewed concern regarding the potential for high fertilizer prices and disruptions in fertilizer supply. In addition, rising global demand for feed grains and oilseeds has increased fertilizer demand, especially for use in corn, wheat, rice, and vegetable production (Myers, 2021). Though fertilizer prices have dropped since the end of 2022, some have remained above the levels observed prior to the Russia-Ukraine war. Changes in fertilizer prices affect farmers' crop management decisions, and these decisions may have environmental implications (Ribaud et al., 2012; Ribaud et al., 2011). Thus, information on factors contributing to fertilizer prices and use may inform U.S. policy and help contextualize the impacts of global market events on U.S. farms.

Several studies published by the USDA, Economic Research Service (ERS) have provided insight on factors influencing fertilizer markets. Huang (2007) focused on the link between natural gas prices and the supply of ammonia, the key input in nitrogen fertilizer production, and found that increases in natural gas prices during 2000–2006 contributed to declines in domestic ammonia production and an increase in U.S. ammonia imports from 15 percent of the U.S. aggregate supply of ammonia in 2000 to 42 percent in 2006. High natural gas prices during that period contributed to a 130-percent increase in the price of ammonia paid by U.S. farmers. Similarly, from 2002 to 2008, nitrogen, potash, and phosphate prices rose in part due to increased global demand and low domestic inventories (Huang, 2009). Huang (2009) noted that fertilizer price increases during 2002–08 were due to a complex combination of market events that affected fertilizer demand (e.g., economic growth, export tariffs, high commodity prices, and increased global consumption) and fertilizer supply (e.g., rising costs of energy, transportation, and raw inputs; increased industry concentration; and strong export fertilizer associations).

This study extends previous work on the drivers of fertilizer prices (Huang, 2009) by characterizing changes in fertilizer markets since the Great Recession and providing an overview of fertilizer use in producing major crop commodities.

U.S. fertilizer production and consumption take place within a global fertilizer market. We identify the main types of fertilizer produced in the United States and discuss how domestic production relates to natural resource availability. Partly due to resource limitations, some of the fertilizer consumed in the United States is imported from other countries. We measure the extent to which the United States relies on imports to meet domestic fertilizer demand. We show that U.S. fertilizer production is sufficient to meet domestic demand for phosphate fertilizer and meets most of the demand for nitrogen fertilizer. However, the United States is heavily dependent on imports to meet potash fertilizer demand. We also highlight U.S. fertilizer imports and exports over time and summarize the U.S. contribution to global fertilizer supply. We discuss national and global market events that have impacted fertilizer prices and contributed to farm costs of production for major crop commodities, specifically corn and wheat.

U.S. Fertilizer Supply

U.S. Fertilizer Production Depends on Available Natural Resources

Below, we introduce the production processes of the various forms of nitrogen, phosphorus, and potassium fertilizers (figure 1), as well as the natural resources needed to produce them.

The Haber-Bosch process, named after its inventors Fritz Haber and Carl Bosch, generates concentrated nitrogen (82 percent nitrogen content) in the form of anhydrous ammonia through a conversion process. The process consists of a reaction between atmospheric nitrogen and hydrogen, under intense heat and pressure, combined with a catalyst (such as iron) that produces ammonia gas (NH₃) (Blois, 2023). Ammonia gas is then condensed using cold water to create liquid ammonia or anhydrous ammonia. Anhydrous ammonia is extensively used across major U.S. corn-producing States.

The production of urea and other forms of nitrogen fertilizer often use anhydrous ammonia as a starting point. Urea, which has a 46 percent nitrogen content, is produced by combining ammonia and carbon dioxide, while urea ammonium nitrate (with a nitrogen content between 28 and 32 percent) is produced by combining urea, ammonia, and nitric acid (Sellars et al., 2021). Ammonium nitrate (34 percent nitrogen content) and ammonium sulfate (21 percent nitrogen content) are also fertilizers derived from ammonia, requiring the addition of nitric acid and sulfuric acid, respectively (International Plant Nutrition Institute (IPNI), 2024). Meanwhile, ammonium nitrate combined with calcium carbonate (also known as limestone) and nitric acid produces calcium ammonium nitrate (21 percent nitrogen content).

Natural gas is considered a key component in the production of nitrogen fertilizer because it is used to create the heat needed for the Haber-Bosch process to produce ammonia gas. Natural gas production in the United States was estimated to be 934.2 billion cubic meters in 2021, roughly 23 percent of global production (EI Statistical Review of World Energy, 2022). U.S. natural gas production increased at an average of 4.2 percent annually from 2011 to 2021. The natural gas produced in the United States is used for domestic consumption and for export to other countries. Though most of the natural gas consumed in the United States is produced domestically, the United States still imports some natural gas; more than 99 percent of these imports come from Canada (U.S. Department of Energy, Energy Information Administration (EIA), 2023). Since the Great Recession, U.S. natural gas imports have mostly trended downward, while U.S. exports have increased substantially.

Since 2011, U.S. natural gas reserves have also trended upwards (British Petroleum Statistical Review of World Energy, 2022). As of 2020, the United States had 12.6 trillion cubic meters of natural gas reserves, 83 percent of North American reserves and 6.7 percent of global reserves. North America made up only 8.1 percent of global natural gas reserves in 2020. The largest share of global natural gas reserves was located in the Middle East (40.3 percent) and the Commonwealth of Independent States¹ (CIS) (30.1 percent). Of the independent states, the Russian Federation had the largest global share at 19.9 percent.

While natural gas is a major input for producing nitrogen fertilizer, producing phosphorus and potassium requires less energy. Phosphorus fertilizers are produced by treating phosphate rock with sulfuric acid to generate phosphoric acid. The phosphoric acid is then used in combination with ammonia to create a form of phosphorus fertilizer that is easily absorbed by plants. Monoammonium phosphate (MAP) and diammonium phosphate (DAP) are considered a good source of phosphorus (P) and nitrogen (N) fertilizer. MAP contains 10 percent nitrogen and 22 percent phosphorus content, while DAP contains 18 percent nitrogen and 20 percent phosphorus content (University of Minnesota Extension, 2024).

¹ The Commonwealth of Independent States includes Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, and Uzbekistan.

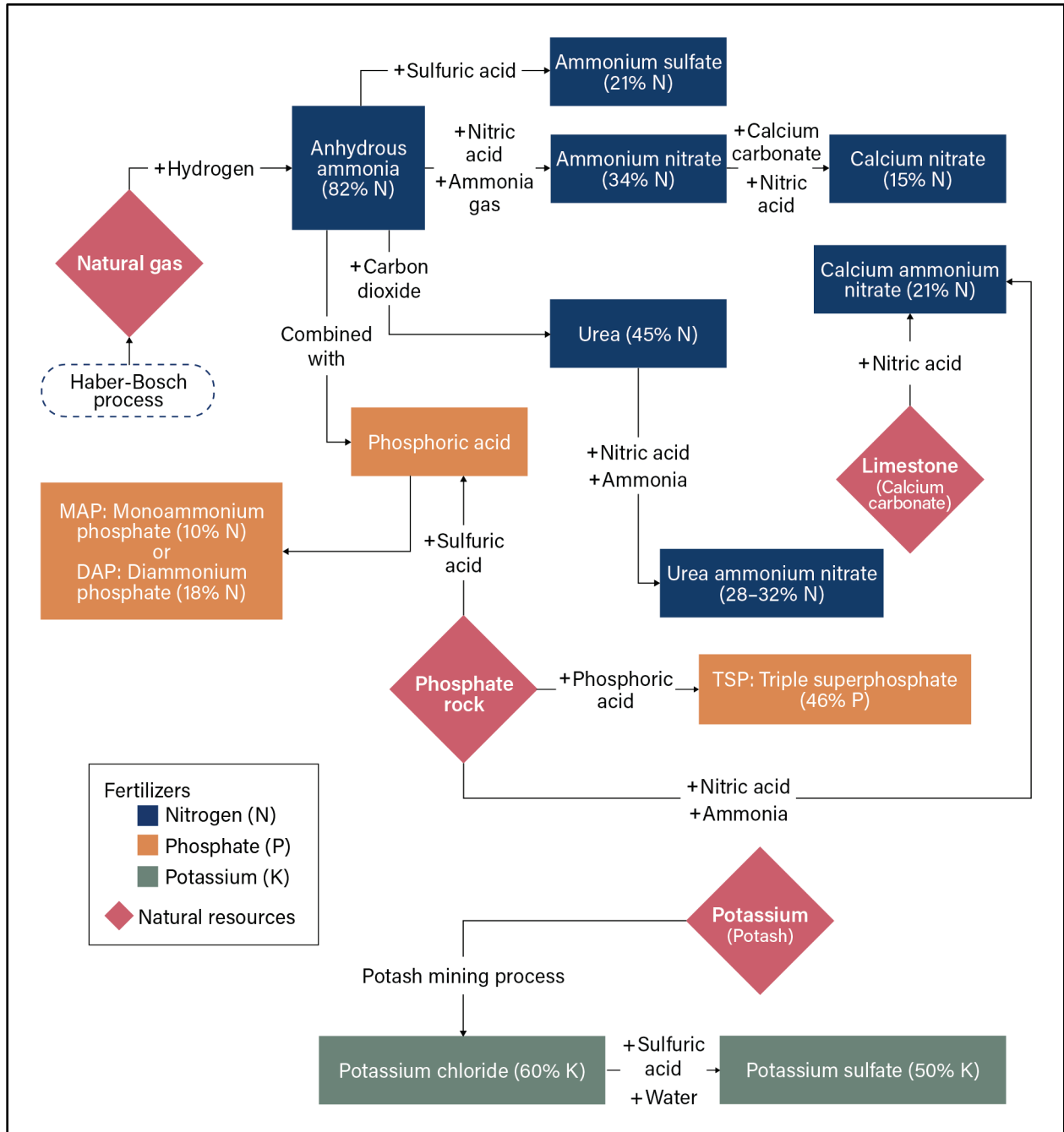
According to the U.S. Geological Survey (USGS) (2022), the United States has 1 billion metric tons in phosphate rock reserves. In 2021, U.S. phosphate rock ore was processed into an estimated 22 million tons of marketable product, about 10 percent of the world total, for a sales value of \$1.7 billion. Since 2017, the U.S. volume of marketable production of phosphate rock has declined 21 percent. More than 75 percent of U.S. phosphate rock production occurred in Florida and North Carolina, and the remainder occurred in Idaho and Utah. More than 95 percent of U.S. phosphate rock output was used in the manufacturing of ammonium phosphate fertilizers and animal feed supplements. Apparent consumption of phosphate rock was estimated at 25 million metric tons, about 10 percent of which was imported. In 2017–21, the U.S. obtained phosphate rock imports from Peru (87 percent) and Morocco (13 percent).

Potassium fertilizers are sourced from potash, which is mined from deep underground. The potash mining process includes injecting hot water deep into the ground to dissolve mineral deposits containing potassium chloride as well as other salts. Potassium chloride, which is also known as muriate of potash (60 percent potassium content), is then separated from other salts and made into a form suitable for agricultural use. Considered an excellent source of potassium for plants, potassium sulfate fertilizer (50 percent potassium content) is obtained by combining potassium chloride with sulfuric acid and water (Crop Nutrition, 2024a).

Reserves of U.S. potash, also known as potassium oxide (K₂O), totaled 220 million metric tons, with the bulk of U.S. potash production located in New Mexico and Utah (USGS, 2022). In 2021, the United States produced marketable potash totaling an estimated 480,000 metric tons of potassium oxide equivalent, only about 1 percent of the world total, for an estimated sales value of \$520 million. Roughly 85 percent of U.S. potash sales were used for fertilizer production. Still, USGS estimated that potash imports comprised 95 percent of U.S. apparent consumption, with imports coming mainly from Canada (75 percent), Russia (10 percent), and Belarus (8 percent) in 2017–21.

Overall, the United States has available reserves of natural gas, phosphate rock, and potash; however, using these reserves may require overcoming challenges associated with available technology, transportation infrastructure, and regional differences in resource prices, among other factors. Thus, imports of mineral commodities are expected to remain a source of feedstock for manufacturing U.S. fertilizer.

Figure 1
Fertilizer production processes and the role of natural resources



Source: USDA, Economic Research Service using information derived from Central Farmers Industries (2023), Crop Nutrition (2024b), Fertilizers Europe (2023), Florida Industrial and Phosphate Research Institute (2024), Hancock (2022), and University of Minnesota Extension (2024).

The Composition of U.S. Fertilizer Supply Has Shifted Over Time

Using data from the International Fertilizer Association (IFA), we analyzed the composition of U.S. fertilizer supply, including production, trade, and apparent consumption, which is equal to production plus

imports minus exports.² Apparent consumption provides a broad look at the availability of fertilizer nutrients because it includes all potential uses (plant nutrition, animal feed, and industrial uses), whereas fertilizer consumption data, to be discussed later, focus on nutrient use for plant nutrition only. We explored trends in 11 major fertilizer products for which data were available from the IFA. In the analysis, we treated these products as the universe of fertilizer products to assess changes in the distribution and composition of fertilizer supply. For each supply component, the volume of fertilizer was measured in metric tons of nutrient (not in terms of the weight of fertilizer product).³

In 2022, the United States produced a total of 36.6 million metric tons of fertilizer, roughly 8.4 percent of the world total (table 1). About 3.2 million metric tons of fertilizer were exported from the United States to other countries, totaling roughly 8.7 percent of U.S. production and 3.1 percent of world exports. In contrast, the United States imported 10.7 million metric tons of fertilizer, making up 10.5 percent of world imports. Imports helped meet domestic demand, as apparent consumption of fertilizer exceeded production by more than 6 million metric tons. The United States alone made up just over one-tenth (10.1 percent) of world apparent consumption of fertilizer.

Table 1

Composition of U.S. fertilizer supply and share of world supply, 2022

| | Production | Imports | Exports | Apparent consumption |
|---|---------------|---------------|--------------|----------------------|
| Thousand metric tons of nutrient | | | | |
| Ammonia | 13,816 | 1,882 | 760 | 14,938 |
| Ammonium nitrate | 2,890 | 93 | 164 | 2,819 |
| Ammonium sulphate | 591 | 159 | 136 | 614 |
| Calcium ammonium nitrate | 0 | 2 | 0 | 2 |
| Diammonium phosphate | 746 | 208 | 306 | 972 |
| Monoammonium phosphate | 1,891 | 467 | 850 | 1,785 |
| Phosphate rock | 5,639 | 750 | 0 | 6,508 |
| Phosphoric acid | 5,968 | 233 | 297 | 4,393 |
| Potassium chloride | 149 | 4,471 | 0 | 4,620 |
| Triple superphosphate | 0 | 147 | 0 | 147 |
| Urea | 4,865 | 2,305 | 665 | 6,505 |
| Total | 36,555 | 10,716 | 3,178 | 43,302 |
| U.S. percent of world total | | | | |
| Ammonia | 9.2 | 12.7 | 5.1 | 10.1 |
| Ammonium nitrate | 18.7 | 4.0 | 7.2 | 18.4 |
| Ammonium sulphate | 9.4 | 4.4 | 3.7 | 9.8 |
| Calcium ammonium nitrate | 0.0 | 0.1 | 0.0 | 0.1 |
| Diammonium phosphate | 4.8 | 3.1 | 4.6 | 6.5 |

Continued on next page ►

² Apparent consumption may not exactly equal production plus imports minus exports partly due to rounding and methods used for aggregation. Apparent consumption data are not disaggregated based on final use (plant nutrition, animal feed, or industrial use). It is a measure of what nutrients are available for the production of fertilizer, though not equivalent to what may have been actually used in the fertilizer production process.

³ Each fertilizer product contains a combination of nitrogen (N), phosphorus (P), and potassium (K), the three main nutrients needed by plants to grow. The nutrient content is listed as a percentage of each component in the form (N-P-K). For the fertilizers discussed in this document, anhydrous ammonia's content is (82-0-0), urea is (46-0-0), and liquid nitrogen is (28-0-0). Since these fertilizers only contain percentages of N, P, and/or K, 1 pound of fertilizer will contain less than 1 pound of any specific nutrient. For example, 1 metric ton (2,204 pounds) of anhydrous ammonia has a nitrogen content of roughly 1,816 pounds.

Table 1 (cont.)

Composition of U.S. fertilizer supply and share of world supply, 2022

| | Production | Imports | Exports | Apparent consumption |
|------------------------------------|------------|-------------|------------|----------------------|
| U.S. percent of world total | | | | |
| Monoammonium phosphate | 12.8 | 7.8 | 14.2 | 12.1 |
| Phosphate rock | 9.0 | 8.7 | 0.0 | 10.6 |
| Phosphoric acid | 13.6 | 5.7 | 7.3 | 10.4 |
| Potassium chloride | 0.4 | 16.3 | 0.0 | 12.9 |
| Triple superphosphate | 0.0 | 10.2 | 0.0 | 6.8 |
| Urea | 5.7 | 9.4 | 2.7 | 7.7 |
| Total | 8.4 | 10.5 | 3.1 | 10.1 |

Note: Supply data are in thousand metric tons of nutrient (N, P₂O₅, and K₂O). Apparent consumption is approximately production plus imports minus exports. Total nutrients for a given supply component may not equal the sum of individual items due to rounding. Source: USDA, Economic Research Service using data from the International Fertilizer Association accessed December 2023.

The composition of global fertilizer supply remained relatively the same from 2006 to 2022, while the composition of U.S. fertilizer supply shifted over time. In 2006–22, nitrogen fertilizers made up over half of global fertilizer production each year and averaged 45 percent of the global fertilizer trade over the period. Phosphate fertilizers made up 30–40 percent of global production each year and averaged 27 percent of global trade, while potash made up less than 10 percent of global production each year but averaged 28 percent of global trade.

In 2022, the top five fertilizers in the United States based on shares of the total metric tons of nutrient produced were ammonia (37.8 percent), phosphoric acid (16.3 percent), phosphate rock (15.4 percent), urea (13.3 percent), and ammonium nitrate (7.9 percent). Similarly, the top five fertilizers available for domestic use based on apparent consumption were ammonia (34.5 percent), phosphate rock (15.0 percent), urea (15.0 percent), potassium chloride (10.7 percent), and phosphoric acid (10.1 percent).

In 2022, monoammonium phosphate (MAP) made up the largest share of exports (26.7 percent), followed by ammonia (23.9 percent) and urea (20.9 percent). Potassium chloride, a fertilizer for which the United States had relatively low production (only about 149,000 metric tons of the nutrient), made up the largest share of fertilizer imports (41.7 percent), followed by urea (21.5 percent) and ammonia (17.6 percent).

Between 2006 and 2022, U.S. production increased for only 4 of the 11 nutrients under study, with a notable 84-percent increase for ammonia, a 62.4-percent increase for urea, and a 32.9-percent increase for ammonium nitrate. On the other hand, U.S. production declined by roughly 80 percent for diammonium phosphate (DAP) and potassium chloride and by about 36 percent each for phosphate rock and phosphoric acid. The United States has not produced calcium ammonium nitrate since 2004 and triple superphosphate since 2006 partly due to a shift from using synthetic fertilizer to using organic fertilizer following the Organic Foods Production Act of 1990. The number of U.S. acres devoted to certified organic production more than doubled between 2000 and 2005, from 1.8 to 4.1 million acres (USDA, ERS, 2013). Despite these changes, ammonia, phosphoric acid, and phosphate rock are still the top three fertilizer products produced by the United States.

Table 2

Nutrient share and ranking in U.S. supply, by component in 2006 and 2022

| | Production | | Imports | | Exports | | Apparent consumption | |
|------------------------------|------------|----------|----------|----------|----------|----------|----------------------|----------|
| | 2006 | 2022 | 2006 | 2022 | 2006 | 2022 | 2006 | 2022 |
| Percent of U.S. total | | | | | | | | |
| Ammonia | 19.5 | 37.8 | 43.6 | 17.6 | 3.7 | 23.9 | 27.9 | 34.5 |
| Ammonium nitrate | 5.6 | 7.9 | 2.8 | 0.9 | 0.8 | 5.2 | 5.2 | 6.5 |
| Ammonium sulphate | 1.4 | 1.6 | 0.4 | 1.5 | 4.1 | 4.3 | 0.8 | 1.4 |
| Calcium ammonium nitrate | - | - | < 0.1 | < 0.1 | - | - | < 0.1 | < 0.1 |
| Diammonium phosphate | 10.6 | 2.0 | 0.3 | 1.9 | 50.1 | 9.6 | 3.4 | 2.2 |
| Monoammonium phosphate | 5.7 | 5.2 | 0.4 | 4.4 | 19.4 | 26.7 | 2.8 | 4.1 |
| Phosphate rock | 23.0 | 15.4 | 5.5 | 7.0 | - | - | 20.4 | 15.0 |
| Phosphoric acid | 24.3 | 16.3 | 0.1 | 2.2 | 7.3 | 9.3 | 19.2 | 10.1 |
| Potassium chloride | 1.9 | 0.4 | 30.9 | 41.7 | 3.8 | - | 10.2 | 10.7 |
| Triple superphosphate | 0.3 | - | 0.2 | 1.4 | 0.6 | - | 0.2 | 0.3 |
| Urea | 7.8 | 13.3 | 15.7 | 21.5 | 10.2 | 20.9 | 9.8 | 15.0 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Rank from high to low | | | | | | | | |
| Ammonia | 3 | 1 | 1 | 3 | 7 | 2 | 1 | 1 |
| Ammonium nitrate | 7 | 5 | 5 | 10 | 8 | 6 | 6 | 6 |
| Ammonium sulphate | 9 | 8 | 6 | 8 | 5 | 7 | 9 | 9 |
| Calcium ammonium nitrate | - | - | 11 | 11 | - | - | 11 | 11 |
| Diammonium phosphate | 4 | 7 | 8 | 7 | 1 | 4 | 7 | 8 |
| Monoammonium phosphate | 6 | 6 | 7 | 5 | 2 | 1 | 8 | 7 |
| Phosphate rock | 2 | 3 | 4 | 4 | - | - | 2 | 2 |
| Phosphoric acid | 1 | 2 | 10 | 6 | 4 | 5 | 3 | 5 |
| Potassium chloride | 8 | 9 | 2 | 1 | 6 | - | 4 | 4 |
| Triple superphosphate | 10 | - | 9 | 9 | 9 | - | 10 | 10 |
| Urea | 5 | 4 | 3 | 2 | 3 | 3 | 5 | 3 |

Note: Percents for a given year may not sum to 100 due to rounding. Percent and rank are only shown for fertilizers with non-zero quantities for a given supply component. The highest rank is indicated in bold for each supply component and year.

Source: USDA, Economic Research Service using data from the International Fertilizer Association accessed December 2023.

The composition of U.S. exports of fertilizers has shifted over time. Based on the amount of nutrient exported, DAP was the top fertilizer exported by the United States in 2006, making up 50 percent of nutrient exports versus only 10 percent in 2022. On the other hand, the export share of MAP increased more than 35 percent since 2006, and MAP is now the top fertilizer exported by the United States.

Potassium chloride and ammonia together made up more than half of all nutrient imports to the United States in 2006 and 2022. However, ammonia's share of U.S. imports dropped to less than half its import share in 2006, while U.S. imports of urea increased 37 percent to be just over one-fifth of fertilizer imported by the United States.

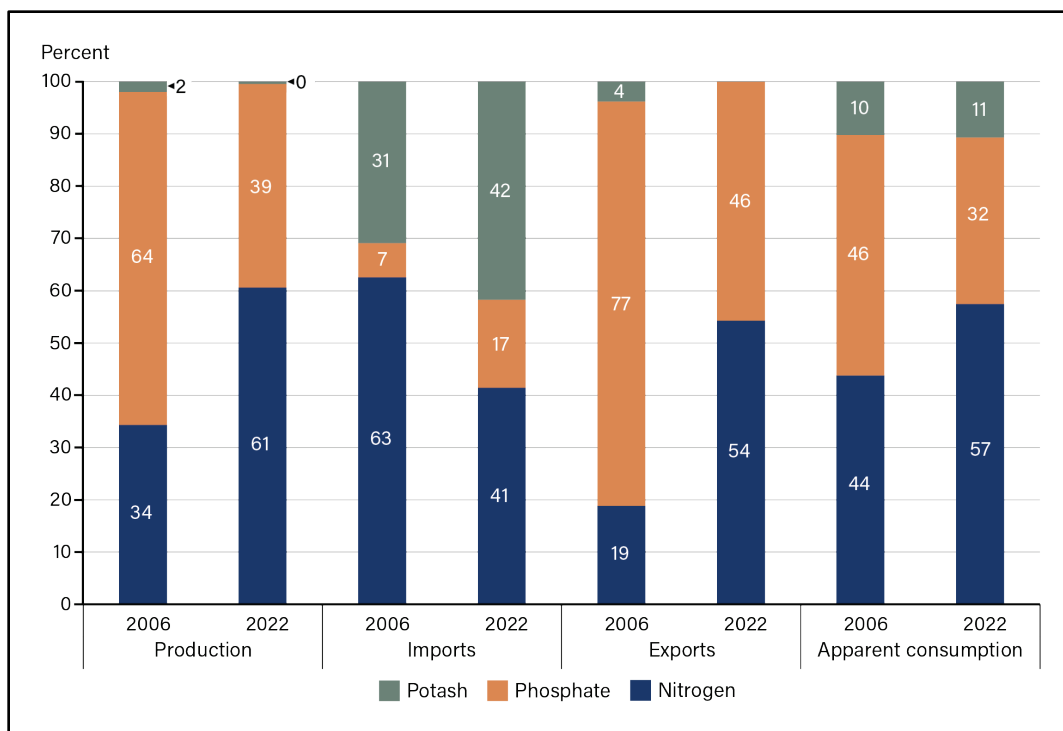
The composition of U.S. apparent consumption has changed slightly since 2006, with large percentage changes mostly occurring for nutrients for which the share of apparent consumption remains less than 10

percent. However, urea’s share of U.S. apparent consumption increased by 54 percent, while that of phosphate rock and phosphoric acid each declined by 26 and 47 percent, respectively.

We also examined changes in the composition of U.S. fertilizer supply for aggregate fertilizer products: nitrogen, phosphate, and potash. Nitrogen products include ammonia, ammonium nitrate, ammonium sulphate, calcium ammonium nitrate, and urea. Phosphate products include DAP, MAP, phosphate rock, phosphoric acid, and triple superphosphate, and potash refers to potassium chloride.

Nitrogen’s share of U.S. fertilizer production increased 77 percent from 2006 to 2022, while that of phosphate and potash declined 39 and 79 percent, respectively (figure 2). These production changes contributed to the share of U.S. fertilizer exports for nitrogen, increasing more than 2.5 times the share in 2006, while the export share for phosphate declined 41 percent and that of potash dropped to near zero. Potash alone made up 42 percent of U.S. fertilizer imports in 2022.

Figure 2
The composition of U.S. fertilizer supply in 2006 and 2022



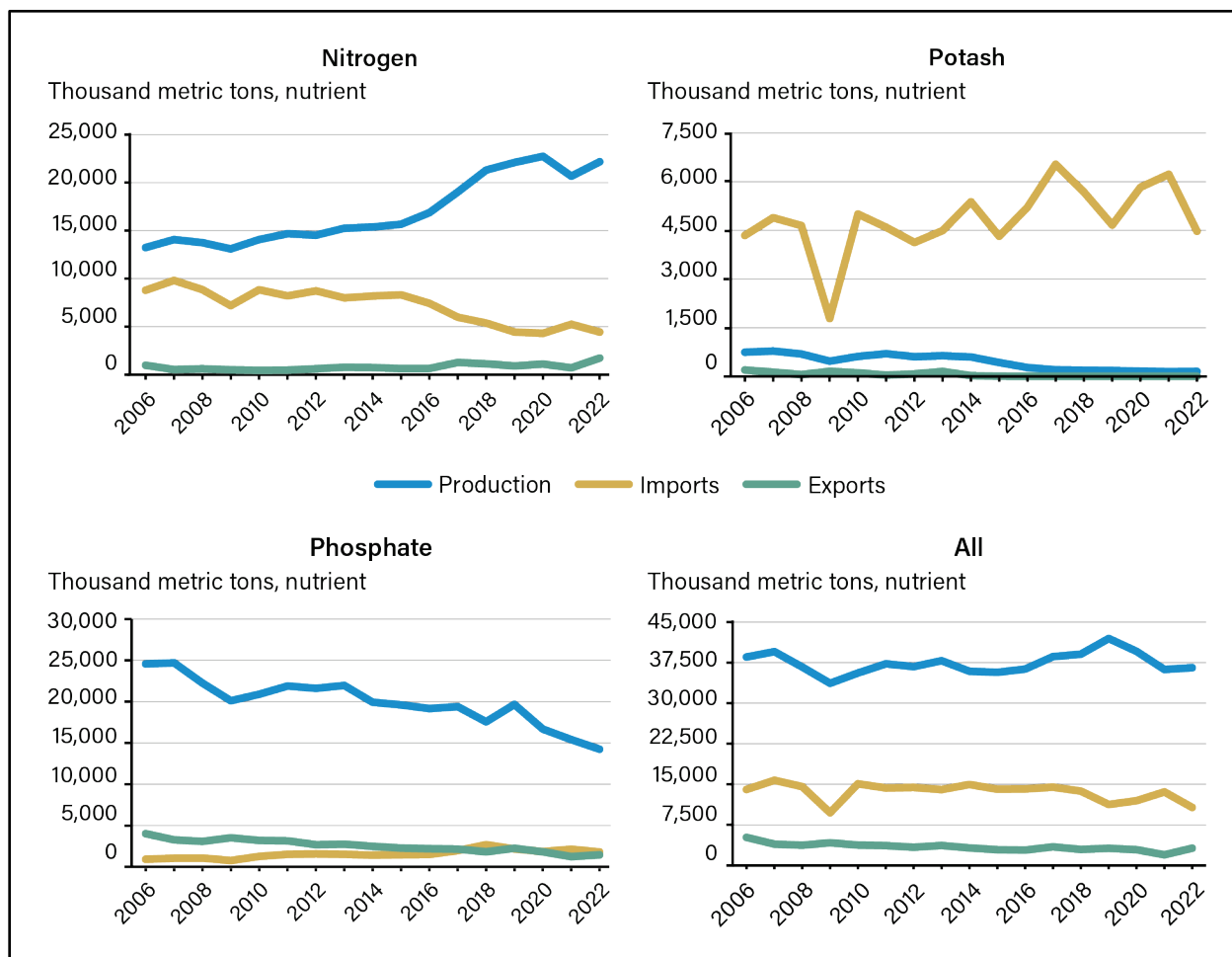
Note: Nitrogen products include ammonia, ammonium nitrate, ammonium sulphate, calcium ammonium nitrate, and urea. Phosphate products include diammonium phosphate, monoammonium phosphate, phosphate rock, phosphoric acid, and triple superphosphate. Potash refers to potassium chloride.
 Source: USDA, Economic Research Service using data from the International Fertilizer Association accessed December 2023.

The Relationship Between U.S. Production and Trade of Fertilizer from 2006 to 2022

We examined trends in U.S. production and trade more closely for aggregate nitrogen, phosphate, and potash fertilizer products from 2006 to 2022 using correlation coefficients (ρ), which measure the strength of the linear relationship between two variables. For nitrogen fertilizers, there was a high negative correlation between production and imports ($\rho = -0.94$): When production increases, the level of imports tends to decline. Figure 3 shows that from 2006 to 2015, nitrogen fertilizer production followed a positive trend, which was related to increased demand for corn in biofuel production following the Energy Policy Act and the Energy Independence and Security Act (Bekkerman et al., 2020). Nitrogen production increased in 2016–17 partly due to increased corn production and reduced natural gas prices (Bekkerman et al., 2020). Though nitrogen production ticked downward in 2021, it recovered in 2022, ending just below that of 2020.

Figure 3

U.S. production and trade of nitrogen, phosphate, and potash fertilizer, 2006–22



Note: Nitrogen products include ammonia, ammonium nitrate, ammonium sulphate, calcium ammonium nitrate, and urea. Phosphate products include diammonium phosphate, monoammonium phosphate, phosphate rock, phosphoric acid, and triple superphosphate. Potash refers to potassium chloride.
Source: USDA, Economic Research Service using data from the International Fertilizer Association accessed December 2023.

For phosphate fertilizers, there was a moderate negative correlation ($\rho = -0.66$) between production and imports, though phosphate fertilizer imports were relatively low compared to production. While imports have increased, phosphate production has followed a largely decreasing trend since 2006, with a notable decline during the Great Recession and another after 2020. The decline was in part due to production

disruptions from natural disasters such as Hurricane Ida and the Texas Freeze in 2021 (Brownlie et al., 2023) and Hurricane Ian in 2022 (The Mosaic Company, 2022).

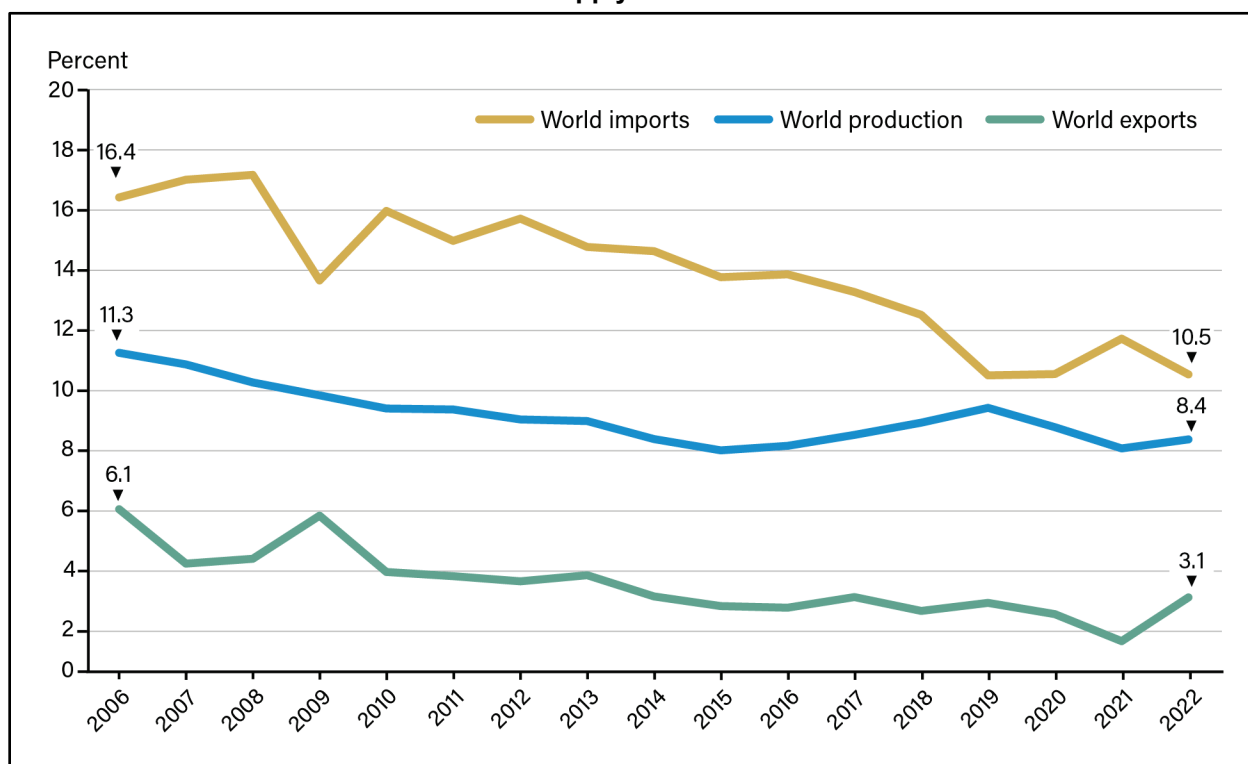
Between 2006 and 2022, U.S. potash production moved in the opposite direction of imports, although the relationship was not strong ($\rho = -0.40$). Though U.S. potash imports have followed an upward trend since 2013, they have fluctuated from year to year. For example, between 2008 and 2009, during the Great Recession, potash prices increased 17 percent, contributing to a 62-percent drop in U.S. potash imports (USGS, 2010 and Jasinski, 2011).

Between 2006 and 2022, total U.S. fertilizer production declined by 5.1 percent, with a 67.5-percent increase in nitrogen production (8.9 million metric tons) being outpaced by a 42.0-percent reduction in phosphate production (10.3 million metric tons). Over the same period, total U.S. fertilizer exports and imports dropped 38.7 and 23.7 percent, respectively. In contrast, world fertilizer production has increased by 27.4 percent, and world fertilizer trade has increased by 18.8 percent since 2006.

The U.S. share of world fertilizer supply declined notably between 2006 and 2022, dropping 25.5 percent for production, 35.8 percent for imports, and 48.4 percent for exports (figure 4).

Figure 4

Trends in the U.S. share of world fertilizer supply from 2006 to 2022



Source: USDA, Economic Research Service using data from the International Fertilizer Association accessed December 2023.

The United States Relies on Imports to Meet Fertilizer Demand

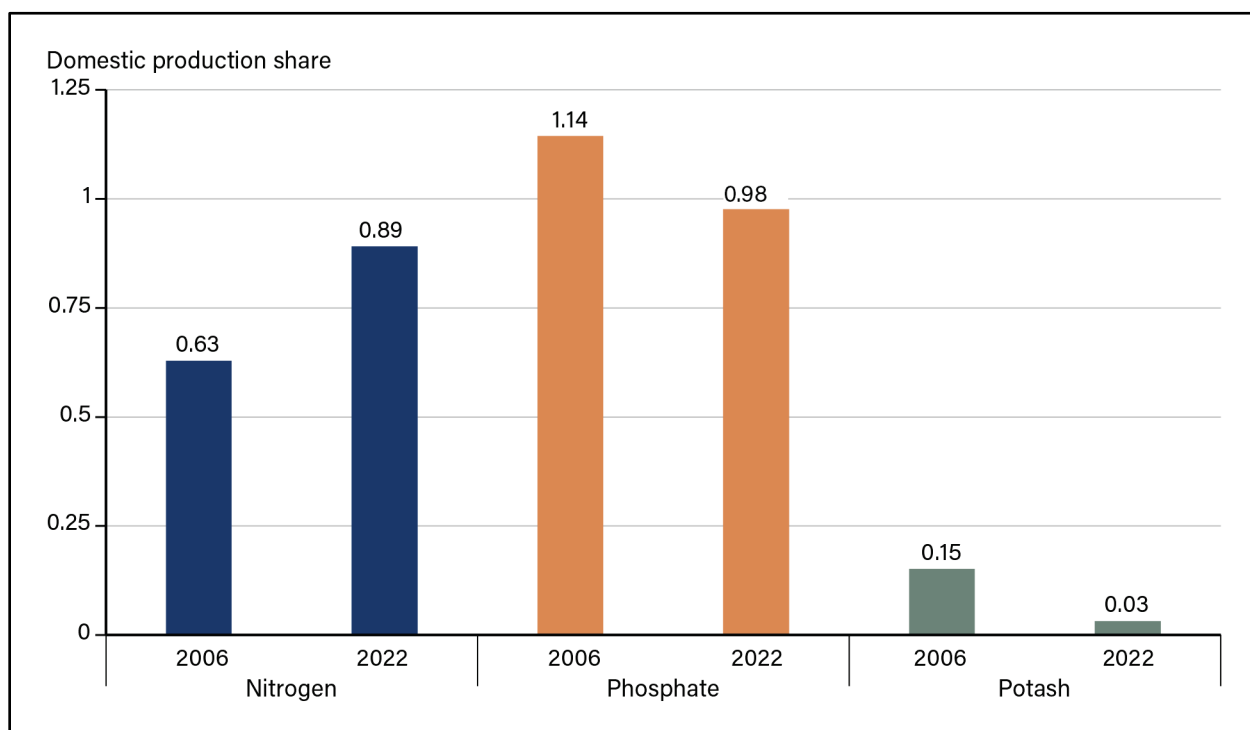
Globally, an average of 80.9 percent of potash fertilizer produced each year was traded in the world market in 2006–22. In contrast, 17.6 percent of the nutrient produced for nitrogen fertilizer and 24.2 percent of that produced for phosphatic fertilizer were traded in the global market each year, on average. These data suggest that countries tend to rely on trade to meet fertilizer demand, particularly for potash fertilizer, because the resources needed for potash production are especially limited to a small group of countries. For example, Russia and Belarus combined provided 40 percent of global potash exports in 2020 (Kee et al., 2023).

We assessed the extent to which the United States relied on imports to meet domestic fertilizer demand by calculating the share of domestic demand that was met by domestic production. Specifically, we divided production by the volume of production plus imports minus exports. A domestic production share of one or higher would mean the United States was able to produce enough fertilizer to meet domestic demand. Given natural resource constraints, a domestic production share greater than one is not necessarily a goal; instead, the measure provides insight on U.S. import reliance and potential supply vulnerabilities to global market shocks.

From 2006 to 2022, the U.S. domestic production share of nitrogen fertilizer increased, while that for phosphate and potash fertilizers declined (figure 5). In 2022, U.S. production was close to meeting domestic demand for phosphate fertilizer, with only 2 percent of phosphate fertilizer needs met through imports. In contrast, the United States continued to rely on imports to meet potash demand, with domestic potash production in 2022 less than 5 percent of that needed for domestic use.

Figure 5

U.S. domestic production shares for aggregate fertilizer products from 2006 to 2022

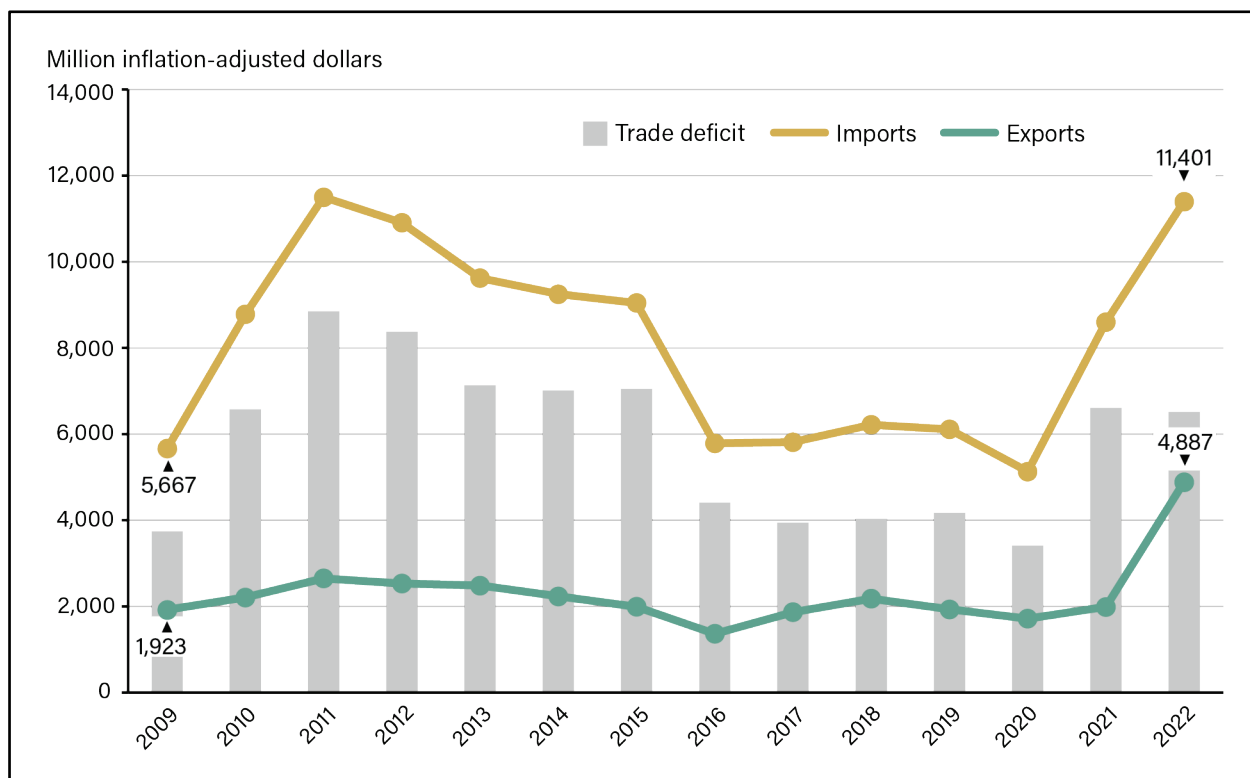


Note: Domestic production share = production / (production + imports – exports), each measured in fertilizer nutrient. Domestic production shares can be used to assess the extent to which a country relies on imports to meet domestic demand. Nitrogen products include ammonia, ammonium nitrate, ammonium sulphate, calcium ammonium nitrate, and urea. Phosphate products include diammonium phosphate, monoammonium phosphate, phosphate rock, phosphoric acid, and triple superphosphate. Potash refers to potassium chloride. Year-to-year variability exists between the 2 years included in this chart.

Source: USDA, Economic Research Service using data from the International Fertilizer Association accessed December 2023.

Using data from the International Trade Association (ITA), figure 6 shows the U.S. trade of nitrogen, phosphate, and potash fertilizer combined from 2009 to 2022, measured in 2023 dollars. We used the all-items Consumer Price Index for All Urban Consumers (CPI-U) to adjust for inflation.⁴ From 2009 to 2022, the United States ran a trade deficit for fertilizer, with the largest deficits occurring in 2011 and 2012 as fertilizer demand increased partly due to the global economic recovery following the Great Recession (Heffer & Prud'homme, 2014). U.S. fertilizer imports dropped in 2016, as the United States ramped up its nitrogen fertilizer production, thereby reducing the trade deficit. The U.S. trade deficit expanded in 2021 after an increase in fertilizer import value, largely driven by increases in the values of nitrogen (104 percent) and potash (52 percent) imports, in part due to fertilizer price increases and a 13.6 percent rise in the overall volume of fertilizer imported by the United States in 2021 (figure 3).

Figure 6
U.S. trade of nitrogen, phosphate, and potash, 2009–22



Note: All values in 2023 dollars. The trade deficit measures the extent to which fertilizer imports exceed fertilizer exports.
Source: USDA Economic Research Service using data from the International Trade Association.

Measured in 2023 dollars, U.S. imports were valued at \$11.40 billion in 2022 (44.7 percent more than the average in 2009–21), while U.S. fertilizer exports were valued at \$4.89 billion (134 percent more than the average in 2009–21). The relative increase in the value of U.S. fertilizer exports was largely driven by higher volumes of nitrogen production (27.8 percent) and exports (126.1 percent) in 2022 relative to their averages in 2009–21.

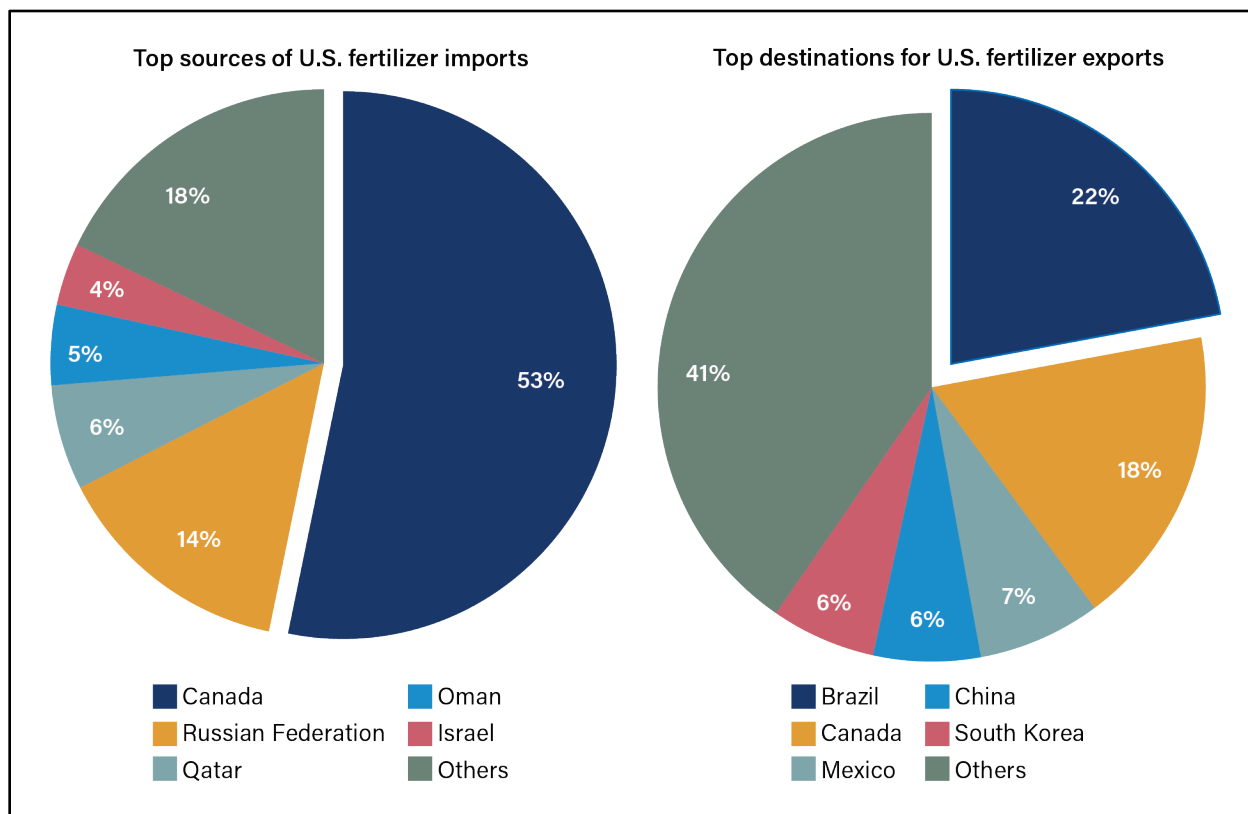
Figure 7 shows the share of U.S. fertilizer imports and exports by trade partner based on dollar value. Combined, countries ranking as one of the top five sources of U.S. fertilizer imports supplied about 82 percent of total U.S. fertilizer imports (figure 7). Canada was the largest source of imports, making up 53 percent of U.S. fertilizer imports, followed by Russia at 14 percent. Destinations for U.S. fertilizer exports were more varied, with countries ranking among the top five destinations (Brazil, Canada, Mexico, China,

⁴ Export (import) values exclude countries for which exports (imports) were less than \$500,000.

South Korea) purchasing only 59 percent of U.S. fertilizer exports. Brazil and Canada were the top two destinations for U.S. fertilizer products at 22 and 18 percent, respectively.

Figure 7

Top U.S. fertilizer trade partners, based on dollar value, 2022



Note: Percentages for each country are based on the dollar value of imports or exports. "Other" includes all the other countries not specifically listed.

Source: USDA Economic Research Service using data from the International Trade Association.

Based on dollar value, when examined by product, the top sources of fertilizer imported by the United States in 2022 were:

- Nitrogen: Canada (20 percent), Russia (18 percent), and Qatar (15 percent).
- Phosphate: Israel (59 percent), Russia (19 percent), and Morocco (10 percent).
- Potash: Canada (81 percent), Russia (11 percent), and Israel (4 percent).

In 2022, the top destinations for U.S. fertilizer exports based on dollar value were:

- Nitrogen: Canada (35 percent), Mexico (12 percent), and France (11 percent).
- Phosphate: Canada (29 percent), Mexico (20 percent), and Colombia (15 percent).
- Potash: Brazil (37 percent), China (12 percent), and South Korea (11 percent).

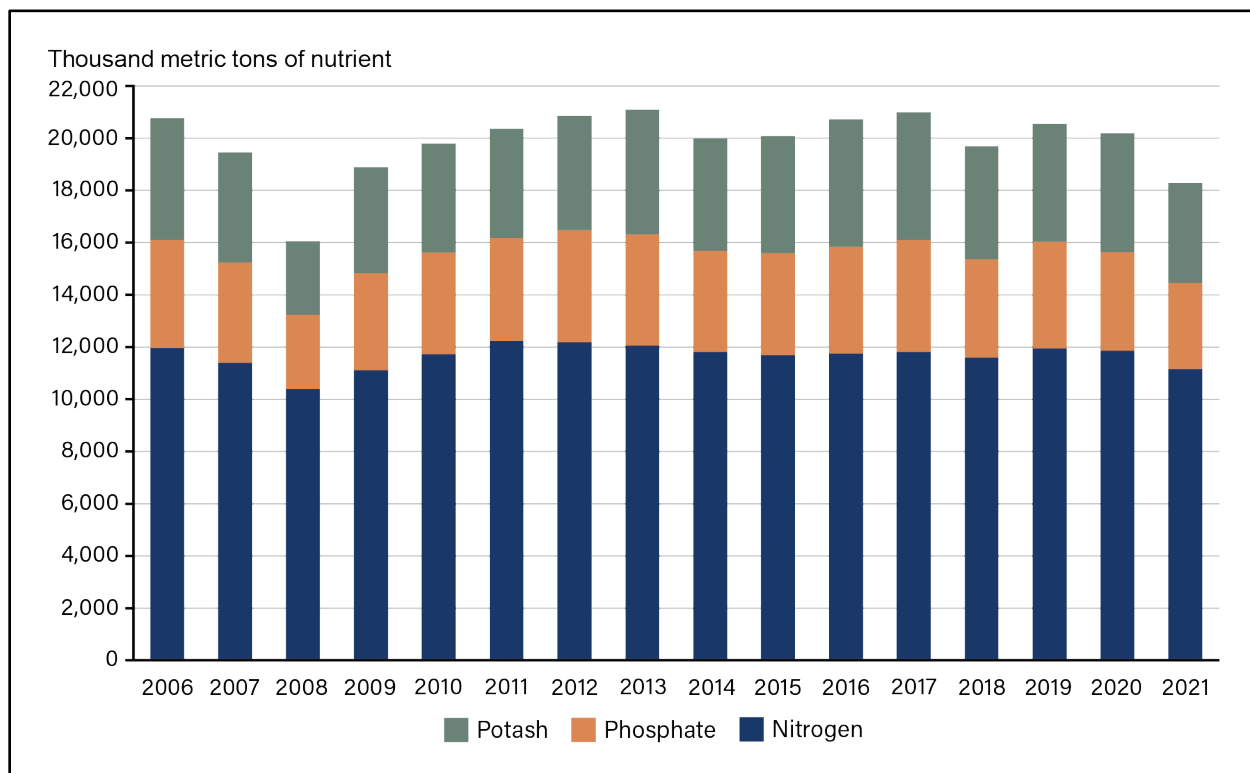
U.S. Fertilizer Use and Cost of Production

U.S. Fertilizer Consumption Dropped Below Pre-Recession Levels in Recent Years

According to data from the International Fertilizer Association (IFA), total U.S. consumption of nitrogen, phosphate, and potassium for plant nutrition, including applications to crops and pastures, decreased by 9.4 percent from 2020 to 2021, the most recent year for which fertilizer consumption data were available.

Figure 8 shows total U.S. fertilizer consumption from 2006 to 2021 and the contribution of nitrogen, phosphate, and potash to overall consumption. In 2021, total fertilizer consumption was roughly 18.3 million metric tons of the combined nutrients. U.S. nitrogen fertilizer consumption was usually more than twice that of phosphate and potassium consumption from 2006 to 2021, with total nitrogen fertilizer consumption remaining higher than phosphate and potassium fertilizer consumption combined.

Figure 8
U.S. fertilizer consumption and composition from 2006 to 2021

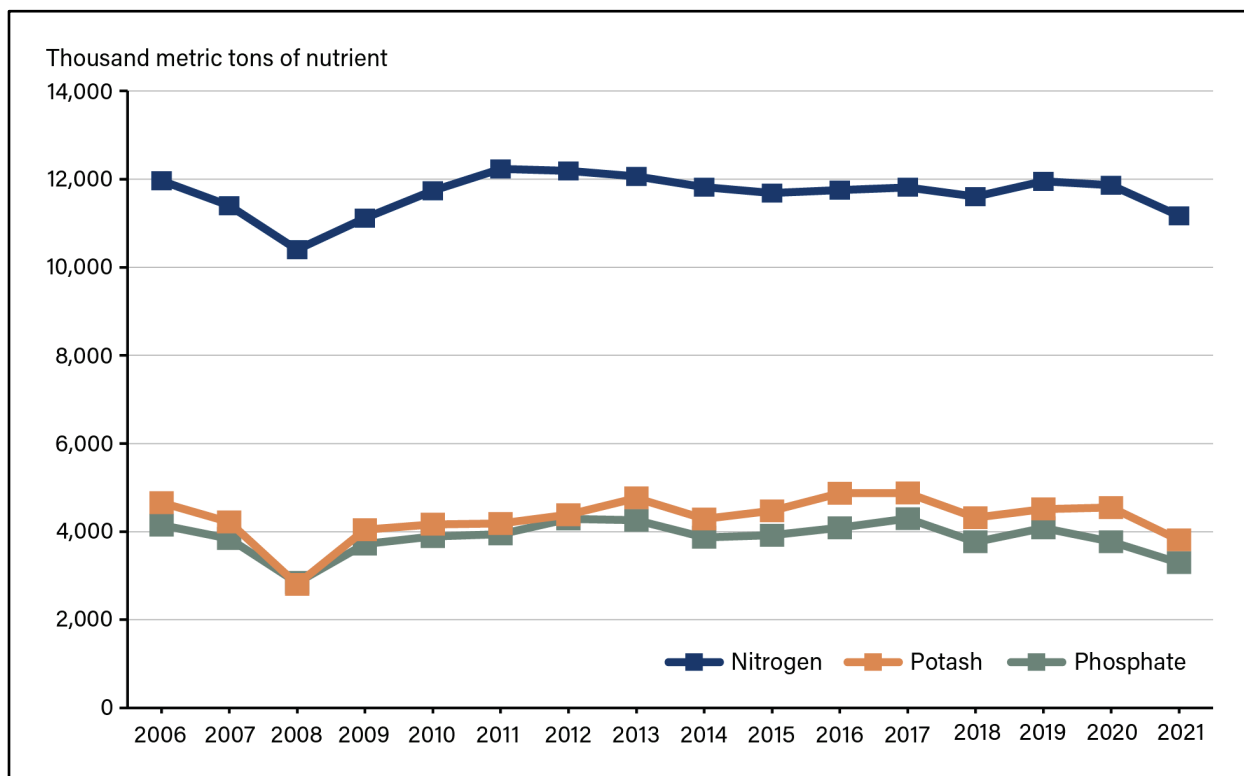


Note: At the time of analysis, 2021 was the latest year for which consumption data were available.
 Source: USDA, Economic Research Service using data from the International Fertilizer Association.

Fertilizer consumption has remained relatively stable since 2006, except for a noticeable drop in consumption during the Great Recession (figure 9). From 2006 to 2008, nitrogen consumption declined by 13.1 percent, while phosphate consumption declined by 31.4 percent, and potash consumption declined by 39.8 percent. For each fertilizer product, consumption increased in 2009, though consumption did not return to at or above pre-recession levels until 2011 for nitrogen, 2012 for phosphate, and 2013 for potash.⁵ In 2018, fertilizer consumption dropped below pre-recession levels. Though fertilizer consumption increased briefly after 2018, recent price increases likely contributed to the decline in consumption, with notable drops in consumption between 2020 and 2021 for nitrogen (5.8 percent), phosphate (12.6 percent), and potash (16.2 percent).

⁵ The USDA, ERS Fertilizer Use and Price data product has data from 2006 to 2015 that show U.S. agricultural urea and ammonium sulfate use generally increased, while anhydrous ammonia use fluctuated during that period. However, after 2015, use-by-fertilizer product information is not readily available.

Figure 9
U.S. fertilizer consumption since 2006



Source: USDA, Economic Research Service using data from the International Fertilizer Association.

Fertilizer Costs Are a Large Share of Farm Operating Costs

Despite declines in fertilizer consumption in 2021, fertilizer costs have remained a large portion of farmers’ costs of production. USDA, ERS monitors fertilizer costs as part of its Commodity Costs and Returns (CAR) data product. The data product uses the Agricultural Resource Management Survey (ARMS) and supplementary data to estimate the total fertilizer cost per acre, which accounts for the value of fertilizers, soil conditioners, and manure.⁶ We used CAR estimates to analyze changes in fertilizer costs from 2006 to 2023.

The CAR estimates are computed using data from ARMS and other sources and have been published twice annually since 1975. The commodities covered in the ARMS commodity-specific questionnaires change from year to year, though surveys for each commodity are usually conducted every 4 to 8 years. CAR estimates are published for the United States and the major farm resource regions that produce each surveyed crop. The estimates are initially developed from the survey-year data, then adjusted each following year using price indices from the USDA, National Agricultural Statistics Service (NASS) and other production values. In years between surveys, estimates are updated to account for price, acreage, and production changes. The resulting Commodity Costs and Returns estimates are reported in nominal terms and lay the foundation for the USDA, ERS Cost-of-Production (COP) Forecasts, which are also released twice per year. See the USDA, ERS Commodity Costs and Returns documentation webpage for more details on methodology. For this report, the CAR data were adjusted for inflation, converting all measures to 2023 dollars using the all-items Consumer Price Index for All Urban Consumers (CPI-U).

⁶ Separate cost estimates for fertilizers, soil conditioners, and manure are not available in the Commodity Costs and Returns data product.

Farm production costs include allocated overhead, which includes the costs of using capital assets that provide services over multiple production periods along with general overhead (e.g., paid labor, taxes and insurance, etc.), and operating costs, which include the costs of expendable inputs that are consumed during the production period (e.g., seed, fertilizer, chemicals, fuel, purchased water, etc.). To better understand changes in how fertilizer costs contribute to production costs in a given period, we focused mainly on fertilizer's share of farm operating costs. Fertilizer costs are considered variable costs because the quantity of fertilizer applied varies with the level of production. Fertilizer costs also vary according to field condition, desired yield, price, and other factors. Understanding trends in fertilizer costs is important because such variable costs affect net farm income, which is the amount of income remaining after deducting expenses. To show the extent to which fertilizer use contributed to farm operating costs, we focused on corn and wheat, two major U.S. field crops, and we analyzed CAR estimates from 2006 to 2023, the most recent data available.

Corn Farm Operating Costs

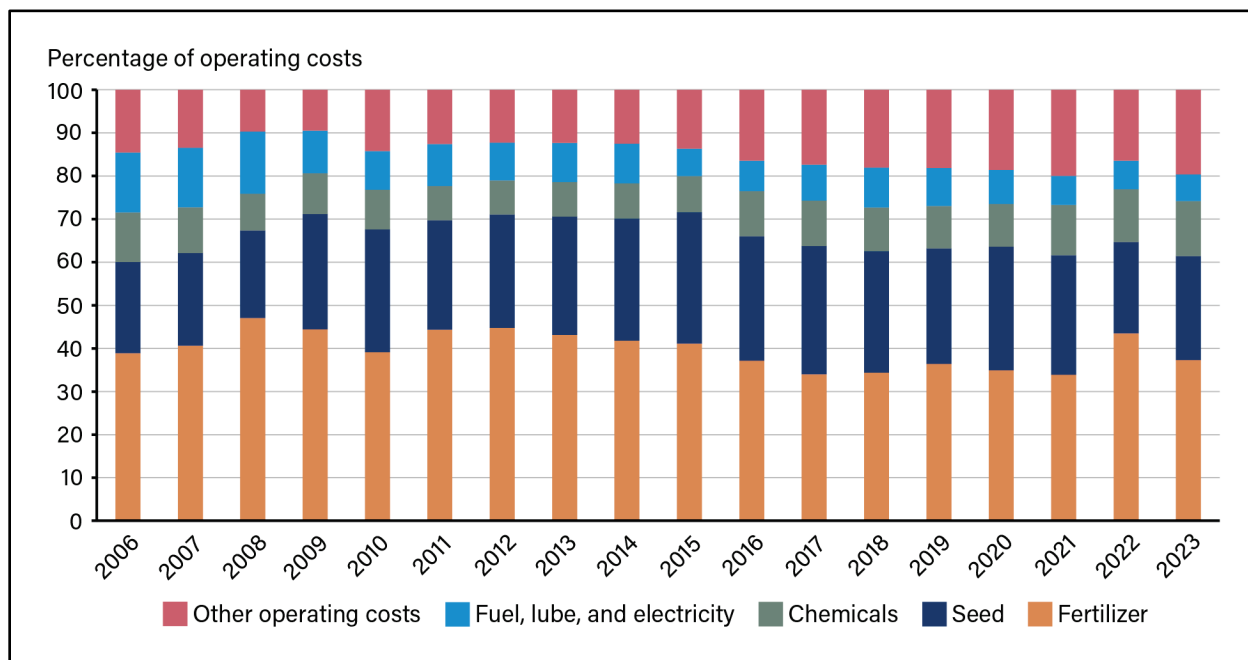
Fertilizer costs affect the net farm income of many crop farms, especially corn producers. According to USDA, NASS, the top corn-producing States in 2022 and 2023 were Iowa and Illinois, both located in the Heartland Region, followed by Nebraska and Minnesota, which largely fall within the Northern Great Plains and Northern Crescent Regions.

Based on corn cost and returns estimates, fertilizer costs made up the largest portion of operating expenses. From 2006 to 2023, fertilizer costs accounted for an average of 39.8 percent of all operating costs for corn producers, so corn producers' net farm incomes are sensitive to fluctuations in fertilizer costs. Although producers can respond to higher fertilizer prices by reducing fertilizer use, their response is limited because reducing fertilizer use reduces yields and revenues. Producers may also choose to switch to less intensive crops. From 2006 to 2023, U.S. corn production was highest in 2023 (15.34 billion bushels) and lowest in 2006 (10.53 billion bushels).

In 2023, \$479.74 in total operating costs were required to produce 1 acre of corn, down around 3 percent from 2022. Fertilizer's share of corn operating costs was highest in 2008, during the Great Recession, when fertilizer accounted for 47.1 percent of total operating costs and 26.3 percent of total production costs. Fertilizer's shares of operating costs and production costs were lowest in 2021, at 33.9 and 16.3 percent, respectively. The 2022 fertilizer price increase resulted in fertilizer costs comprising 43.5 percent of operating costs. Corn fertilizer costs per acre then decreased to 37.3 percent of operating costs in 2023.

Figure 10

U.S. corn farm operating cost summary from 2006 to 2023



Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

The second-largest operating cost category for corn production is seed, ranging from roughly 20 to 30 percent of total operating costs from 2006 to 2023. In 2023 dollars, corn seed costs amounted to \$28.81 per acre in 2006 and steadily increased, amounting to an average of about \$79 per acre from 2016 to 2021. Average seed costs jumped to roughly \$111 in 2022 and 2023. Chemical and fuel costs averaged around 9 percent of operating costs each from 2006 to 2023. Fuel cost was another production measure that peaked in 2022, increasing from \$21.23 per acre in 2021 to \$33.25 in 2022. Fuel prices leveled out somewhat in 2023, dropping to an estimated \$29.73 per acre. Other operating costs include custom services, repairs, purchased irrigation water, and interest on operating capital. On average, other operating costs accounted for 15 percent of total operating costs from 2006 to 2023, but these costs fluctuated.

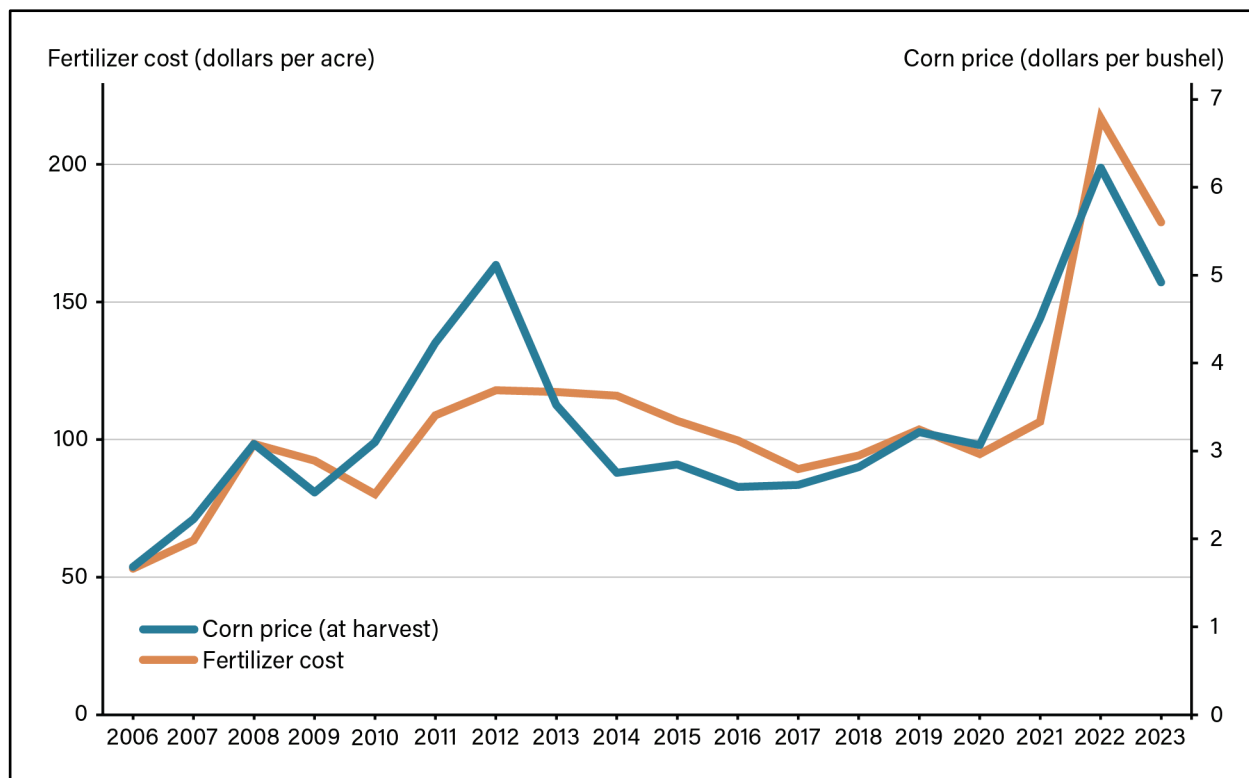
Figure 11 illustrates corn fertilizer costs over time along with harvest month (typically October) corn prices received per bushel in 2023 dollars.⁷ Inflation-adjusted (real), fertilizer costs for corn reached a record high in 2022, at \$216.81 per acre, before decreasing back to \$178.94 per acre in 2023. Although lower than the peak, 2023 was still a year of record-high fertilizer prices. The next-highest years were 2012 and 2013, when corn fertilizer costs per acre hovered around \$118, while the lowest corn fertilizer costs in this period occurred in 2006 at just \$53.04 per acre.

Fertilizer costs and corn prices both displayed peaks in 2012 and 2022. Despite remaining relatively high, both fertilizer costs and corn prices declined sharply from 2022 to 2023. The 2011–12 increases in corn and fertilizer costs were related to food commodity price increases driven by extreme weather events that affected crop production (Trostle, 2011). The 2021–22 increases in corn and fertilizer costs were related

⁷ The harvest month depends on geographic location and data availability. For most States, we used USDA, NASS prices for the harvest month of October. However, Texas is located in the South, so for Texas, we used the September price. Georgia and New York do not have monthly prices, so for those two States, we used the State marketing year price as a proxy.

to global supply and demand issues that began in 2020 but were exacerbated by the Russia-Ukraine military conflict that began in 2022 (Kroeger, 2023).

Figure 11
Corn fertilizer costs and corn price trends, 2016–23

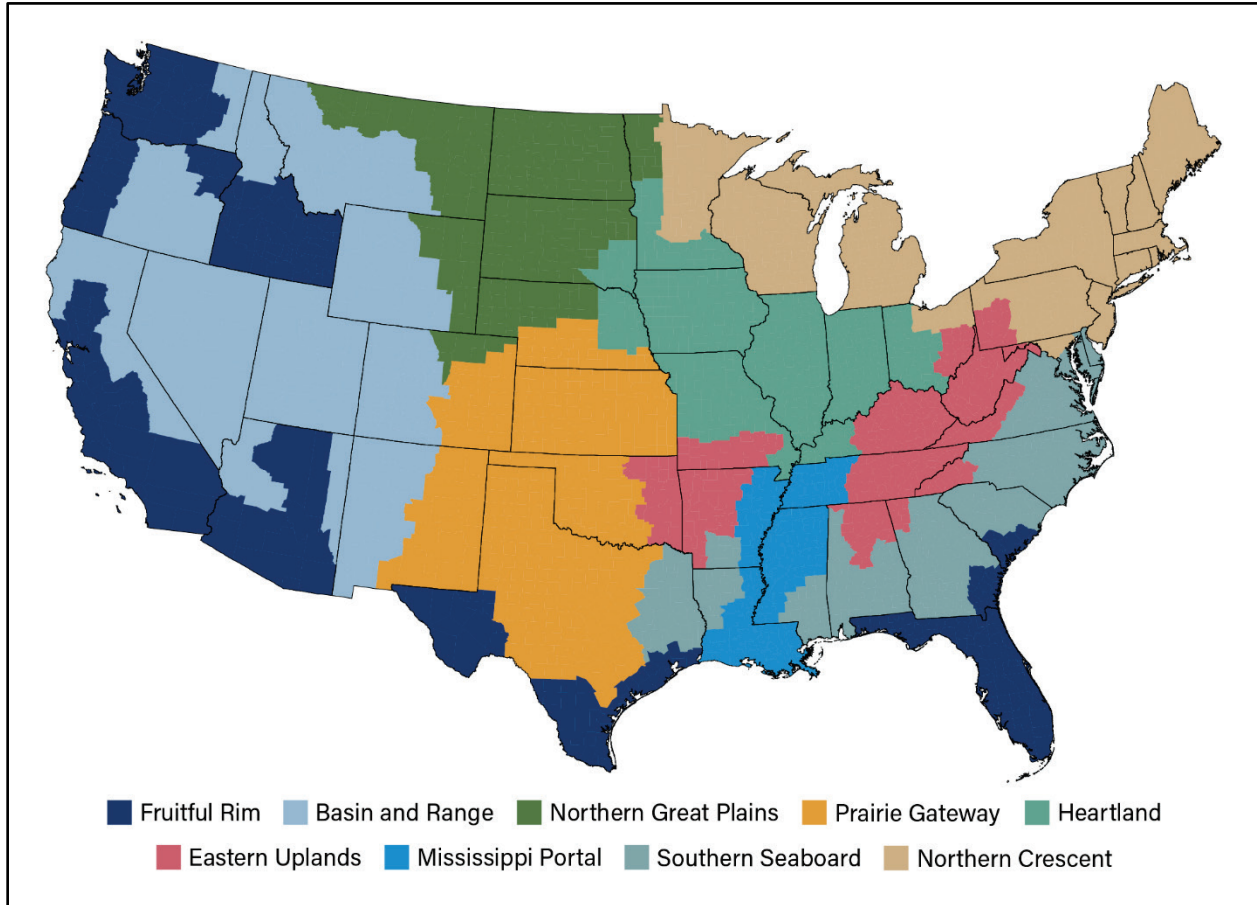


Note: Fertilizer costs and corn prices are measured in 2023 dollars.
 Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Corn was \$6.22 per bushel in 2022, 21 percent above the 2012 high of \$5.12. Relative to 2022, corn prices dropped 21 percent to \$4.92 in 2023. Inflation-adjusted fertilizer costs hovered around an average of \$98 per acre from 2016 to 2021 before rising to \$216.81 per acre in 2022. Like 2023 corn-price trends, fertilizer costs dropped 17.5 percent to \$178.94 in 2023.

Fertilizer costs may differ across regions for various reasons, such as regional differences in prices or fertilizer quantities needed. USDA, ERS identifies Farm Resource Regions (figure 12) that account for the geographic distribution of farm production based on similarities in climate, soil, water, and topography (Heimlich, 2000), each of which may affect fertilizer application rates. Measured in 2023 dollars, average fertilizer costs in major corn-producing regions from 2006 to 2021 showed that the Prairie Gateway (\$74 per acre) and Northern Great Plains (\$78 per acre) regions usually had lower fertilizer costs per acre, while the Eastern Uplands (\$115 per acre) and Southern Seaboard (\$123 per acre) regions had higher costs per acre. In 2022, corn farmers in the Southern Seaboard spent an average of \$289.47 on fertilizer per acre, more than double their average costs per acre in the prior 16 years, while Northern Crescent corn farmers spent an average of \$246.49, Heartland farmers spent \$229.92, and Northern Great Plains farmers spent \$195.24. Although fertilizer costs decreased in 2023, fertilizer costs in the Southern Seaboard remained at an elevated \$238.57 per acre. Similarly, total operating costs in 2006–23 were lowest in the Northern Great Plains at \$240.52 per acre of corn, on average, and highest in the Southern Seaboard at \$304.72 per acre.

Figure 12
USDA, Economic Research Service Farm Resource Regions

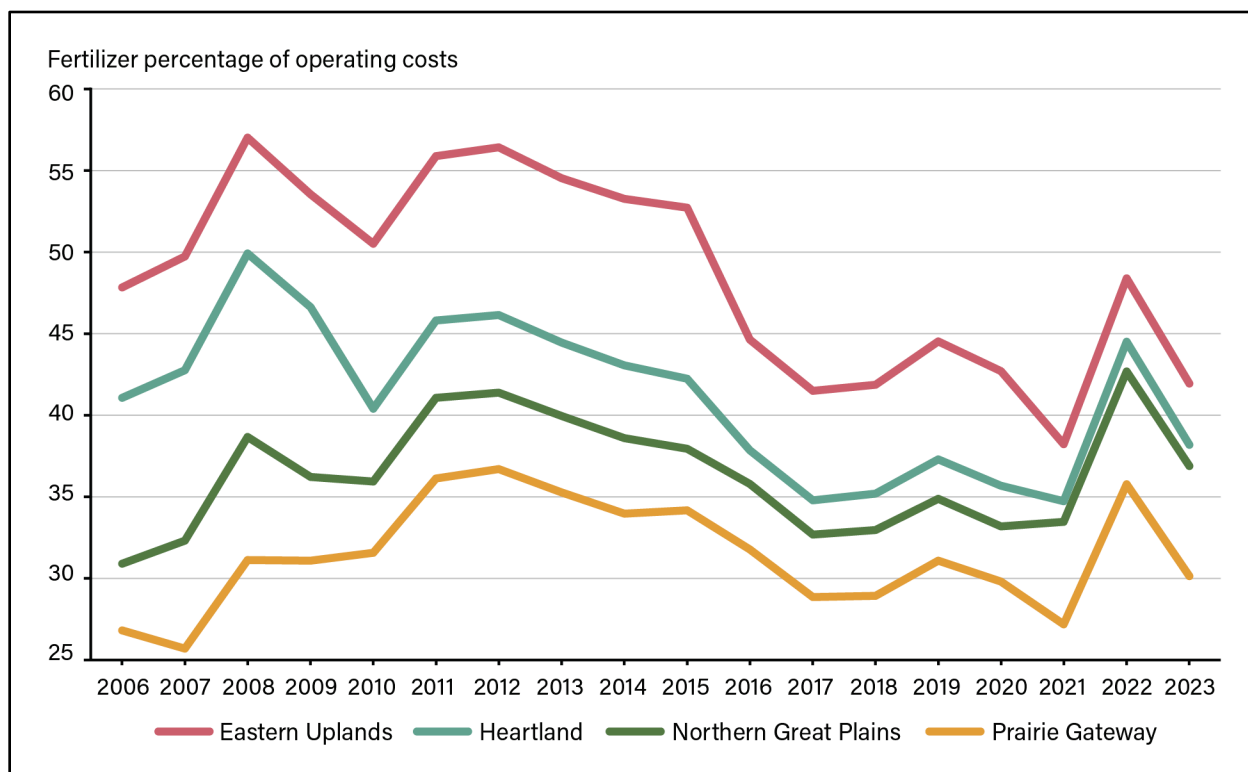


Source: USDA, Economic Research Service, Farm Resource Regions (AIB-760), August 2000.

Differences in fertilizer costs, as well as regional variation in other operating costs, contribute to differences in fertilizer's share of corn operating costs across regions. Figure 13 shows fertilizer costs relative to total operating costs for corn from 2006 to 2023 for select farm resource regions.

Figure 13

Corn fertilizer costs as a percent of total operating costs by region, 2006–23



Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

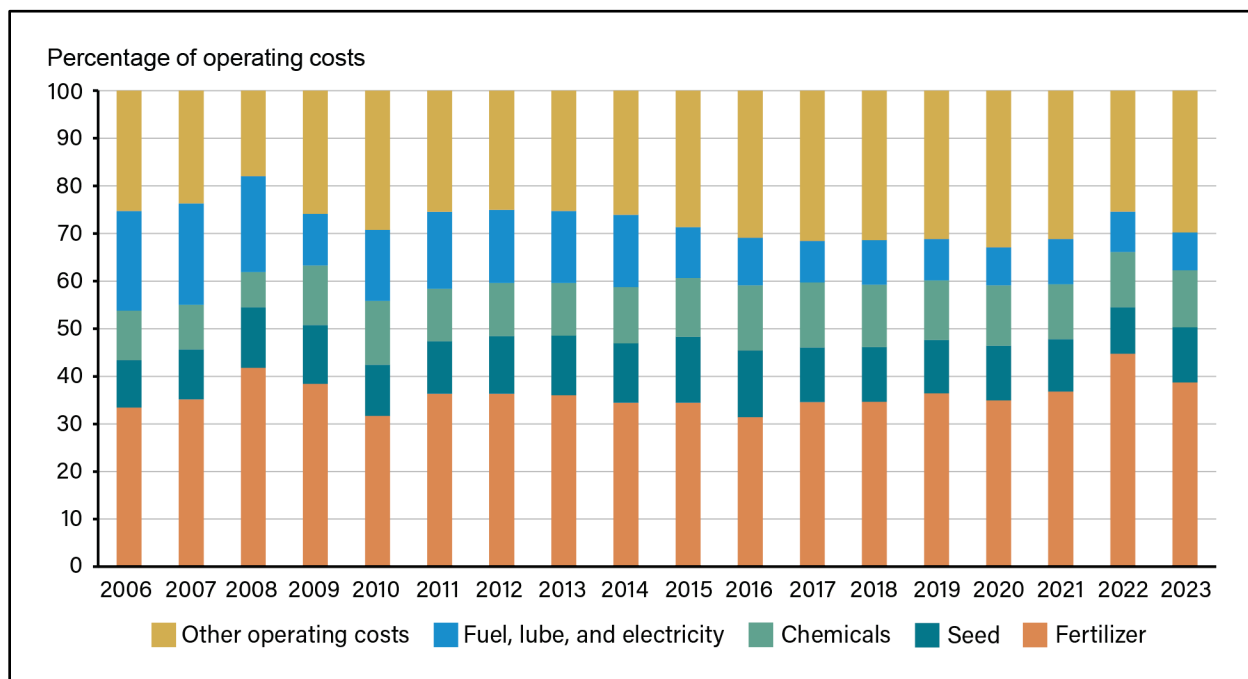
Although fertilizer cost shares for corn followed a similar pattern across regions, notable differences exist. Throughout the period, the Eastern Uplands region consistently had the highest fertilizer share of operating costs, followed by the Heartland, Northern Great Plains, and Prairie Gateway regions. Fertilizer’s share of total operating costs was highest for the Heartland (49.9 percent) and Eastern Uplands (57.0 percent) in 2008 but peaked for the Prairie Gateway (36.7 percent) in 2012. Fertilizer’s share of operating costs in the Northern Great Plains peaked during the fertilizer price increase of 2022 (42.7 percent). For the Prairie Gateway and Northern Great Plains regions, fertilizer’s share of operating costs was lowest in 2006 and 2007, while that of the Heartland and Eastern Uplands regions were lowest in 2021. The fertilizer price increase in 2021 contributed to sharp increases in the fertilizer share of operating costs for corn in 2022.

Wheat Farm Operating Costs

In 2023, total wheat acreage nationwide was 74 percent winter wheat, 23 percent spring wheat, and 3 percent durum wheat. USDA, ERS Cost of Production (COP) data do not include separate estimates by wheat type, so the analysis below refers to all wheat types.

Based on the wheat COP estimates shown in figure 14, fertilizer accounted for an average of 35 percent of total operating costs from 2006 to 2021. In 2022, fertilizer’s share of wheat operating costs peaked at 44.7 percent before dropping back to 38.7 percent in 2023. The 2022 jump in fertilizer’s share of operating costs suggests that, although costs were rising for many production inputs, fertilizer costs rose at a disproportionate rate.

Figure 14
U.S. wheat farm operating cost summary from 2006 to 2023



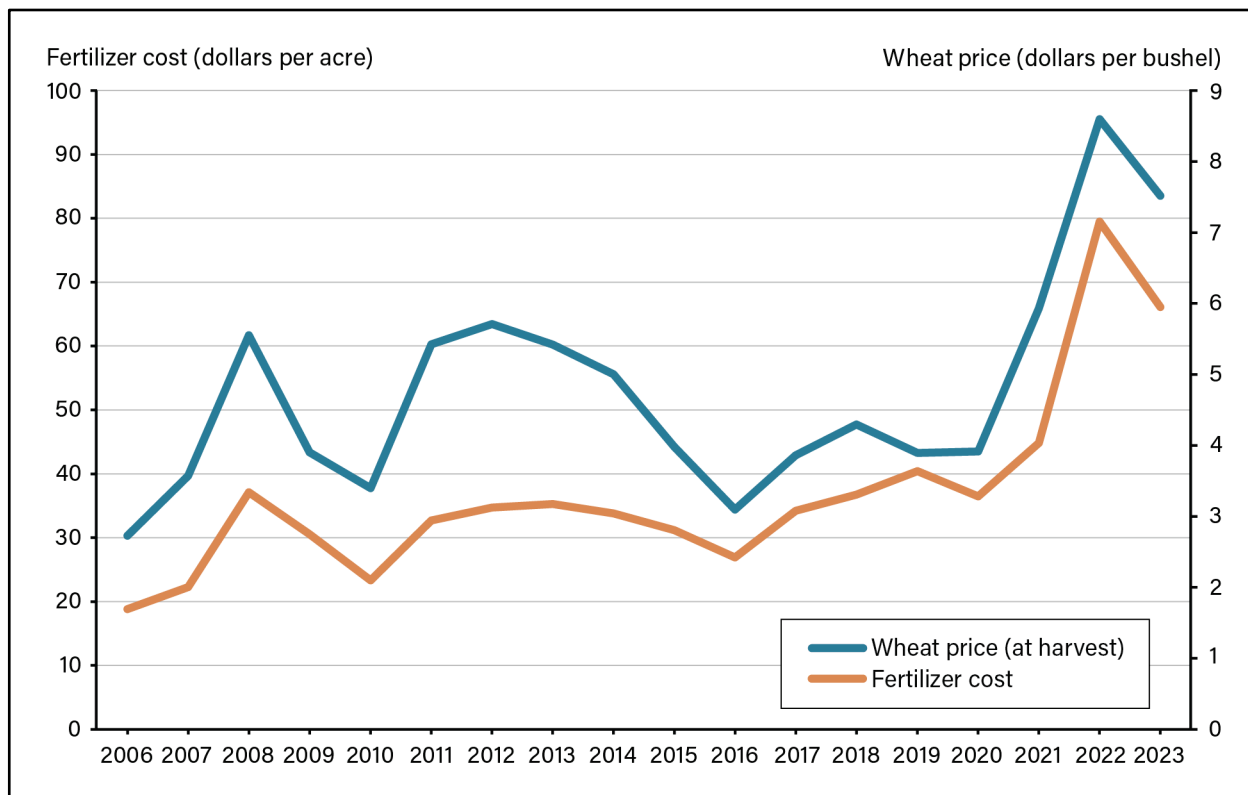
Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Between 2006 and 2021, the highest fertilizer costs per acre for wheat occurred in 2008, 2019, and 2021 (\$37.10, \$40.42, and \$44.83 per acre, respectively). Total operating cost for wheat was lowest in 2006 at \$56.24 per acre. This contrasted with the total operating cost of \$177.68 per acre in 2022 and \$170.61 per acre in 2023.

Relative to corn, wheat operations consistently incurred a higher cost for repairs as a share of total operating costs. Repairs are included in other operating costs, along with custom services, purchased irrigation water, and interest on operating capital. While the share of operating costs for seed and chemicals have remained relatively constant over time, averaging about 12 percent each from 2006 to 2023, fuel's percentage of operating costs for wheat gradually declined from 2006 to 2023. Fuel costs accounted for just over 21 percent of wheat operating costs in 2007 but only around 8 percent by 2023.

Fertilizer made up a slightly lower portion of total operating costs for wheat than for corn but was still a substantial production cost. Figure 15 compares wheat fertilizer costs per acre and wheat price per bushel at harvest in 2023 dollars. Wheat prices were highest in 2008, 2012, 2022, and 2023. Similarly, fertilizer costs were the highest in 2022 and 2023, with period peaks in 2008 and 2012. As with corn, fertilizer costs and wheat prices seem to follow the same general trend over time. The average harvest month price was \$8.60 per bushel of wheat in 2022, a 45-percent increase from \$5.93 per bushel in 2021. Wheat prices declined to \$7.52 per acre in 2023, 12.6 percent less than the prior year.

Figure 15
Wheat fertilizer costs and wheat price trends, 2006–23



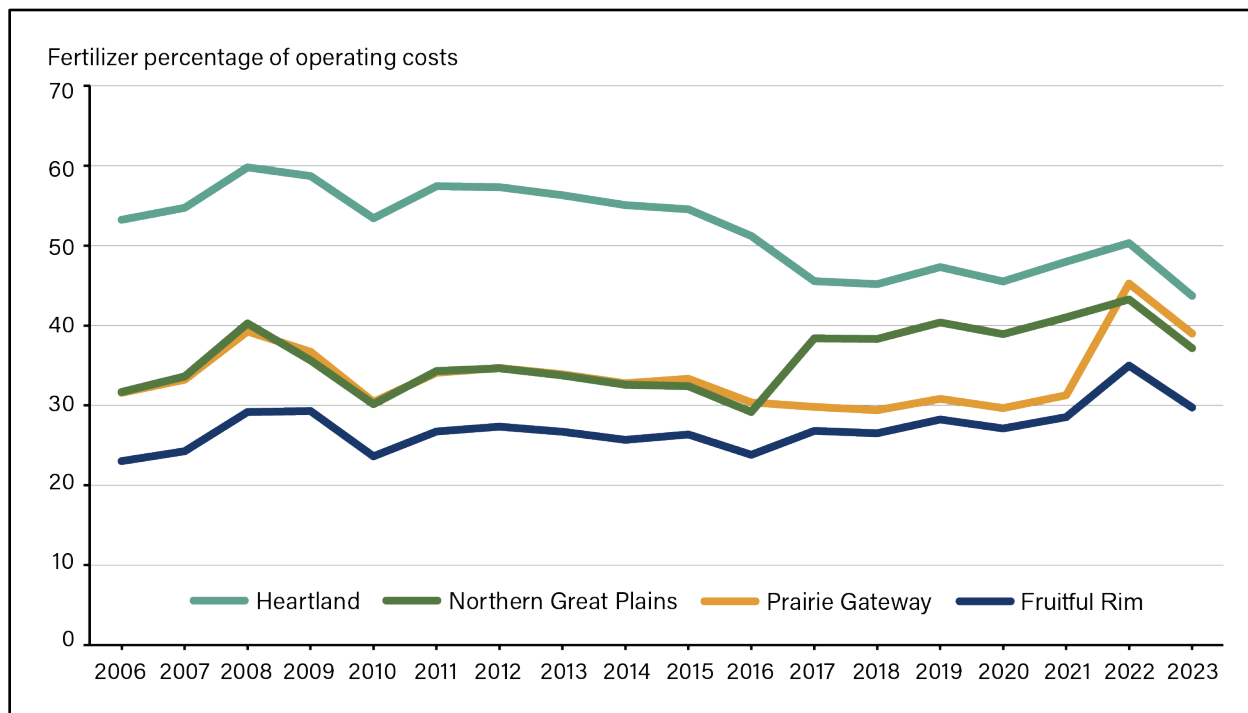
Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Four major U.S. wheat-producing regions are the Fruitful Rim, Heartland, Northern Crescent, and Prairie Gateway. Adjusted for inflation, from 2006 to 2023, average wheat fertilizer costs were lowest in the Prairie Gateway (\$29.99 per acre) and highest in the Heartland (\$74.80 per acre). Total operating costs for wheat were very similar in the Fruitful Rim and Heartland regions, averaging around \$146 per acre, while operating costs were relatively low in the Prairie Gateway at \$87.04 per acre. Total operating costs for wheat were moderate in the Northern Great Plains region, averaging around \$97 per acre.

Fertilizer costs in the Fruitful Rim averaged 27.1 percent of total operating costs over the period, the lowest across the four regions (figure 16). In contrast, fertilizer’s share of operating costs was highest in the Heartland, averaging 52.1 percent of total operating costs in 2006–23. Trends in fertilizer’s share of operating costs were almost identical in the Prairie Gateway and Northern Great Plains regions until 2017, when the Northern Great Plains experienced a flash drought that affected wheat production (Hoell et al., 2020). For the Northern Great Plains, fertilizer’s share of total operating costs was lowest in 2016 at 29.2 percent, jumping to 38.4 percent the following year, and peaking in 2022 at 43.3 percent.

Figure 16

Wheat fertilizer costs as a percent of total operating costs by region, 2006–23



Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

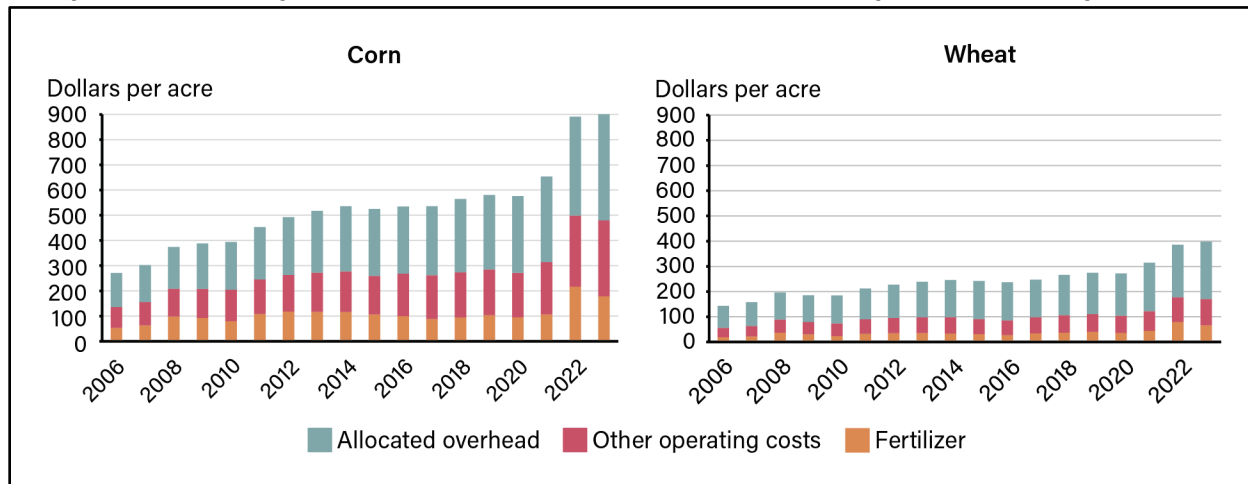
Cross-Commodity Analysis of Farm Production Costs

Figure 17 shows changes in the composition of farm production costs for corn and wheat since 2006, measured in 2023 dollars. Recall, total farm production costs are the sum of operating costs and allocated overhead costs. Operating costs for both crops were highest in 2022 and 2023, though there were vast differences in cost per acre for corn and wheat production. Operating costs were lowest for corn and wheat in 2006 at \$136.28 and \$56.24 per acre, respectively. Over time, total production costs for both crops increased steadily. The increase began in 2021 and continued to increase through 2023. Although we see a decline in fertilizer costs from 2022 to 2023 for both crops, total production costs increased slightly from 2022 to 2023.

Although fertilizer costs have increased since 2021, increases in other operating costs and allocated overhead costs have also contributed to the overall increases in total production costs for corn and wheat. At their highest in 2022, corn operating costs totaled \$498.59 per acre, while wheat operating costs totaled \$177.68 per acre, 266 percent and 216 percent higher than corn and wheat operating costs in 2006, respectively. From 2006 to 2022, fertilizer costs per acre increased 309 percent for corn and 322 percent for wheat when adjusted for inflation. Fertilizer costs for both commodities declined around 17 percent each from 2022 to 2023.

Figure 17

Composition of farm production costs for corn and wheat, 2006–23, production cost per acre



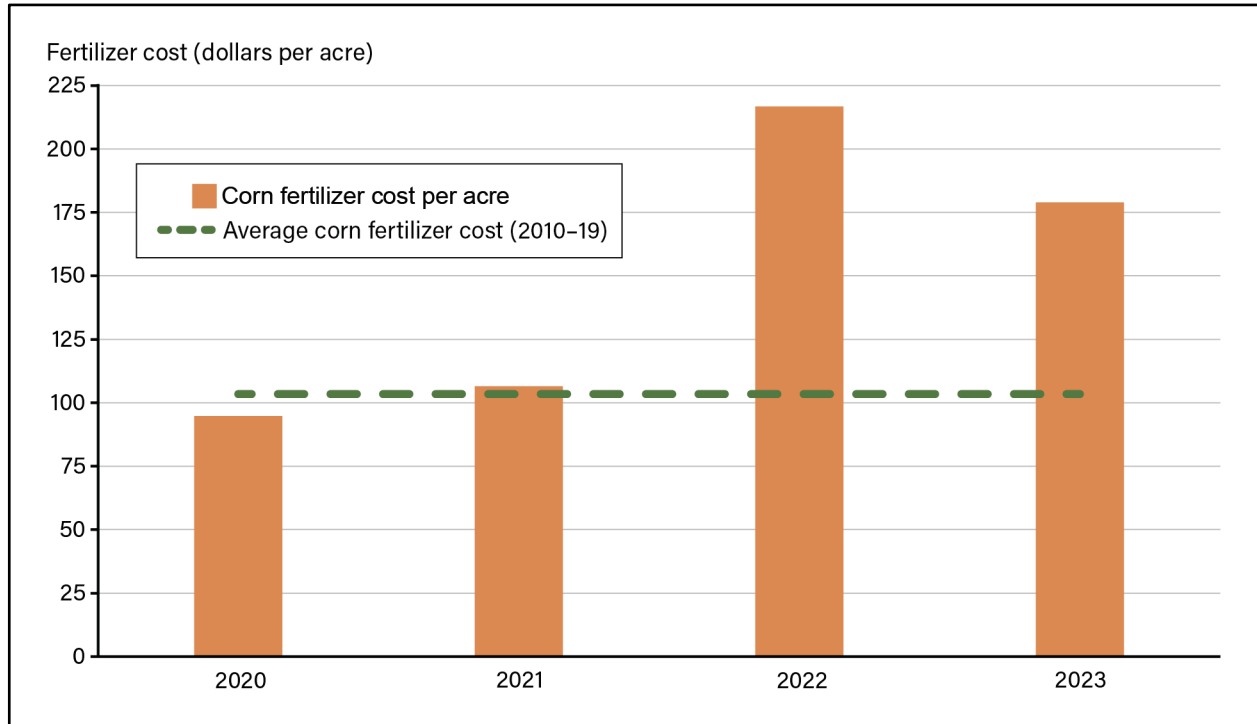
Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Relative to the 10-year average in 2010–19, fertilizer cost per acre for corn was lower in 2020 and relatively similar in 2021, but 110 percent higher than the 10-year average in 2022, reaching \$216.81 per acre (figure 18). Corn fertilizer costs in 2023 were lower than in 2022 but still 73 percent higher than the 10-year average in 2010–19. For comparison, the price of corn was \$4.92 per bushel in 2023, a 50-percent increase from its 10-year average (\$3.28 per bushel); corn yields were 13.4 percent higher in 2023 relative to average corn yields in 2010–19.

In 2022, wheat fertilizer costs per acre reached a height of \$79.49, an increase of 141 percent compared to the 2010–19 average (figure 19). Similar to corn, wheat fertilizer costs in 2023 were slightly lower than in 2022 but remained high at around 101 percent more than the 2010–19 average. For comparison, the price of wheat was \$7.52 per bushel in 2023, a 70.6-percent increase relative to its 10-year average (\$4.41 per bushel), while wheat yields were relatively similar between 2010–19 and 2023.

Figure 18

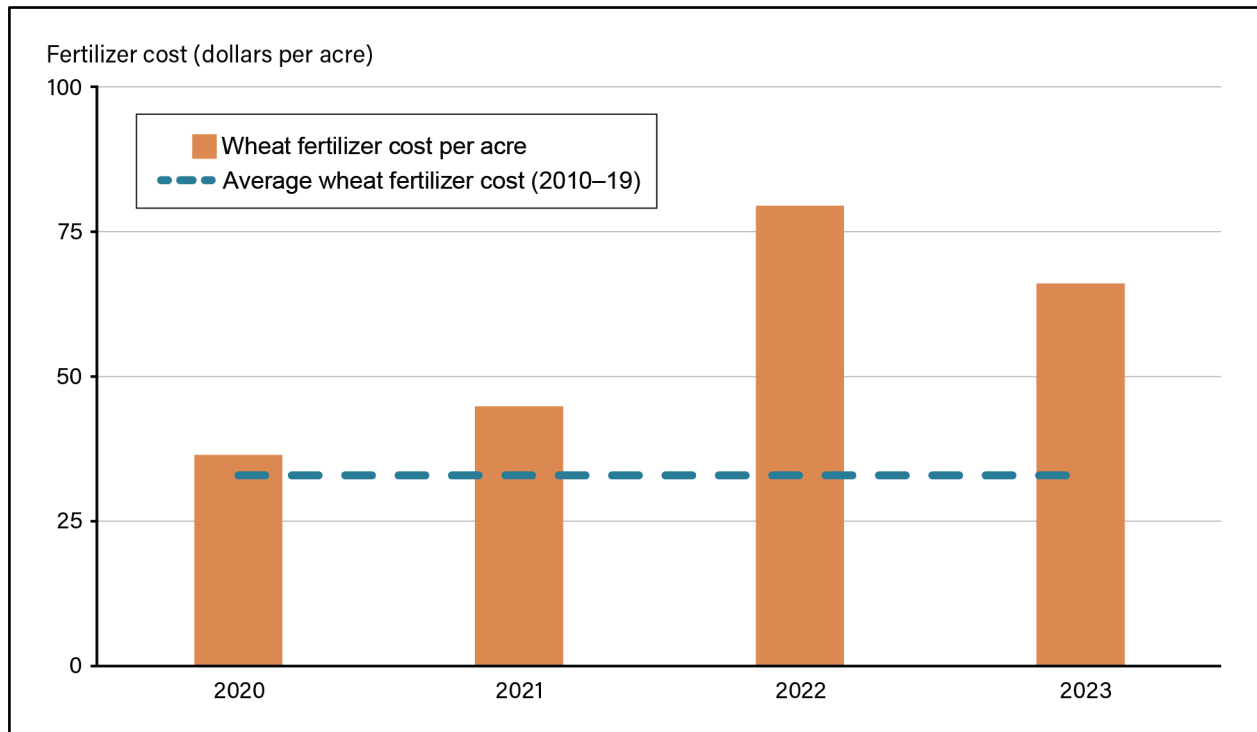
Recent corn fertilizer costs per acre compared to the 2010–19 historical average



Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Figure 19

Recent wheat fertilizer costs per acre compared to the 2010–19 historical average



Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Factors Contributing to Trends in Fertilizer Prices

Fertilizer prices are affected by energy costs, natural disasters, crop prices, and crop production decisions. For much of the analysis below, we focus on trends in nitrogen fertilizer prices because U.S. nitrogen fertilizer consumption far outweighs that of phosphate and potassium fertilizers.

Changes in Energy Costs Contribute to Fertilizer Prices

Fluctuations in energy costs can have major implications for fertilizer markets. Nitrogen, a nutrient that is necessary for plant growth, is the most energy-intensive fertilizer to produce. To generate nitrogen in the form of ammonia, a conversion process consisting of a reaction between nitrogen gas and hydrogen under high heat and pressure leads to the creation of ammonia (NH₃). Urea and other forms of nitrogen often use ammonia as a starting point. Natural gas, which is used to create the heat needed for the process, is considered a key component in the production of nitrogen fertilizer, as discussed earlier in this report.

The use of natural gas as an energy source and its link to nitrogen prices have been well researched over time. Huang (2007) examined the impact of rising natural gas prices on U.S. ammonia prices from 1985 to 2005. Ammonia prices and natural gas prices became strongly correlated between 2000 and 2005, a period marked by high volatility in natural gas prices. Huang (2007) found that increasing natural gas prices negatively impacted the profits of U.S. ammonia producers and contributed to many ammonia producers ceasing production or merging operations with others. From 2000 to 2006, the number of ammonia plants in the United States declined from 40 plants to 25 plants (Huang, 2007). During the same period, U.S. ammonia production capacity dropped 35 percent, and U.S. ammonia imports increased 115 percent, with imports coming primarily from Trinidad and Tobago, Russia, and Canada (Huang, 2007).

The relationship between nitrogen and natural gas prices has changed over time. Prior to March 2010, nitrogen fertilizer prices were strongly associated with natural gas prices at the Henry Hub, a major distribution hub in Louisiana that serves as the pricing point for natural gas futures contracts on the New York Mercantile Exchange (Wongpiyabovorn, 2021). However, after 2010, nitrogen prices were more strongly associated with international natural gas prices, signaling a shift toward a more globalized fertilizer market (Wongpiyabovorn, 2021).

Some researchers have analyzed the relationship between energy and fertilizer prices, while accounting for the possibility that changes in fertilizer and energy prices may also be related to changes in commodity prices (Etienne et al., 2016; Yang et al., 2022). Etienne et al. (2016) and Yang et al. (2022) analyzed interactions among natural gas, ammonia, and corn prices for 1994–2014 and 2011–21, respectively. The two studies showed that the inter-relationships between fertilizer, energy, and commodity markets are complex. For example, Etienne et al. (2016) analyzed weekly data in 1994–2011 and found that, in the long run, natural gas prices were positively associated with ammonia prices, with a 1-percent increase in natural gas price associated with a 0.6-percent increase in ammonia price, on average. Etienne et al. (2016) also found that increases in both natural gas and corn prices positively influence ammonia prices in the short run. However, Yang et al. (2022) analyzed daily prices in 2011–21 and found that natural gas prices were negatively associated with fertilizer prices in both the long run and the short run. Mixed results in the literature suggest that the observed relationship between natural gas and nitrogen fertilizer prices may be affected by data frequency, data source, and the study period.

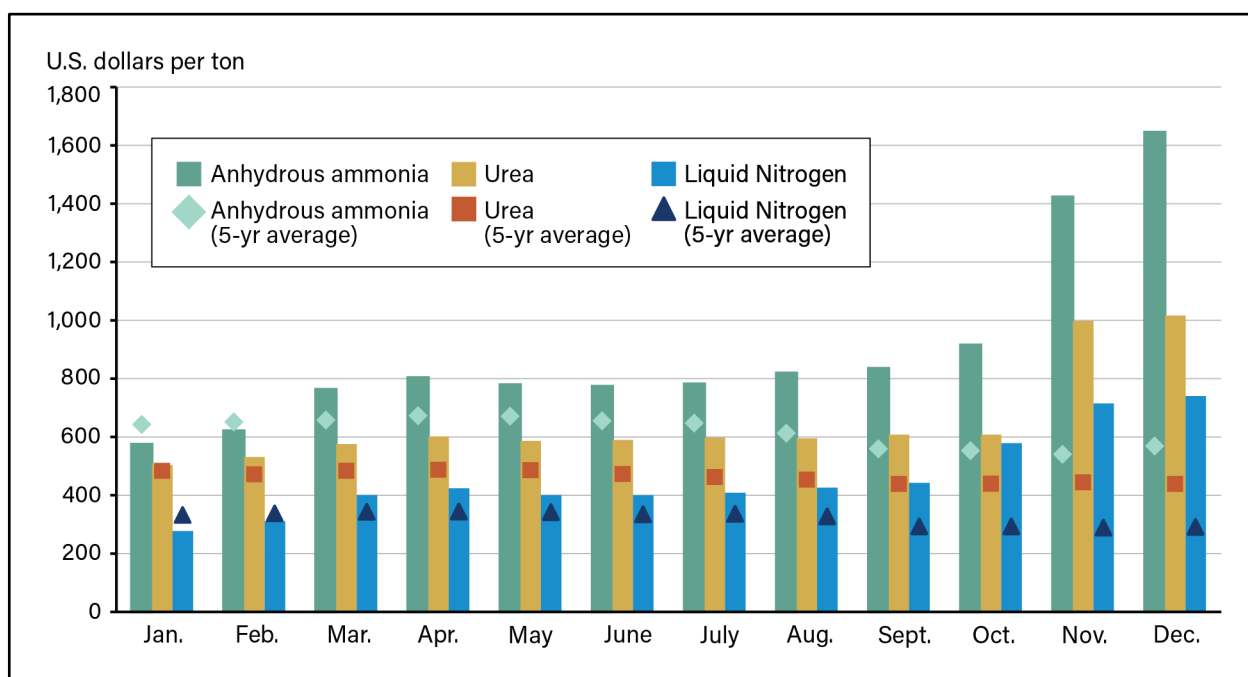
Ott (2012) found that higher food and energy prices contributed to higher fertilizer prices, with higher food prices contributing to increased fertilizer demand. Ott (2012) also found that higher energy prices were associated with higher fertilizer prices, consistent with Etienne et al. (2016).

Trends in Nitrogen Fertilizer Prices Relate to Changes in Natural Gas Prices in 2013–23

Using monthly data on production costs for Iowa,⁸ we analyzed price trends for various forms of nitrogen fertilizers and related them to trends in natural gas prices from 2013 to 2023. Using inflation-adjusted (real) prices, we assessed price trends in anhydrous ammonia (a compressed liquid form of nitrogen that is injected directly into the soil), urea (a solid form of nitrogen that is often spread onto cropland prior to planting), and liquid nitrogen fertilizer (a form of nitrogen that can be applied either prior to planting or in later growth stages of many row crops).

Focusing first on price increases in 2021, figure 20 shows monthly nitrogen prices by type for 2021 relative to 5-year average monthly prices computed from 2016 to 2020. From March 2021 to December 2021, monthly prices exceeded 5-year averages for each type of nitrogen fertilizer; and by November 2021, monthly nitrogen prices for each type were more than double their 5-year averages. Thus, price trends in 2021 were similar across the three nitrogen products.

Figure 20
Monthly nitrogen fertilizer prices by type, 2021 and 5-year average (2016–20), deflated to 2023



Source: USDA, Economic Research Service using data from the USDA, Agricultural Marketing Service.

As shown in figure 21, real monthly average prices of each nitrogen fertilizer product have followed a similar trajectory since 2013. Prices of anhydrous ammonia rose sharply from a 2-year low of \$483 per ton in 2020 to a record high of \$1,665 per ton in spring 2022, more than tripling its price in a matter of 12 months. Anhydrous ammonia prices averaged \$622 from September 2016 to September 2021 when fertilizer prices began their rapid increase. Prices fell nearly as rapidly as they rose, dropping from a high of \$1,665 in April of 2022 to \$619 in September 2023, which is relatively close to the 5-year average before the price increase.

From September 2016 to September 2021, prices of urea averaged around \$474 before reaching a peak of \$1,020 per ton in 2022 (figure 21). Urea prices hovered just under the 5-year average price of \$474 per

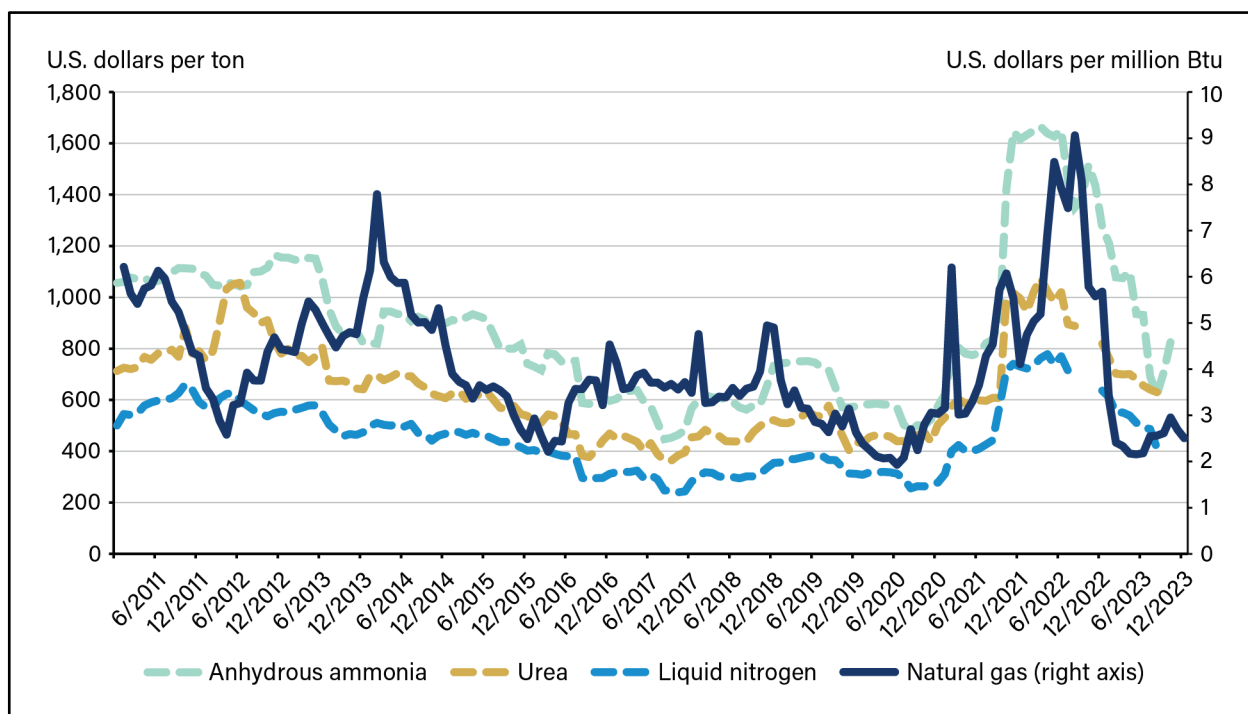
⁸ USDA, Agricultural Marketing Service, Historical Data Iowa Costs of Production.

ton throughout 2020 before beginning to rise sharply in the second quarter of 2021. The initial rapid increase in urea prices temporarily settled at \$996 per ton in January 2022 before experiencing a second rapid increase in March 2022, near the beginning of the military conflict between Russia and Ukraine. Similar to anhydrous ammonia, urea prices dropped from a record-high monthly average of \$1,075 in April 2022 to \$630 in September 2023.

Liquid nitrogen fertilizer prices increased from more than \$260 per ton in late 2020 to more than \$770 per ton by mid-2022, over twice the 5-year average of \$321 per ton before July 2021, just before prices began to rise sharply (figure 21). Since summer 2022, liquid nitrogen prices have declined from record highs but remain elevated relative to historical prices.

Recent increases in nitrogen fertilizer prices are associated with increased natural gas prices, though historically, natural gas prices have been more volatile than fertilizer prices (figure 21). Natural gas prices rose from a 4-year low of \$2 per million British thermal units (Btu) in early 2020 to nearly triple that price at \$5.50 per million Btu in 2021. Prices temporarily dipped below \$3 per million Btu before rising to nearly \$5 per million Btu at the beginning of 2022. Natural gas prices have subsequently experienced a third peak in the last 2 years at more than \$8 per million Btu in July 2022. Since the record-high prices in summer 2022, natural gas prices have dropped to levels in line with historic trends.

Figure 21
Monthly average inflation-adjusted prices of nitrogen fertilizer and natural gas, 2011–23



Btu = British thermal unit.
 Source: USDA, Economic Research Service using data from the USDA, Agricultural Marketing Service and the U.S. Department of Energy, Energy Information Administration.

Natural Disasters Can Disrupt Fertilizer Supply Chains

Extreme weather and other natural disasters affect fertilizer supplies in the short term by reducing the supply of key inputs or by halting production at fertilizer plants. In the past, the U.S. fertilizer supply chain has been disrupted by winter storms, extreme cold, hurricanes, drought, and flooding, which then drove fertilizer prices higher.

Recent examples include freezes in States near the Gulf of Mexico that halted natural gas production and led to delays in fertilizer supply. For example, the “Big Freeze” in February 2021 reduced Texas natural gas production by 45 percent and U.S. natural gas production by 21 percent (U.S. Department of Energy, Energy Information Administration (EIA) 2021b; Gimon, 2021). Natural gas production in the southern States is more vulnerable to extreme cold weather relative to that in northern States where much of the natural gas production infrastructure is winterized (EIA, 2021b).

Southern States are also vulnerable to tropical storms and hurricanes. In 2021, Hurricane Ida disrupted U.S. natural gas production, causing more shut-ins (halted production) than any other hurricane in the previous 10 years (EIA, 2021a). Oklahoma, Texas, and Louisiana made up about 60 percent of total U.S. ammonia production capacity in 2021 due to their large natural gas reserves (USGS, 2022). In Louisiana, where a large amount of fertilizer is produced and transported, Hurricane Ida forced fertilizer plants to shut down and disrupted fertilizer barge shipments throughout the State’s river system. Similarly, in 2022, Hurricane Ian delayed fertilizer production in Florida, which accounts for more than 60 percent of U.S. phosphate production according to USGS.

In addition, in 2022 drought conditions dropped water levels in the Mississippi River Basin to near-record lows, delaying fertilizer shipments upstream (National Oceanic and Atmospheric Administration (NOAA), 2022). Given that crops require specific timing of fertilizer application during the crop year, timely transportation and delivery are important. The conditions in 2022 exacerbated impacts from a multiyear drought in the Missouri River Basin.

Historically, the South, Central, and Southeast U.S. regions have experienced the highest frequency of and highest cost from billion-dollar disaster events (NOAA, 2023). Table 3 identifies the 10 States with the greatest number of billion-dollar natural disasters and the number of operational nitrogen and phosphate fertilizer production sites located in each. Based on data from NOAA (2023), disaster costs in the top 10 States comprised 64 percent of the U.S. total disaster cost. Though we do not account for differences in production volume, data from The Fertilizer Institute suggest that 31 percent of nitrogen fertilizer production sites and 61 percent of phosphate fertilizer production sites are located in the top 10 States that are most vulnerable to natural disasters.

Table 3

Nitrogen and phosphate fertilizer production sites in the 10 U.S. States with the highest historical natural disaster costs

| State | Natural disaster costs since 1980 (million dollars) | Number of natural disasters, 2013–22 | Nitrogen fertilizer sites | Phosphate fertilizer sites |
|----------------|---|--------------------------------------|---------------------------|----------------------------|
| Texas | 375,320 | 75 | 3 | 1 |
| Florida | 373,480 | 29 | 1 | 11 |
| Louisiana | 293,420 | 36 | 3 | 4 |
| California | 141,891 | 19 | 3 | 0 |
| North Carolina | 83,902 | 46 | 0 | 1 |
| Mississippi | 80,074 | 37 | 1 | 1 |
| New York | 77,166 | 34 | 1 | 1 |
| New Jersey | 60,348 | 23 | 0 | 0 |
| Iowa | 56,476 | 31 | 3 | 0 |
| Missouri | 49,686 | 48 | 1 | 1 |

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Table 3 (cont.)

Nitrogen and phosphate fertilizer production sites in the 10 U.S. States with the highest historical natural disaster costs

| State | Natural disaster costs since 1980 (million dollars) | Number of natural disasters, 2013–22 | Nitrogen fertilizer sites | Phosphate fertilizer sites |
|-------------------|---|--------------------------------------|---------------------------|----------------------------|
| Top 10 States | 1,591,673 | - | 16 | 20 |
| U.S. total | 2,475,629 | - | 51 | 33 |

Note: Data on natural disasters include the frequency and cost of billion-dollar weather and climate events, as defined by the National Oceanic and Atmospheric Administration (NOAA, 2023). Natural disasters include droughts, flooding, freezes, severe storms, tropical cyclones, wildfires, and winter storms. Production sites include operational nitrogen and phosphatic fertilizer production sites identified by The Fertilizer Institute (TFI). TFI reported no operational potash production sites in the 10 States included in the table. Total disasters across States not reported because a given natural disaster may affect multiple States. Source: USDA, Economic Research Service using data from NOAA and The Fertilizer Institute as of January 2023.

Global trade of fertilizer has played a large role in mitigating the impact of market disruptions associated with weather or geopolitical events (e.g., the Ukraine-Russia military conflict). When a market disruption affects the supply of inputs or production, international trade can contribute to balancing the market (Baldos & Hertel, 2015). In some cases, the international response to fertilizer shortages from some nations is to facilitate trade agreements that shift fertilizer products from surplus regions to regions facing deficits. For example, in late 2021 some fertilizer plants in Europe temporarily stopped or reduced fertilizer production due to high natural gas prices. Fertilizer imports from other nations, including the United States, Australia, and Trinidad and Tobago, partially replaced the European Union's (EU) own production. At the time, the United States also faced its own supply disruption resulting from Hurricane Ida, extreme cold temperatures in Texas, and the Coronavirus (COVID-19) pandemic, which contributed to higher world fertilizer prices (Wongpiyabovorn et al., 2022).

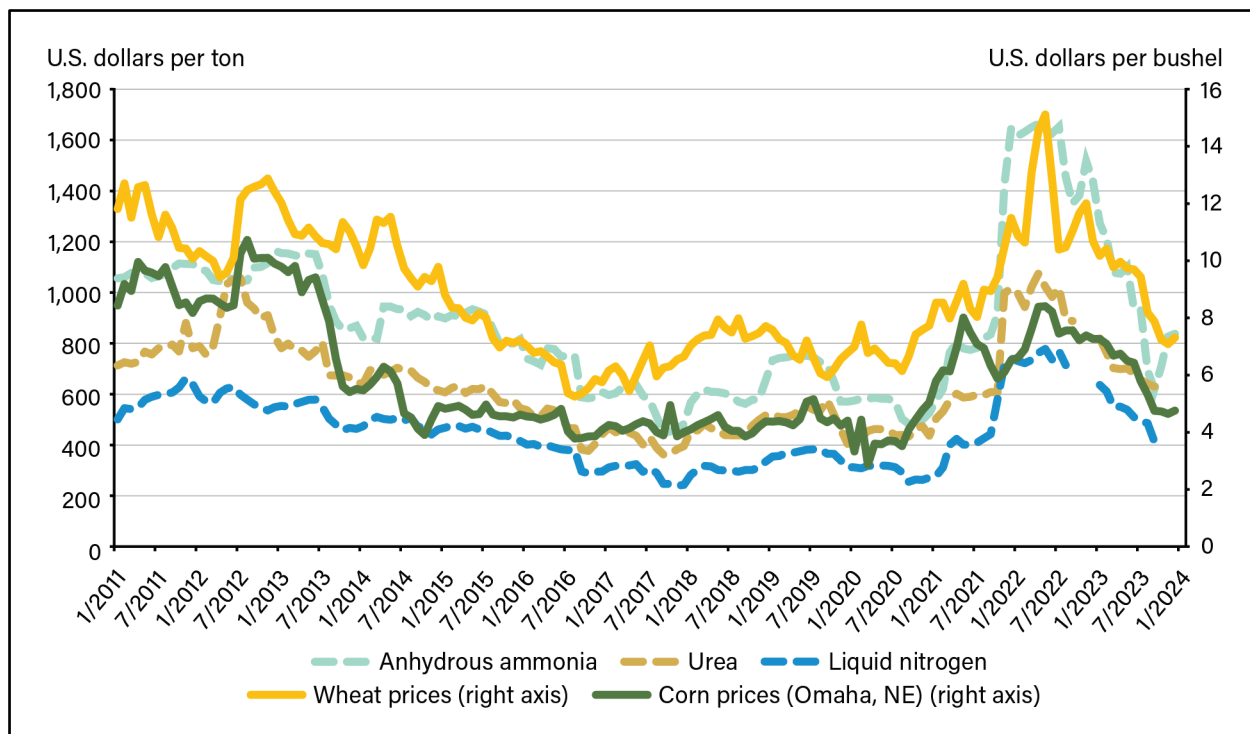
Crop Prices and Crop Production Affect Fertilizer Demand

Crop prices and crop production also affect fertilizer prices due to their impact on fertilizer demand. When making decisions on how much fertilizer to purchase and apply, farmers may compare fertilizer prices to prices they expect to receive for commodities produced. Data gathered from USDA, NASS show that fertilizer and crop prices move in similar patterns.

Figure 22 shows fertilizer prices along with corn and wheat prices from 2011 to 2023. The data suggest that changes in fertilizer prices observed throughout the period are generally associated with changes in corn and wheat prices. Corn and wheat prices followed a similar trend, remaining relatively steady from 2016 through late 2020 before climbing to record or near-record highs in 2022. Prices for corn, wheat, and fertilizer steadily declined since peaking in summer 2022, but each remained above typical levels observed the decade before.

Figure 22

Monthly average inflation-adjusted corn, wheat, and fertilizer prices, 2011–23



Btu = British thermal unit.

Source: USDA, Economic Research Service using data from USDA, Agricultural Marketing Service.

Relationships Among Nitrogen Fertilizer, Natural Gas, and Corn Prices

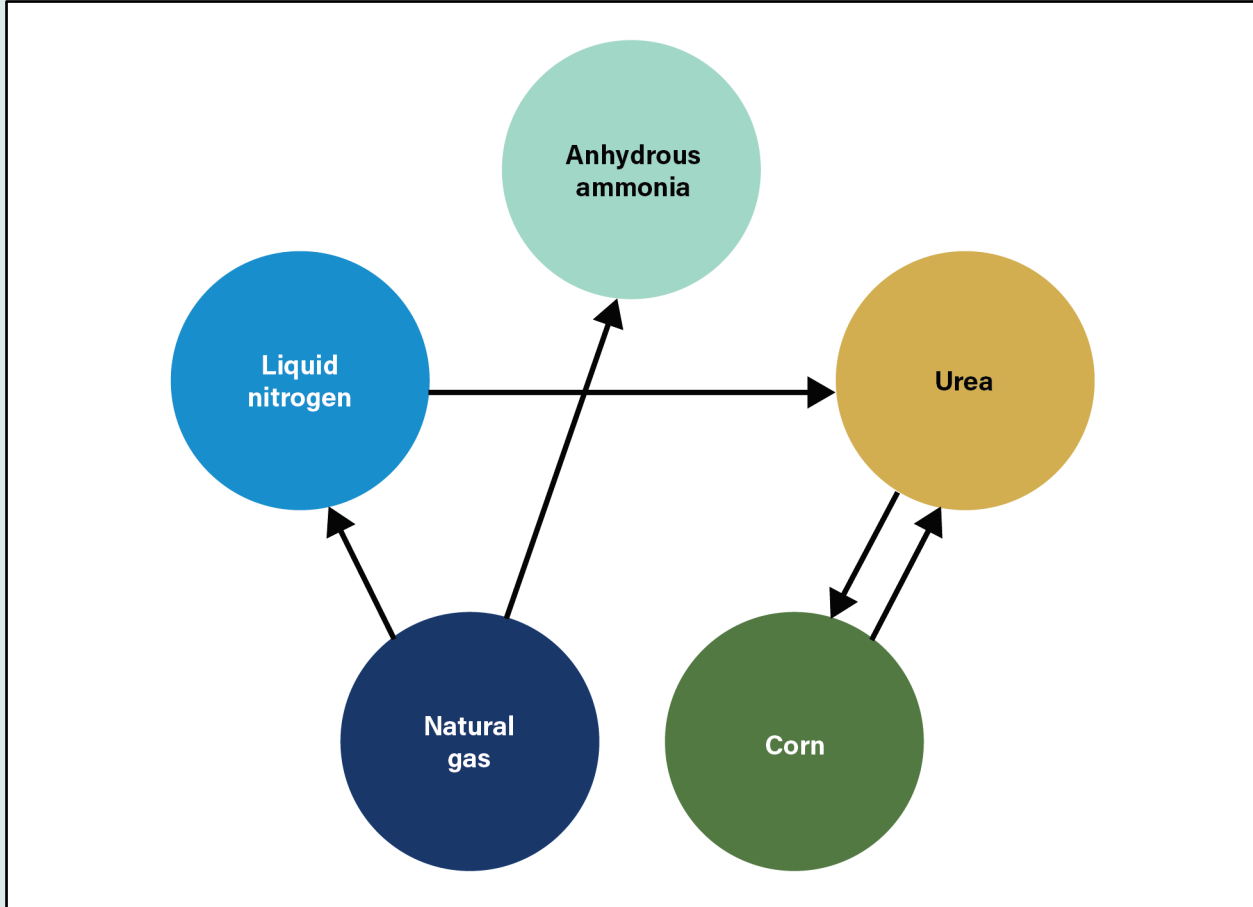
The prices depicted in figures 21 and 22 show price movement similarities for nitrogen fertilizers, natural gas, and corn. Given these similarities, we tested whether knowing prices for one of these products helps understand the movement in prices of other products, a concept referred to as Granger causality. Understanding how natural gas is related to nitrogen-based fertilizer and commodity prices aids in anticipating emerging trends in fertilizer markets. For example, Granger causality would imply that analyzing changes in natural gas prices would help predict (or foreshadow) changes in nitrogen fertilizer prices. Though more complex time series analyses are beyond the scope of this study, the results of Granger causality tests provide further evidence regarding the associations observed.

Box figure 1 illustrates the results of Granger causality tests and suggests that relationships exist between nitrogen-based fertilizer prices in Iowa, natural gas prices, and corn prices in Omaha, Nebraska. In the figure, circles represent prices and arrows indicate Granger causality in one direction. For example, the arrow between anhydrous ammonia prices and natural gas prices indicates that knowing the price of natural gas helps predict the price of anhydrous ammonia.

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Box figure 1

Directions of price relationships based on Granger causality tests on prices of nitrogen fertilizer, corn, and natural gas, January 2011–October 2021



Note: Circles represent product prices. Arrows indicate Granger causality in the direction of the arrow. All relationships shown are statistically significant at the 90-percent level of confidence or above.

Source: USDA, Economic Research Service using data from the USDA Agricultural Marketing Service

The results suggest that Granger causality exists among the included prices. We found Granger causality between liquid nitrogen and urea, implying that knowing price movements for one helps predict price movements in the other. We also found that natural gas prices helped predict two nitrogen fertilizer prices, anhydrous ammonia and liquid nitrogen. Urea prices were found to help predict corn prices but not the prices of other nitrogen fertilizers. Corn prices were also found to help predict urea prices.

These interrelationships are to be expected, given farmers' ability to substitute (to some extent) between nitrogen fertilizers, substitute to less nitrogen-intensive crops, and given the input-output relationships between the goods. For example, natural gas is used in nitrogen fertilizer production and nitrogen fertilizers are used in corn production. For more information about the methodology used for Granger causality tests, see appendix A.

Corn production is one of the largest uses of fertilizer in the United States. According to Myers (2021), global corn production represents 16 percent of farm-use fertilizer, and wheat makes up another 15 percent of global fertilizer use. Although corn and wheat producers are the largest global consumers of fertilizer, food staples such as rice, vegetables, and fruits require another 14 percent, 9 percent, and 7 percent of all global fertilizers, respectively (Myers, 2021).

U.S. planted acreage for corn climbed from 88.9 million acres in 2018 to 93.4 million acres for the 2021 crop year (figure 23). Moving into the 2022 crop year, the U.S. planted acreage of corn was down to 88.6 million acres. This decrease was due (in part) to a slow start in planting given weather conditions, changes in corn prices due to the Russia-Ukraine military conflict, and increased fertilizer prices. For the 2011–23 period, planted acreage for wheat fluctuated less than that of corn. In 2023, planted acreage for wheat was the highest in 7 years, as high wheat prices drove producers to increase acreage (USDA, NASS, 2023).

Figure 23
U.S. corn and wheat acreage, 2011–23



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

Export Restrictions by Major Suppliers Add Pressure to Fertilizer Prices

Export restrictions by major fertilizer producers also contributed to fertilizer price changes. In recent years, Russia has supplied an increasing volume of urea to the United States’ East Coast and New Orleans markets. Although U.S. urea import volumes have been increasing, Russia recently placed constraints on nitrogen and finished-fertilizer exports (Fedorinova & Durisin, 2021). The 6-month export quota, which was put in place from December 1, 2021 to May 31, 2022 to ensure adequate domestic fertilizer supply, was 5.9 million metric tons for nitrogen fertilizers and 5.35 million metric tons for complex products. In the first half of 2022, Russia exported a combined 6.3 megatons⁹ of urea, urea ammonium nitrate, and ammonium nitrate products, exceeding the 6-month quota by 6 percent in 2022. Russia renewed the export quota for the spring 2024 planting season, with the quota set at 9.81 million metric tons for nitrogen fertilizers and 7.14 million metric tons for complex fertilizers. Although Russian producers have since diverted phosphate shipments to regions outside the United States, Russia still accounts for 10–20 percent of U.S. annual urea imports.

Major international players such as the European Union (EU) placed sanctions on Russia’s potash imports following Russia’s military invasion of Ukraine (European Council, 2023). To prevent domestic shortages

⁹ One megaton equals 1 million tons.

and accompanying price hikes, the United States did not place sanctions on Russian fertilizer. The Black Sea Grain Initiative and the relaxation of sanctions in late 2022 resulted in a reduction in fertilizer prices, but in January 2023, Russia levied a 23.5-percent duty on all fertilizer exports for which the price exceeded \$450.00 per ton (Kee et al., 2023).

China also imposed export restrictions on fertilizer products to contain domestic prices and support their own agricultural production (Kee et al., 2023). As a key supplier of urea and phosphates, restrictions on exports by China have added to the volatility of global fertilizer prices.

Conclusion

We used descriptive statistics and trend analyses to assess changes in U.S. fertilizer supply, demand, and prices since the Great Recession. Between 2020 and 2021, U.S. fertilizer prices increased substantially, driven in part by trends in energy and crop prices. Conflicts involving fertilizer producing countries (e.g., Russia and Ukraine) exacerbated already high fertilizer prices, and the more recent conflict involving Israel sparked renewed concern regarding fertilizer prices.

U.S. fertilizer consumption also declined and remains below pre-recession levels. These consumption changes occurred alongside increases in fertilizer costs per acre and as a share of total operating costs, for both corn and wheat producers. Recent price increases have exacerbated the decline in fertilizer consumption since 2018, with nitrogen, phosphate, and potash consumption declining 5.8 percent, 12.6 percent, and 16.2 percent between 2020 and 2021, respectively.

Though still amounting to 8.4 percent of global fertilizer production, U.S. fertilizer production declined since the Great Recession, and the composition of U.S. fertilizer supply has shifted from phosphate to nitrogen making up the largest share of production. Extreme weather and natural disasters in the United States contributed to reduced fertilizer production in recent years. Decreasing domestic fertilizer supply (while global fertilizer supply was increasing) resulted in a decline in the U.S. share of world fertilizer production, imports, and exports.

U.S. fertilizer production depends on natural resource availability. Before and after the Great Recession, the United States relied on imports to meet domestic fertilizer demand, especially for potash.

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Appendix

Granger Causality Test

Granger causality tests are performed to assess whether Granger causality is present among variables and, if so, in what direction. For the purposes of our work, Granger causality would imply that past prices from one commodity (lags) are helpful in predicting the price of another commodity. For example, Granger causality would indicate that changes in natural gas prices help predict changes in nitrogen fertilizer prices or that changes in nitrogen fertilizer prices help predict changes in corn prices, or both.

To identify the forecasting ability between the selected nitrogen-based fertilizer prices in Iowa, natural gas prices, and corn prices in Omaha, Nebraska, we proposed the Granger causality test on a Vector autoregression (VAR) model. A VAR model is employed given the simplicity of its assumptions in explaining the dynamic relationships between multiple time series. Researchers emphasize that VAR models represent a coherent and credible approach to data description, forecasting, and inference (Sims, 1980). In general, VAR models with nonstationary and cointegrated variables must be differenced to conduct the testing. However, Sims et al. (1990) show that VAR models with unit roots (nonstationary) are consistently estimated by least squares in level form. Additionally, the lagged endogenous variable coefficient estimates are asymptotically normal, and the test of excluding one price from another's equations will remain asymptotically valid.

As such, a Granger causality test was performed under the null hypothesis that restricts the coefficients of the lags to zero on a subset of the variables, followed by a Wald test on the restrictions for the coefficients of the VAR model.

We used the Akaike Information Criteria (AIC) to determine the optimal number of lags, and for our data set the optimal number of lags was 2.

Granger Causality Test Results

Table A.1 provides results from Granger causality tests among prices for nitrogen fertilizers (i.e., anhydrous ammonia, urea, and liquid nitrogen fertilizer), natural gas, and corn from February 2011 to October 2021. The Granger causality tests revealed statistically significant relationships among some prices under study. The test results suggest that knowing the price movements for natural gas holds forecasting ability in predicting price movements for two nitrogen-based fertilizers (i.e., anhydrous ammonia and liquid nitrogen). This result is expected because natural gas is an essential input in nitrogen fertilizer production and is used in manufacturing anhydrous ammonia and liquid nitrogen.

Table A.1

Granger causality test among prices for nitrogen fertilizers, natural gas, and corn, February 2011–October 2021

| Dependent variable | Independent variable | P-value | Dependent variable | Independent variable | P-value | Direction of causality |
|--------------------|----------------------|----------|--------------------|----------------------|---------|-------------------------------|
| Anhydrous ammonia | Urea | 0.168 | Urea | Anhydrous ammonia | 0.162 | No causality |
| Anhydrous ammonia | Liquid nitrogen | 0.589 | Liquid nitrogen | Anhydrous ammonia | 0.141 | No causality |
| Anhydrous ammonia | Natural gas | 0.007*** | Natural gas | Anhydrous ammonia | 0.604 | Natural gas → AA |
| Anhydrous ammonia | Corn prices | 0.308 | Corn prices | Anhydrous ammonia | 0.416 | No causality |
| Urea | Liquid nitrogen | 0.029** | Liquid nitrogen | Urea | 0.487 | Liquid nitrogen → Urea |
| Urea | Natural gas | 0.641 | Natural gas | Urea | 0.238 | No causality |
| Urea | Corn prices | 0.095* | Corn prices | Urea | 0.033** | Urea ↔ Corn prices |
| Liquid nitrogen | Natural gas | <.001*** | Natural gas | Liquid nitrogen | 0.161 | Natural Gas → Liquid nitrogen |
| Liquid nitrogen | Corn prices | 0.186 | Corn prices | Liquid nitrogen | 0.970 | No causality |
| Corn prices | Natural gas | 0.708 | Natural gas | Corn prices | 0.439 | No causality |

AA = Anhydrous ammonia.

Note: Each row includes results from Granger causality tests, one for each potential direction of causality between the two stated variables. *, **, and *** indicate statistical significance at the 10-percent, 5-percent, and 1-percent levels, respectively. The final column indicates the direction(s) of causality identified through the Granger causality tests, if any.

Source: USDA, Economic Research Service using data from the USDA, Agricultural Marketing Service.

Although we tested for relationships between each type of nitrogen fertilizer, we only found Granger causality between liquid nitrogen and urea. We also found that urea Granger causes corn prices, confirming that changes in input prices may ultimately influence prices further down the supply chain. Additionally, in our sample, corn prices were found to Granger cause urea; which suggests that as demand for corn increases, the demand for nitrogen fertilizers used to produce corn also increases. Collectively, these results may imply that (with respect to corn) price movements further upstream in the supply chain (such as for nitrogen fertilizer inputs) may be helpful in predicting prices downstream, while downstream prices for corn may also be helpful in predicting fertilizer prices upstream.¹⁰

¹⁰ Results in this study are applicable only to relationships between fertilizer prices in Iowa, natural gas prices, and corn prices in Omaha, Nebraska. Although prices for corn, fertilizer, and natural gas across locations tend to move together, results may differ if the same methodology were applied to prices from other localities.