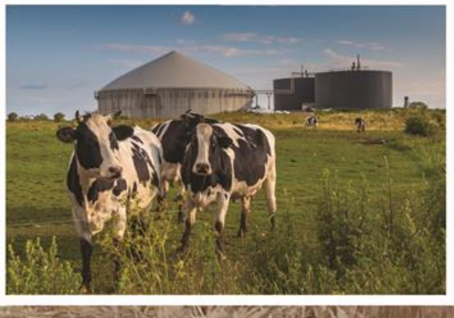
USDA
United States Department of Agriculture

Agricultural Conservation on Working Lands:
Trends From 2004 to Present



Office of the Chief Economist Technical Bulletin 1950 November 2018

AGRICULTURAL CONSERVATION ON WORKING LANDS: TRENDS FROM 2004 TO PRESENT

Contributors:

Marci Baranski, Helena Caswell, Roger Claassen, Charlotte Cherry, Kirsten Jaglo, Alex Lataille, Sharon Pailler, Diana Pape, Anne Riddle, Drew Stilson, and Kate Zook.

Published by:

U.S. Department of Agriculture
Office of the Chief Economist
Washington, D.C. 20250

USDA is an equal opportunity provider, employer, and lender.

For more Information:

Marci Baranski, USDA Office of Energy and Environmental Policy, mbaranski@oce.usda.gov

Kate Zook, USDA Office of Energy and Environmental Policy, kzook@oce.usda.gov

Suggested Citation:

Baranski, M., Caswell, H., Claassen, R., Cherry, C., Jaglo, K., Lataille, A., Pailler, S., Pape, D., Riddle, A., Stilson, D. and Zook, K., 2018. *Agricultural Conservation on Working Lands: Trends From 2004 to Present*. Technical Bulletin Number 1950. Office of the Chief Economist, U.S. Department of Agriculture, Washington, D.C. 127 pages. November 2018.

Acknowledgements:

USDA's Office of the Chief Economist gratefully acknowledges and thanks the following individuals for the time and effort they provided to produce this report: From the USDA Economic Research Service, Roger Claassen, Sharon Pailler, and Anne Riddle. From ICF, Diana Pape, Kirsten Jaglo, and Alexander Lataille. The contributions of these teams played a key role in developing the analysis and producing this report. USDA would also like to acknowledge those who reviewed and commented on previous drafts of the report. Addressing these comments significantly improved the quality of this document.

Cover photo credit:

Photos used for the cover are reprinted courtesy of: the USDA Natural Resources Conservation Service, South Dakota; Conservation Media Library NRCS/SWCS photo by Lynn Betts; and Shutterstock.

CONTENTS

EXECUTIVE SUMMARY

The U.S. Department of Agriculture (USDA) supports the use of conservation practices and technologies on working lands as a strategy to improve environmental outcomes. Use of conservation practices on farms can produce a variety of benefits, including improved soil and water quality, carbon sequestration, reduced greenhouse gas (GHG) emissions, reduced production costs, and increased yields. Conservation practices on working lands also have tradeoffs between different environmental benefits and have variable costs to implement and maintain.

In order to improve the effectiveness of USDA and other organizations supporting agricultural conservation, it is important to understand recent trends in adoption of conservation practices. For USDA, we need this knowledge to inform setting priorities and managing natural resources. In recent years, the private sector, including companies within the food and agricultural sectors, have set greenhouse gas reduction targets. An essential aspect of tracking progress towards GHG goals is having underlying data on agricultural production practices, including conservation practices. In response to this data gap in the private sector and other data needs, researchers at USDA and ICF have produced this report which outlines adoption of conservation practices over the past decade.

Tracking every conservation practice is beyond the scope of this report; as a result, the scope was narrowed to track a subset of working-lands conservation practices producing a common benefit: reduced GHG emissions or increased carbon sequestration. Specifically, we included practices that were targeted as part of USDA's Building Blocks for Climate-Smart Agriculture and Forestry initiative and narrowed those to practices for which survey data were available. Such practices include reduced tillage (mulch tillage and no tillage), nitrogen management, use of cover crops, use of precision agriculture technologies, and use of anaerobic digesters for manure, which generate GHG benefits by reducing emissions of nitrous oxide, methane, carbon dioxide, and/or increasing carbon sequestration. Reducing GHG emissions is not the only environmental benefit these practices provide. They can also reduce nutrient and sediment runoff, improve water quality, improve yields, and improve on-farm profitability, among other benefits.

This report fills an important gap in USDA publications in that it presents national- and regional-scale data on conservation practice and technology trends over the past decade. Data are primarily from the USDA Economic Research Service (ERS)-National Agricultural Statistics Service (NASS) Agricultural Resources Management Survey (ARMS) and the U.S. Environmental Protection Agency's (EPA's) AgSTAR database. National-scale data from the USDA Conservation Effects Assessment Program on tillage were also included. For practices where data were available by crop type and region, we present data for corn, soy, and wheat. Results are presented regionally by cropping system and farm size. By combining publicly available survey data on the implementation rates of these agricultural practices between 2004 and 2016, this report provides an improved understanding of U.S. farmers' use of conservation and establishes sector-wide trends in adoption of conservation practices during this time period. Importantly, this report tracks practices adopted by the agricultural community at large, reported only through statistically representative survey data. As such, the results of this report do not distinguish between practices adopted with the support of USDA programs and those adopted without financial assistance or through other incentive programs.

Nitrogen is an important agricultural input critical for crop production. Runoff and volatilization of nitrogen from the soil has negative impacts on atmospheric and water quality. Thus, applying nitrogen according to the “4Rs” (right source, right rate, right time, right place) can improve environmental outcomes. Over the time period studied, nitrogen rate increased slightly for corn, remained constant for soy, and remained about the same for wheat. The Southeast region had the highest nitrogen application rates in 2016 for corn. Nitrogen applied per bushel decreased slightly for corn from 2005 to 2016, for soy from 2006 to 2012, and for wheat for 2004 to 2009. In terms of nitrogen application method and timing for corn production, results were relatively constant from 2005 to 2016 (fall vs. spring application and incorporation vs. no incorporation). Enhanced efficiency fertilizers are another avenue to increase the nitrogen-use efficiency of crops. From 2005 to 2010, use of enhanced efficiency fertilizers on corn increased from 8.5 percent to 12.5 percent.

Precision agriculture includes the use of various technologies, such as tractor guidance systems using a global positioning system (GPS), GPS soil sampling, and GPS yield mapping. These technologies help farms gather information on field conditions and site-specific within-field limitations and allow for adjustments to production practices, such as variable-rate technology. Adoption of precision-agriculture techniques, including variable-rate technology (VRT) and GPS guidance systems, increased substantially over the period studied. For corn grown in the Corn Belt, adoption of VRT increased from 6 to 8 to 35 percent from 2005 to 2010 to 2016. Larger farms were more likely to adopt VRT. Adoption of VRT increased in all regions for corn. Similarly, for GPS-guided auto steer systems, the percent of corn acres grown using auto steer increased overall from 2005 to 2016 in all regions, except for the Southeast region which decreased from 2010 to 2016. Adoption rates of auto steer for corn increased from 13 to 47 to 56 percent in the Corn Belt from 2005 to 2010 to 2016.

Cover crops, or crops that are not harvested, can contribute to conservation goals including reduced erosion, improved soil quality, and reduced GHG emissions. Adoption of cover crops increased from 2010 to 2015, though cover crop adoption is relatively low, overall. Cover crops were grown on a very small percentage of acres in each of the five major production regions. Nationally, the acreage of cover crops planted was 7.7 million acres in 2010 (2 percent of all planted acres) and increased to 16.3 million acres in 2015 (4 percent of all planted acres). The Corn Belt had the largest increase in acres of cover crops planted from 2010 to 2015, while the Northeast had the highest ratio of adoption.

Tillage is the preparation of soil for seeding. It is also used to control weeds and pests and to incorporate fertilizers and manures. The more disruptive or intense the tillage, the higher the likelihood of soil erosion, nutrient runoff into nearby waterways, and the release of GHGs. Results on reduced tillage varied by crop and region. The proportion of acres grown using no tillage showed the greatest increase for wheat, increased slightly for corn, and decreased slightly for soybeans, based on ARMS data. The proportion of acres grown using some type of reduced tillage (mulch tillage or no tillage) was relatively constant for corn for 2005 to 2016, decreased for soybeans, and increased for wheat. Data from USDA’s Conservation Effects Assessment Program (CEAP) come from all crops over 3 consecutive years. Based on these data, the vast majority of crops grown annually (93 percent) are grown using some type of reduced tillage from 2003 to 2006.

Anaerobic digester systems can reduce biogas (and methane emissions) by capturing the emitted gases and using them to generate electricity and/or heat or converting them to carbon dioxide (CO_2). The number of operating digesters increased from 63 in 2004 to 248 in 2017. Complete mix (35 percent) and plug flow digesters (42 percent) were the two most common types of anaerobic digesters built between 2004 and 2017. Most new digesters were fed by dairy cow manure (196 out of 248).

This report helps establish a baseline of adoption of select conservation practices and technologies on working lands in the United States. Ideally, this effort would be repeated every two years to incorporate new data and to add new practices. Lack of consistent, nationally and statistically relevant data has limited the types of conservation practices that can be described in detail. Large data gaps remain in data for grazing lands and manure management.

INTRODUCTION

Purpose of Report

Agricultural conservation has been a priority for the U.S. Department of Agriculture (USDA) since the 1930s, and USDA continues to promote conservation on working lands today (USDA NRCS, 2018b; USDA, 2017). The use of conservation practices on farms can produce a variety of benefits, including improved soil and water quality, carbon sequestration, reduced greenhouse gas (GHG) emissions, reduced production costs, and increased yields (Boyle, 2006; Stute, 2013; Mitchell & Moore, 2014; Wade, Claassen, & Wallander, 2015).

It is important to understand the trends in adoption of conservation practices over time in order to improve the effectiveness of USDA and other organizations supporting agricultural conservation. USDA conservation programs are only one of many avenues that inform farmers of conservation opportunities and incentivize farmers to adopt conservation practices. There are State conservation programs, programs managed by non-governmental organizations, private-sector initiatives and coalitions, stewardship programs, and producer groups that encourage farmers to improve environmental outcomes. A wide diversity exists in the type and location of practices adopted across these programs. In addition, farmers may choose to adopt a conservation practice on their own, without a financial incentive. Without a firm understanding of which agricultural conservation practices are adopted in various regions across the United States, it is difficult to efficiently prioritize and set baselines and targets for their conservation strategies.

In addition to measuring progress toward conservation goals, studying trends in adoption can help identify patterns in farmer motivation, allowing USDA and other organizations to improve conservation program delivery. There are tradeoffs associated with implementing conservation practices on farms (Naidoo, et al., 2006). Although on-farm benefits (such as improved soil health and increased yield) can result from adopting conservation practices, there are typically up-front costs necessary to implement these practices (Boyle, 2006; Stute, 2013; Mitchell & Moore, 2014; Wade, Claassen, & Wallander, 2015; Carlisle, 2016). Therefore, it should not be assumed that farmers will adopt conservation in the absence of financial or educational support. Farm conservation ultimately requires action on the part of private landowners, who must go beyond conventional production methods and invest time and money to provide environmental benefits—ultimately generating public goods, such as cleaner air and water (Swinton, Rector, Robertson, Jolejole-Foreman, & Lupi, 2015).

USDA and other organizations encourage a wide variety of on-farm conservation practices, such as reduced tillage, irrigation management, and manure management planning. Each conservation practice provides a set of environmental benefits, and these vary depending on the practice. Choosing to implement one practice, or a suite of practices, depends on the producer’s goals and operation, and organizations supporting farm conservation may encourage a particular practice to achieve a specific environmental outcome.

Tracking every conservation practice is beyond the scope of this report; as a result, the scope was narrowed to track a subset of working-lands conservation practices producing a common public benefit: reduced GHG emissions or increased carbon sequestration. Specifically, we included practices that were targeted as part of USDA's Building Blocks for Climate-Smart Agriculture and Forestry initiative and narrowed that to practices for which survey data were available. Such practices include reduced tillage (mulch tillage and no tillage), nitrogen management, use of cover crops, use of precision agriculture technologies, and use of anaerobic digesters for manure, which generate GHG benefits by reducing emissions of nitrous oxide, methane, carbon dioxide, and/or increasing carbon sequestration (Eve, et al., 2014). Reducing GHG emissions is not the only environmental benefit these practices provide. They can also reduce nutrient and sediment runoff, improve water quality, improve yields, and improve on-farm profitability, among other benefits (Boyle, 2006; Stute, 2013; Mitchell & Moore, 2014; Wade, Claassen, & Wallander, 2015).

Results are presented regionally by cropping system and farm size. By combining publicly available survey data on the implementation rates of these agricultural practices between 2004 and 2016,[1] this report provides an improved understanding of U.S. farmers' use of conservation and establishes sector-wide trends in adoption of conservation practices during this time period. Importantly, this report tracks practices adopted by the agricultural community at large, reported only through statistically representative survey data. As such, the results of this report do not distinguish between practices adopted with the support of USDA programs and those adopted without financial assistance or through other incentive programs.

This report fills an important gap in USDA publications in that it presents national- and regional-scale data on conservation practice and technology trends. By identifying current adoption rates and trends of select agricultural conservation practices that both reduce GHG emissions and provide additional environmental benefits, USDA and other organizations can better understand farmers' actions today and develop strategies to increase adoption of these practices in the future.

Agriculture and GHG Emissions

Agriculture comprised approximately 9 percent of all GHG emissions in the United States in 2015, the majority of which came from agricultural soil management (including nitrogen fertilization resulting in nitrous oxide emissions), enteric fermentation, and manure management (EPA, 2017b). Conservation practices with the potential to reduce nitrous oxide emissions include variable rate technology (VRT) used for fertilizer application and improved nitrogen management, such as the use of nitrogen stabilizers and nitrogen inhibitors (ICF International, 2013; Butchee, May, & Arnall, 2011; Balafoutis, Koundouras, Anastasiou, Fountas, & Arvanitis, 2017). Conservation practices that have been shown to increase carbon sequestration and/or reduce carbon dioxide (CO_2) emissions from soils include growing cover crops and using reduced tillage (ICF International, 2013; ICF International, 2016). Digesters, by design, reduce GHG emissions by capturing and utilizing

[1] Tracking varies for each type of conservation program or practice. Data on acres using these practices are determined through agricultural surveys, such as those conducted by USDA ARMS or CEAP. See section 1.3.2 for more information on these surveys.

or burning methane emissions produced from the breakdown of manure by anaerobic microbes (USDA NRCS, 2009; ICF International, 2013).

Practices That Reduce GHG Emissions and Provide Environmental Benefits

For the purposes of this report, the focus is on those conservation practices that reduce GHG emissions while also providing additional environmental benefits. Specifically, the report addresses:

- **Cropland conservation practices**, including:
  - Soil health-related practices that improve soil organic matter, enhance soil carbon sequestration, and reduce emissions from soils and equipment.
  - Nitrogen stewardship practices that reduce nitrous oxide emissions, potentially reduce impacts to water quality, and provide cost savings to farmers by reducing inputs. This is accomplished by focusing on the right timing of application, using the right nutrient source, right placement, and applying the right amount of nutrients (typically referred to as the "4Rs").
- **Manure management**, manure treatment, and renewable energy production from use of anaerobic digesters.

Within each of these categories, we focus on specific practices. A definition of each of the practices included in this report is provided below.

Soil Health

- **Tillage Management** for four categories:
  - **Conventional tillage:** Less than 15 percent residue cover remaining. Moldboard plow or other intensive tillage used such as chisel or disc. Cultivation and/or herbicides for weed control (Osteen, Gottlieb, & Vasavada (eds.), 2012).
  - **Mulch tillage:** 15 to 30 percent residue cover remaining. No use of moldboard plow and intensity of tillage reduced. Soil is disturbed prior to planting, using less intensive tillage tools. Cultivation and/or herbicide for weed control (Osteen, Gottlieb, & Vasavada (eds.), 2012).
  - **Reduced tillage:** Term that refers to any tillage practice that results in greater than 15 percent of residue cover remaining, including mulch tillage, no tillage, or a combination of the two practices. Other publications may use the term "conservation tillage."
  - **No tillage:** 30 percent or greater of the soil surface covered by residue after planting. No tillage performed. Weed control typically accomplished primarily with herbicides (Osteen, Gottlieb, & Vasavada (eds.), 2012).
- **Soil Tillage Intensity Rating (STIR)[2]:** STIR is a rating scale based on the kind, severity, and number of ground-disturbing activities in a crop field. Lower numbers indicate less

[2] STIR ratings are an evaluation tool, not a production practice. However, they are included on this list as STIR ratings are used to categorize CEAP tillage practices later in the report.

overall disturbance to the soil. No tillage management requires a STIR value of 10 to 30 or less.[3] Values may range from 0 to 200. Components of STIR include:

- Operating speed of tillage equipment,
- Tillage equipment type,
- Tillage depth,
- Percent of surface area disturbed (USDA NRCS, 2006; USDA NRCS, 2008).

- **Cover Crop:** A crop which is not harvested. Conservation purpose includes reducing soil erosion, improving soil's physical and biological properties, supplying nutrients, and suppressing weeds (USDA RMA, 2016).

Nitrogen Stewardship

- **Nutrient Management:** Managing the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments (NRCS, NHCP, 2012).
- **Enhanced Efficiency Fertilizers:** Fertilizer products with characteristics that allow increased plant uptake and reduce the potential of nutrient losses to the environment (e.g., gaseous losses, leaching, or runoff) when compared to an appropriate reference product (AAPFCO, 2013).
- **Precision Agriculture:** A management system that is information and technology based, and site-specific. The system typically uses one or more of the following sources of data: soils, crops, nutrients, pests, moisture, or yield, for optimum profitability, sustainability, and protection of the environment (USDA NRCS, 2007).
  - **Variable Rate Technology (VRT)**: Computer-controlled equipment that continually readjusts the application. Sampling data provide the development of a prescription for nutrients, pesticides, seeds, or irrigation water to be applied to each area. In the application of nutrients, pesticides, and seeds, this may include "on the fly" adjustments in the field, which are made possible by a GPS receiver that recognizes the area and provides a prescription for specific areas in the field. Computer-controlled nozzles can also vary the type and amounts of specific inputs according to the variable rate application plan (USDA NRCS, 2007).
  - **Integrated Guidance Systems (Auto steering equipment)**: A GPS guidance system that steers agricultural equipment with centimeter accuracy. These systems provide reduced inputs by decreasing gaps and overlaps, as well as delivering fertilizer directly to the seed trench more accurately (USDA NRCS, 2007).

Manure Management

- **Manure Digesters**: Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel (complete mix or plug flow digester) or a covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and methane (CH_4), which are captured and flared or used as a fuel (EPA, 2016b). An anaerobic digester is a component of a waste management system that provides biological treatment in the absence of oxygen (USDA NRCS, 2009).

[3] In this report, STIR ratings of <30 are considered "no tillage."

Overview of Goal, Research, Data Sources, and Agricultural Conservation Indicators

Goal

This project was developed to establish a baseline using data from 2004 to present and to frame a process for tracking adoption of select agricultural conservation practices that both reduce GHG emissions and provide additional environmental benefits from 2018 and beyond. By identifying current adoption rates and trends at the regional and national levels, USDA may be able to better understand farmers' actions today and develop strategies to increase future adoption of these practices. Additionally, as described above, use of these practices can reduce the net GHG emissions produced by agriculture (USDA NRCS, 2017h). As the United States estimates agricultural GHG emissions annually in the U.S. Greenhouse Gas Inventory, a better understanding of the adoption rates of these practices can be used to improve GHG estimates for the agriculture sector.

Research

A targeted literature search was conducted to summarize publicly available data on adoption of the selected conservation practices. The search focused primarily on peer-reviewed journal articles, reports, and databases from Federal and State agencies (e.g., USDA, EPA) and agriculture industry reports. Specifically of interest were reports and/or databases on the historical and current use of the conservation practices of interest in the United States, especially those that could be used for time-series analyses for adoption of the conservation practice. Table 2 lists the terms that were evaluated in the literature search.

TABLE 1. Conservation-Related Terms for Literature Search

- Reduced Tillage
  - Soil Tillage Intensity Rating (STIR)
  - Erosion control measures
  - Types of tillage
- Double Cropping
- Cover Crops
  - Planting data
  - Type of cover crop
  - Termination method
  - Termination date
- Nutrient Management
  - Application timing
  - Fertilizer type
  - Application method
  - Application rate
- Nutrient Management (continued)
  - Nitrogen inhibitors
  - Compost additions
  - Manure additions
  - Slow-release fertilizers
- Manure Management
  - Percent of livestock managed by each manure management system (by State, livestock type)
  - Manure management systems (e.g., anaerobic lagoons, ponds, deep-pit manure storage, covered lagoons)
  - Methane capture
  - Land application of manure
  - Per unit greenhouse gas (GHG) intensity

Results from the literature search indicated that the desired granularity of data was not available for most of the agricultural practices or categories listed above. In certain categories, such as use of nitrogen inhibitors, limited data were available at the national level, and very detailed data were available at the State level.

Our literature search indicated that there were several data sources that could provide enough data at the level of granularity needed to establish a baseline for some conservation practices. Each of these sources and the data provided are described below.

USDA NASS/ERS ARMS

Through a joint enterprise of USDA's National Agricultural Statistics Service (NASS) and Economic Research Service (ERS), a wide range of farming-related data is collected through the Agricultural Resource Management Survey (ARMS). ARMS surveys do not cover the entire United States. The survey is designed to provide coverage of farms in the 48 contiguous States plus State-level data for 15 major cash receipt States (USDA, 2018). Survey sample rates are weighted so that sampled States are calibrated to official USDA estimates for production and acreage where possible. However, not all States are sampled each year, based on the target crop.[4] Thus, total crop acreage reported from ARMS is typically about 90 to 95 percent of official USDA acreage estimates from the USDA Census of Agriculture.

For this report, ERS compiled data on tillage practices (mulch tillage and no tillage), average nitrogen application rates, and precision agriculture (both VRT and guidance steering) by farm size, crop type (corn, soybean, and wheat), and production region for the years between 2004 and 2016 for which data were collected— corn (2005, 2010, and 2016 surveys), soybean (2006 and 2012 surveys), and wheat (2004 and 2009 surveys). Additionally, ERS compiled data on nitrogen application timing and application method by farm size and USDA region for corn in 2005, 2010, and 2016. For cover crops, data on farm size (including both crop and animal production) and number of acres where cover crops were planted were compiled by ERS by region for which data were collected (2010, 2011, 2012, and 2015 surveys). As the data were grouped by farm production region, no confidential or sensitive information was shared.

USDA Conservation Effects Assessment Project (CEAP)

CEAP is a multi-agency effort to quantify the environmental effects of conservation practices and programs and develop a science base for managing the agricultural landscape for environmental quality (USDA CEAP, 2017a). CEAP integrates the National Resources Inventory (NRI), geospatial databases, conservation practice implementation data, and partner monitoring data with analytical models and methods. CEAP Assessments are carried out at field, watershed, and landscape scale and include analysis of the cumulative effects and benefits of conservation practices on natural resources and the environment (USDA CEAP, 2017a). For this report, data on tillage in a 2003-2006 multi-year rotation were provided by NRCS and ERS.

---

[4] For more information on ARMS sampling and analysis, see https://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/documentation/

A more comprehensive list of USDA sources of conservation data (for cropland, sensitive lands, and livestock) is available in Appendix A.

As the goal of this project is to track U.S. adoption of agricultural conservation practices that both enhance carbon sequestration and reduce GHG emissions as well as provide additional environmental benefits, our literature review demonstrated that large data gaps remain for many of the practices of interest (see TABLE 1 for the terms that were evaluated in the literature search). The practices for which enough data were found to either determine a change in practice over time or establish a baseline of current practice adoption are:

- Nitrogen application amount, timing and method[5]
- VRT
- Integrated guidance systems (auto steering equipment)
- Cover crops
- Reduced tillage
- Anaerobic digesters

Note on Statistical Significance and Uncertainty in This Report

Any practice-adoption data with a relative standard error of 50 percent or higher are not included in this report. Consequently, all of the adoption estimates reported are significantly different from zero with 95 percent confidence. However, it is important to note that **the trend estimates are not necessarily significantly different from each other**, particularly when the differences are small (error bars are not included in this report). Therefore, for the majority of practices included in this report, conclusions drawn about trends in adoption over time are not necessarily statistically valid and should instead be interpreted as anecdotes.

Appendix C contains tables showing the number of data points for each region and the relative standard error (RSE) for each data set used in the report. When possible, data in the report are aggregated in two different ways: (1) by USDA region at all farm sizes; and (2) by farm size (i.e., <250 acres, 250–299 acres, 1,000+ acres) at the national level. The data source and the specific data used for each practice are described in more detail below.

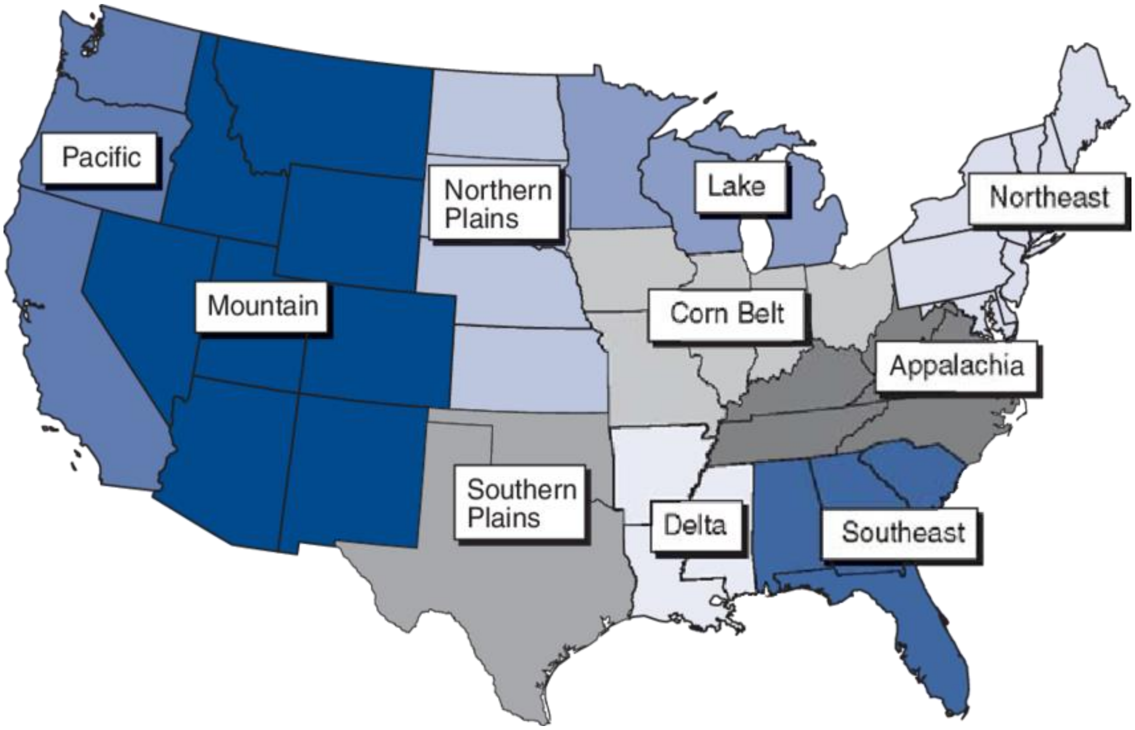
USDA Regions and Crop Production Areas

Farm Production Regions

Data presented in this report are shown either at the national level or aggregated into farm production regions. FIGURE 1 is a map showing the contiguous 48 States broken into 10 Farm Production Regions. Crop production in Alaska and Hawaii is not included in this report. See Appendix C for a list of States in each region.

[5] Data on nitrogen application timing and method are for corn only.

FIGURE 1. Farm Production Regions



Source: (Aillery, et al., 2005)

U.S. Crop Production Data

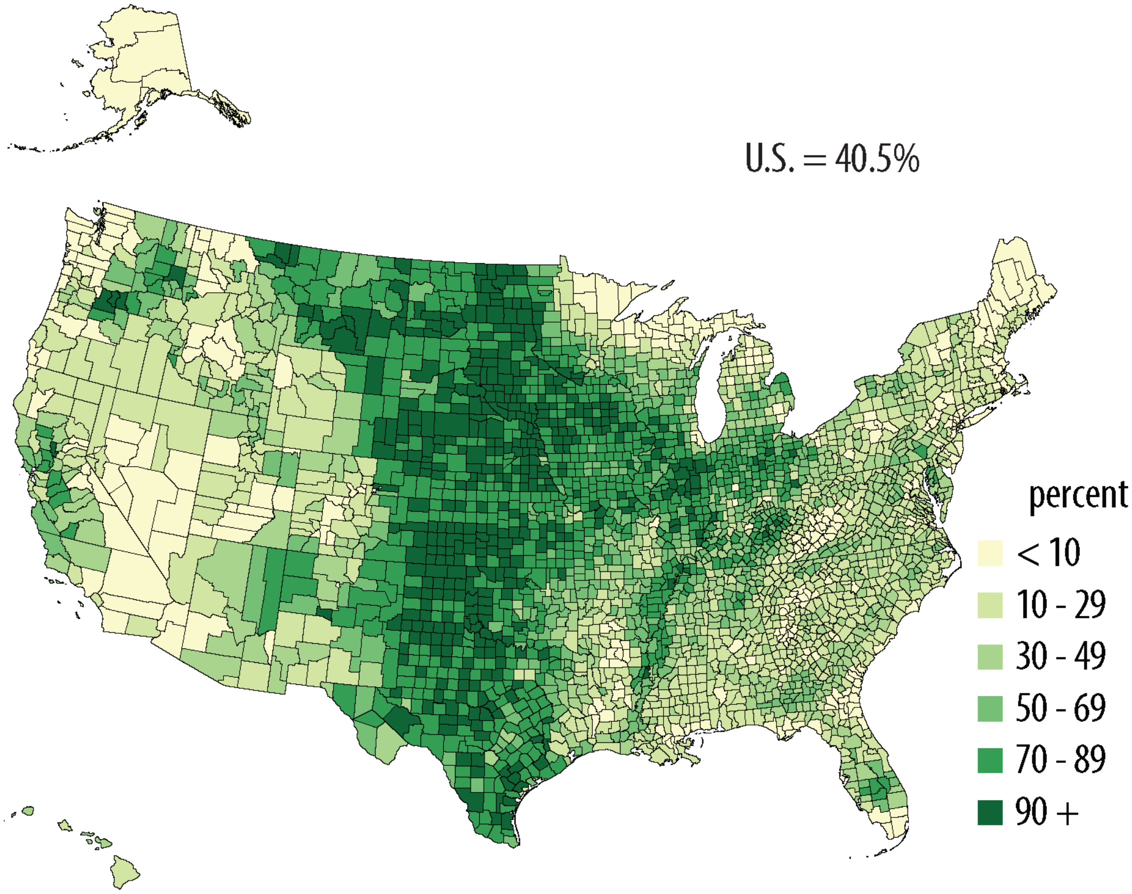
Data for most of the crop conservation practices included in this report are specific to corn, soybeans, and wheat. Corn, soybeans, and wheat were chosen to track conservation practice trends as, combined, they consistently account for approximately 65–70 percent of cropland in the United States and data are available on these practices for multiple years from USDA ARMS. For example, in 2007, corn, soybeans, and wheat (including winter, spring, and durum) comprised approximately 67 percent (207 million acres) of the 309.6 million harvested cropland acres, based on Census of Agriculture data (USDA, 2014). Similarly, in 2012, 220 million combined acres of corn, soybeans, and wheat were grown out of the 315 million harvested cropland acres (70 percent) (USDA, 2014).

In contrast, some of the data in this report are not specific to corn, soybeans, and wheat. For example, in addition to the crop-specific data, reduced tillage also includes an analysis of the types of tillage used during multi-year crop rotations on croplands. For cover crops, data are for farm-wide changes in acreage regardless of the cash crop.

U.S. Farmland

In 2012, the Census of Agriculture indicated that the proportion of U.S. farmland is approximately 915 million acres, making up slightly more than 40 percent of all U.S. land. Of these acres, 45.4 percent were permanent pasture, 42.6 percent were cropland, 8.4 percent were woodland, and the remaining 3.6 percent acres were livestock facilities, farmsteads, buildings, etc. (USDA, 2014). These acreages and land use breakdowns are nearly identical to those indicated by the 2007 Census of Agriculture (922 million farmland acres, 44.3 percent permanent pasture, 44 percent cropland, 8.2 percent woodland, and 3.4 percent other) (USDA, 2014). A map showing 2012 farmland as a percentage of land area by county is shown in FIGURE 2.

FIGURE 2. U.S. Farmland as a Percentage of Land Area by County, 2012



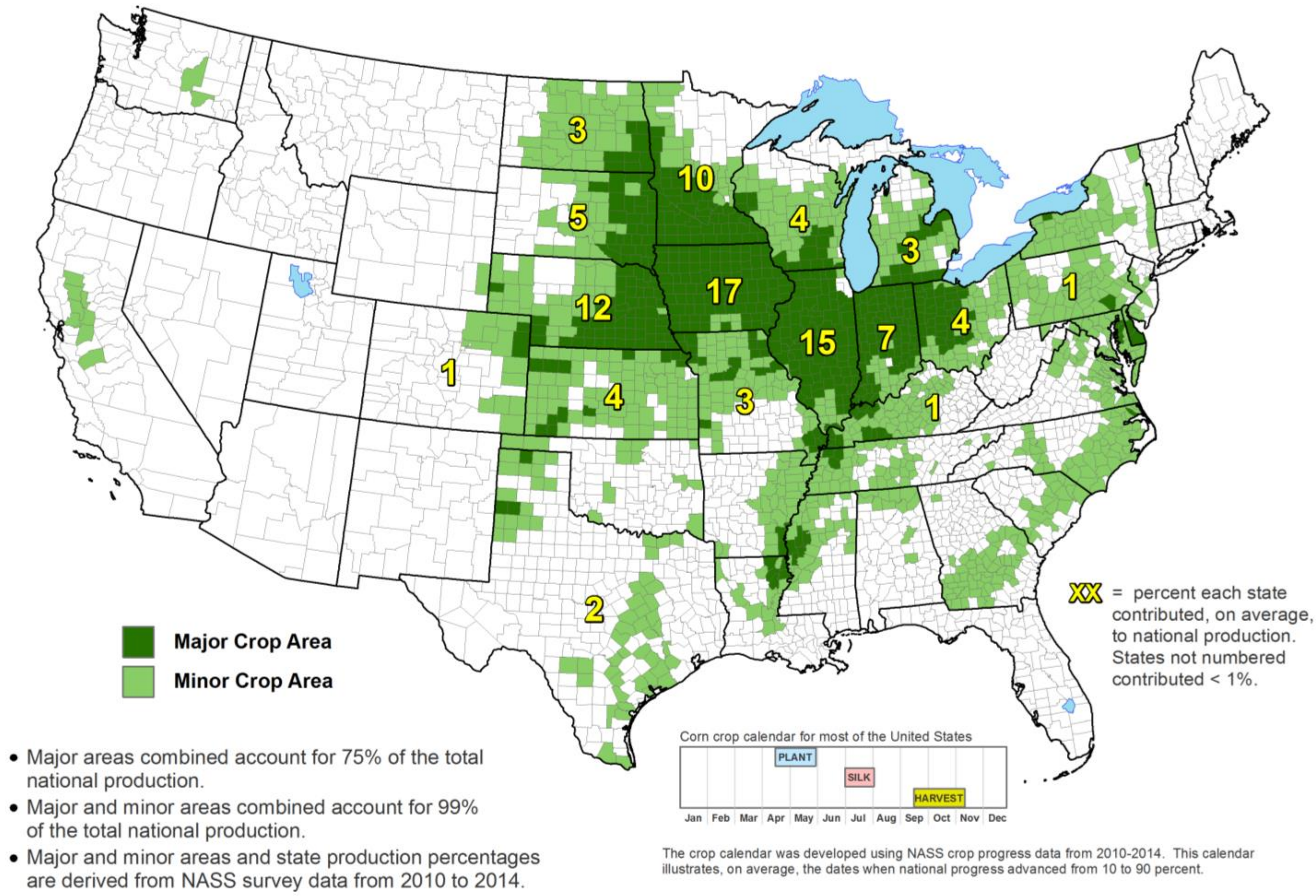
Source: (USDA, 2014)

Corn Production Regions

Corn is the most widely produced feed grain in the United States, accounting for more than 95 percent of total production and use for livestock (Corn and Other Feed Grains: Overview, 2017c). Based on ARMS surveys, in 2005, approximately 77,161,000 acres were planted; in 2010, approximately 81,894,000 acres were planted; and approximately 86,856,000 acres were planted in 2016 (USDA ERS, 2005; USDA ERS, 2010b; USDA

ERS, 2016a).[6] The regions with the highest production levels include the Corn Belt, the Northern Plains, and the Lake States (see FIGURE 3 below for more details). These regions make up approximately 90 percent of U.S. corn production.

FIGURE 3. United States Corn Production Regions, 2010–2014



Source: (USDA OCE, 2014a). USDA NASS = National Agricultural Statistics Service.

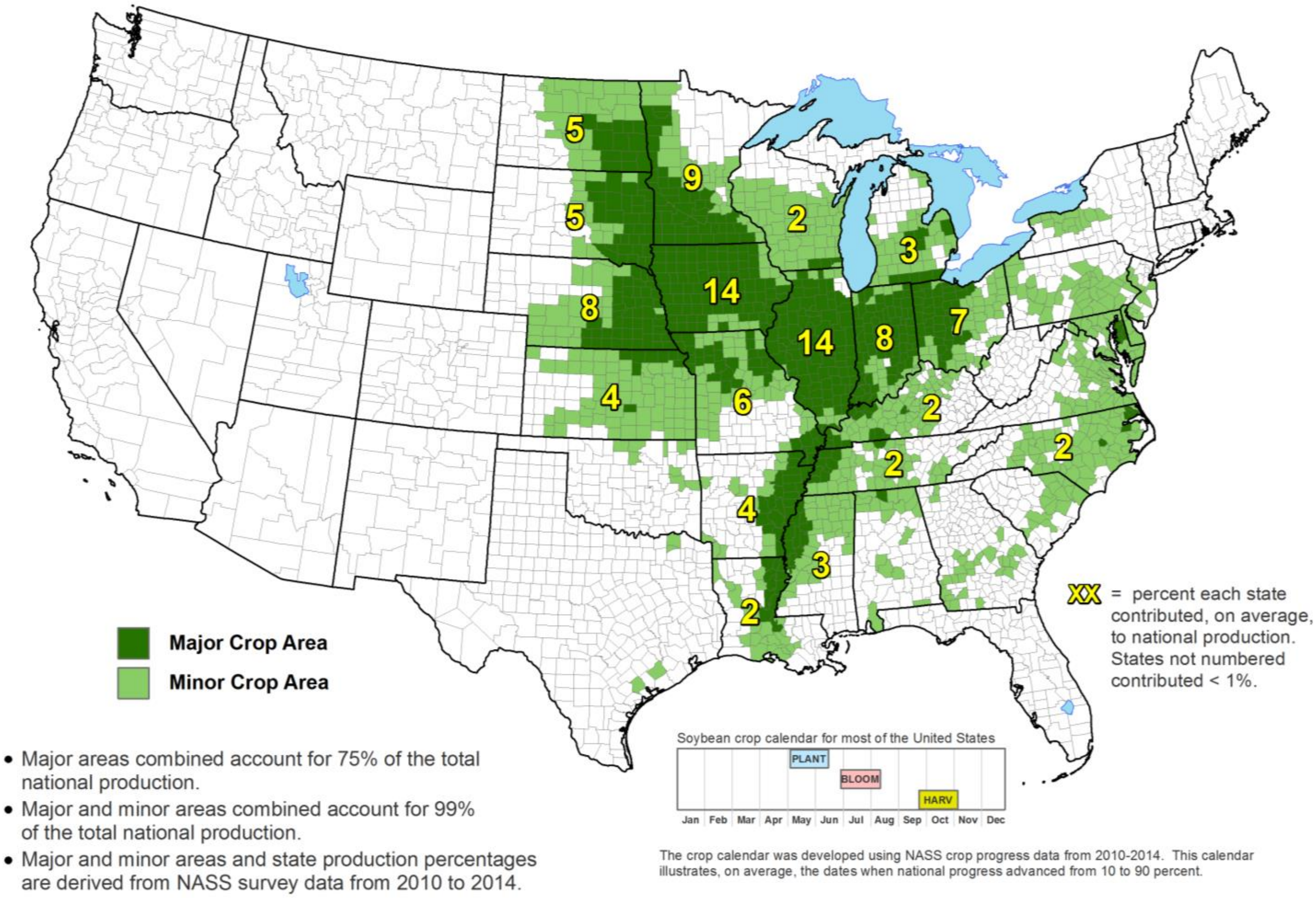
Soybean Production Regions

Soybeans are the dominant oilseed produced in the United States, accounting for about 90 percent of U.S. oilseed production (USDA ERS, 2017b). Based on ARMS surveys, in 2006, approximately 73,278,000 acres were planted, and approximately 74,247,000 acres were planted in 2012 (USDA ERS, 2006; USDA ERS, 2012b). Like corn production, the regions

[6] Note that the values in this report are from ARMS surveys, which have acreages that are approximately 90-95% of the acreages in the Census of Agriculture. To remain consistent, acreages of the selected production practices and total acreages are all from ARMS surveys in this report.

with the highest production levels include the Corn Belt, the Northern Plains, and the Lake States (see FIGURE 4 below for more details).

FIGURE 4. United States Soybean Production Regions, 2010–2014

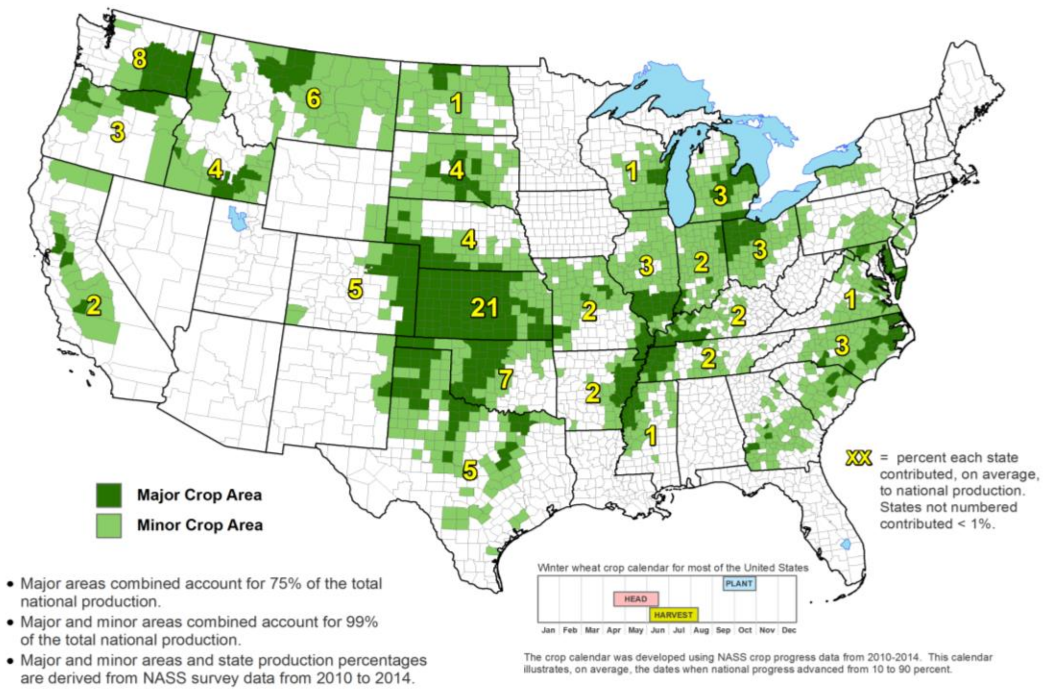


Source: (USDA OCE, 2014c). USDA NASS = National Agricultural Statistics Service.

Wheat Production Regions

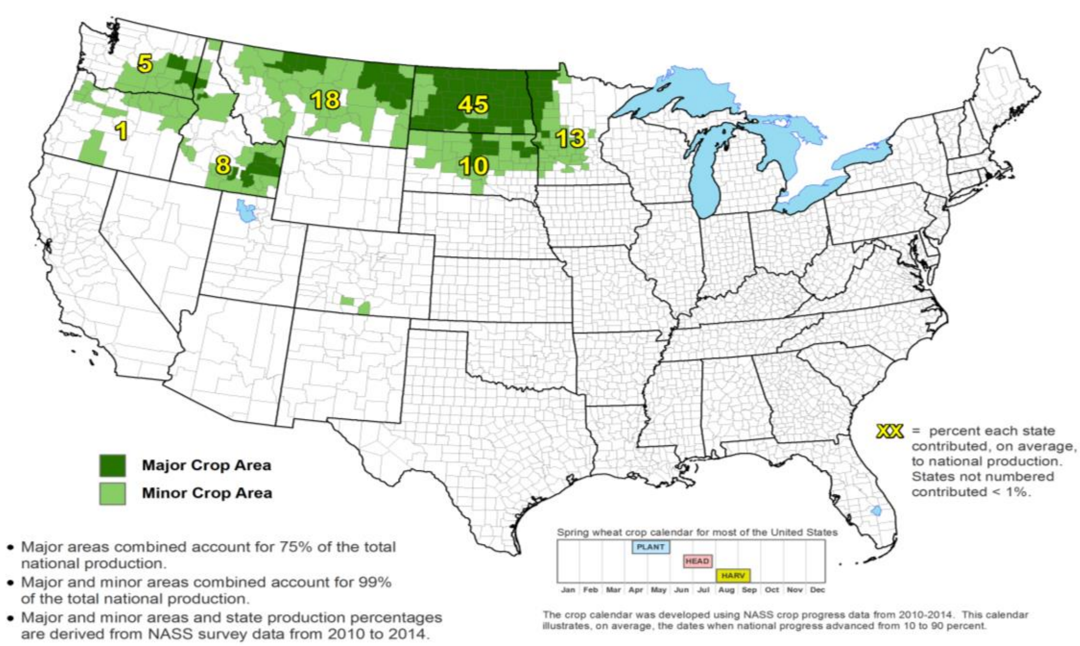
Wheat ranks third among U.S. field crops in planted acreage and production, behind corn and soybeans. The three main types of wheat planted in the United States are winter, spring, and durum wheat (USDA ERS, 2017d). ARMS data used in this report include combined production data from all three types. Based on ARMS data, in 2004, approximately 53,598,000 acres were planted and approximately 52,206,000 acres were planted in 2009 (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c). The regions with the highest wheat acreage include the Northern Plains, the Southern Plains, and the Mountain regions (see FIGURE 5, FIGURE 6, and FIGURE 7 below for more details).

FIGURE 5. United States Winter Wheat Production Regions, 2010–2014



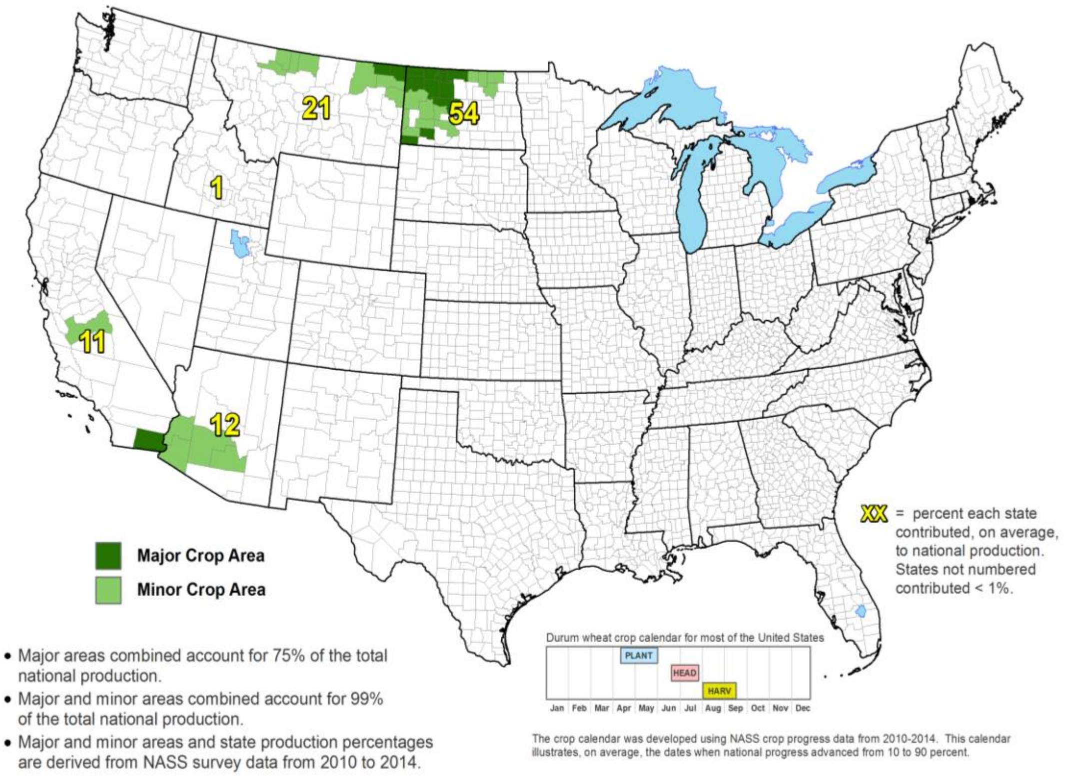
Source: (USDA OCE, 2014e). USDA NASS = National Agricultural Statistics Service.

FIGURE 6. United States Spring Wheat Production Regions, 2010–2014



Source: (USDA OCE, 2014d). USDA NASS = National Agricultural Statistics Service.

FIGURE 7. United States Durum Wheat Production Regions, 2010–2014



Source: (USDA OCE, 2014b). USDA NASS = National Agricultural Statistics Service.

CROPLAND

Overview of Cropland Agricultural Conservation Practices

As described above, data for several types of agricultural practices were collected and analyzed for this report. These practices include:

- Amount of nitrogen applied by planted acre and yield
- Nitrogen timing and application method (corn only)
- Variable rate technology (VRT)
- Integrated guidance systems (auto steering equipment)
- Cover crops
- Reduced tillage

When possible, data were collected by year, region, and farm size either for land used for crops and livestock (cover crops), cropland (mulch tillage/no tillage) or for corn, soybean, and wheat (nitrogen application amount, timing, and method;[7] precision agriculture; and mulch tillage/no tillage).

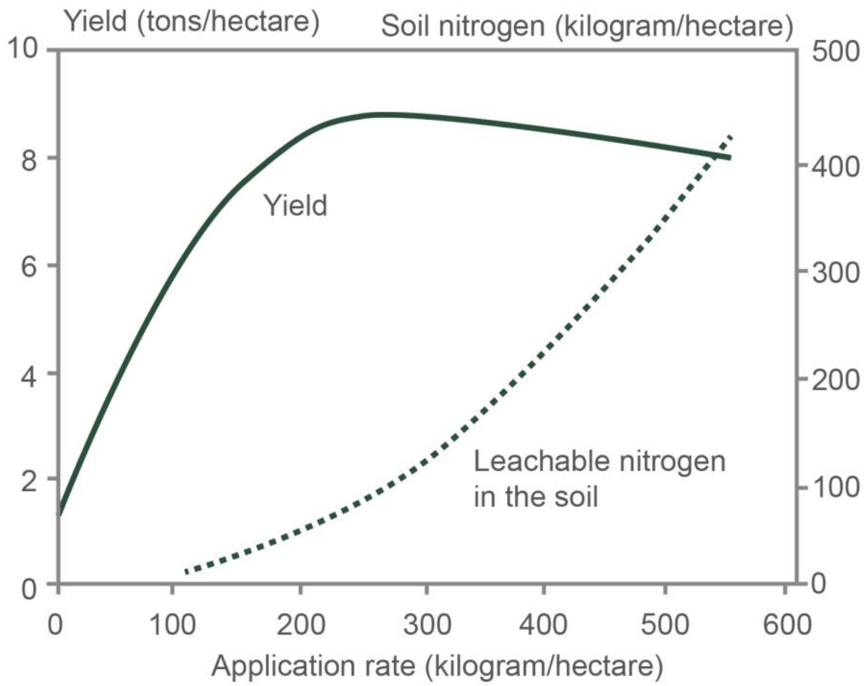
Nitrogen Application

Nitrogen fertilizer is an important input in crop production. Applied annually, 40 to 70 percent of the fertilizer nitrogen applied is utilized by the crop, resulting in crop production (Johnson, 2011). Average application rates (on acres that receive nitrogen) vary across regions due to variations in crop mixes, soil and climatic conditions, and current fertilizer recommendations. As a general rule, rates are higher for corn than for wheat and nitrogen is typically not applied to soybeans (Wade, Claassen, & Wallander, 2015; La Menza, Monzon, Specht, & Grassini, 2017; Mourtzinis, et al., 2018).

For most crops, increasing nitrogen application rate increases yield until a crop-specific maximum yield is reached. Nitrogen addition beyond this point will not result in any additional yield gains and may actually result in decreased yield. Additionally, as more nitrogen is applied, more is lost to the environment through volatilization into the air, leaching into ground water, emission from soil to air, and runoff into surface water (USDA ERS, 2016c). This loss increases dramatically as more nitrogen is applied in excess of the maximum yield. See FIGURE 8 for the effect of nitrogen fertilizer application rate on corn yield and soil nitrogen.

[7] Data on nitrogen application timing and method are for corn only.

FIGURE 8. Effects of Nitrogen Fertilizer Application Rate on Corn Yield and Soil Nitrogen



Source: (Hauck, 1990). Redrawn from California Agriculture, University of California, 31(5), 24-25 ©1977 The Regents of the University of California.

Reactive forms of excess nitrogen fertilizer, such as ammonia (NH_3), ammonium (NH_4), nitrogen oxides (NO_x), nitrous oxide (N_2O), and nitrate (NO_3), can lead to acidification and eutrophication (nutrient enrichment) effects on forests, soils, and freshwater aquatic ecosystems; nitrate contamination of drinking water aquifers; biodiversity losses in terrestrial and aquatic ecosystems; and other adverse effects (Ribaudo, et al., 2011). TABLE 2 below shows avenues of loss and percentage loss for different types of nitrogen.

TABLE 2. Principal Nitrogen Forms

Avenues of Loss	Principal Nitrogen Forms	Percent Loss
Immobilization	Organic (-NH_2), Ammonium (NH_4^+) and Nitrate (NO_3^-)	10 – 40%
Denitrification	Nitrate (NO_3^-) and Nitrite (NO_2^-)	5 – 35%
NH_3 Volatilization	Ammonia (NH_3), Urea ($CO=(-NH_2)_2$	0 – 30%
Leaching	Nitrate (NO_3^-) and Urea ($CO=(-NH_2)_2$	0 – 20%
Erosion	Organic (-NH_2), Ammonium (NH_4^+) and Nitrate (NO_3^-)	0 – 20%

Source: (Johnson, 2011)

Application of nitrogen fertilizers to soils is the largest source of GHG emissions in agriculture. In 2015, it accounted for approximately 75 percent of N_2O emissions and 3.8 percent of total emissions in the United States (EPA, 2017b).

Nutrient management helps ensure that crops have the nutrients they need while minimizing the opportunity for nutrients to be lost to the environment through runoff, leaching, or volatilization (Wade, Claassen, & Wallander, 2015). Increasing plant nitrogen-use efficiency (NUE) (i.e., maximizing the amount of applied fertilizer that makes it into the crop) can maintain or increase plant yield even while reducing fertilizer application (Ribaudo, et al., 2011; Robertson, et al., 2013). NUE for crops can be improved through using the "4Rs" in nitrogen application: applying the right source, at the right rate, at the right time, in the right place (USDA NRCS, 2017a). Studies indicate that the majority of corn grown in the United States could use improvements in NUE and that such improvements (i.e., use of the 4Rs) could potentially reduce nitrogen emissions by 20–80 percent (Ribaudo, et al., 2011; Snyder & Fixen, 2012).

To improve nitrogen application timing, synchronization of application and crop nitrogen demand (i.e., applying the nitrogen when the plant most needs it) can increase nitrogen availability to the crop while reducing excess nitrogen in the soil. Determining the "best" nitrogen application timing requires considering multiple factors, including: specific plant needs, workload, application costs, seasonal differences in fertilizer price, and the risks of weather impeding application at the right time (Ribaudo, et al., 2011). Using corn as an example, instead of applying nitrogen in the fall without using a nitrogen inhibitor, improved nitrogen application timing[8] could mean either using split application (i.e., applying part of the nitrogen pre-plant and part of the nitrogen at or after planting), applying nitrogen at planting, or applying nitrogen after planting when plant needs are greatest (Ribaudo, et al., 2011; Robertson, et al., 2013; USDA NRCS, 2017a).

Nitrogen fertilizer placement can affect the availability of nitrogen to crop uptake and the sucepability of nitrogen to be transformed into reactive forms. Fertilizer placement falls into two general types:

1. Applied to surface of soil and not incorporated (i.e., broadcast).
2. Surface applied then incorporated into the soil or applied below the soil surface (i.e., broadcast and mechnically incorporated, injection of nutrients below the soil surface, or subsurface band application).

When nitrogen fertilizer is broadcast on the soil surface, it is less available to plant roots for uptake and, depending on conditions, has been found to have up to 50 percent higher N_2O emission rates than incorporated fertilizer (USDA NRCS, 2017a; Ribaudo, et al., 2011; Paustian, et al., 2016; Millar, Robertson, Grace, Gehl, & Hoben, 2010; Cavigelli, Del Grosso, Liebig, & al., 2012; Snyder C. , 2016). As such, incorporating fertilizer into the soil typically increases plant NUE and reduces N_2O emissions.

[8] "Improved nitrogen application timing" is defined as applying nitrogen at a time(s) that will increase plant NUE. In this report, improved nitrogen application timing includes split application before and at planting and application after planting. Nitrogen application in the fall before planting is not considered to be "improved" nitrogen application timing in this report, as we assume no nitrogen inhibitor is applied.

Nitrogen Application Amount Key Findings:

- Corn had the highest nitrogen per acre application rate and the highest percentage of applied acres of the three crops studied.
- The total amount of nitrogen applied to corn[9] increased from between 2005 and 2016, while the average pounds of nitrogen per bushel[10] decreased during this time period.
- Wheat had the highest nitrogen per bushel application rate of the crops studied.
- Soybeans had the largest increase in total nitrogen applied nationally despite having the lowest application rate. The increase in applied nitrogen from 2006 to 2012 was due to an increase in applied acres. The national average pounds of nitrogen/bushel for soybeans remained about the same from 2006 to 2012.

Reasons for Adoption Trends:

- Differences in application rates for corn, soy, and wheat are due to crop-specific nitrogen needs (Wade, Claassen, & Wallander, 2015).
- The decrease over time in the average pounds of nitrogen per bushel for corn and wheat could be an indication of improved nitrogen management of these crops, in addition to increases in yield per acre (USDA ERS, 2016d).
- The dramatic increase in percentage of applied acres of nitrogen for soybeans and the slight increase in pounds of nitrogen per bushel from 2004 to 2009 could be due to newer production practices encouraging nitrogen fertilization to increase soybean yield (La Menza, Monzon, Specht, & Grassini, 2017; Mourtzinis, et al., 2018).

Application Amount

In this report, data on the total acreage of crops, the mean amount of nitrogen fertilizer applied per acre, and per bushel to corn, soybean, and wheat crops are from USDA ARMS. The estimation of amount applied per bushel is based on the survey respondent's estimate of the yield of that crop, not actual yield. The corn data are from the 2005, 2010, and 2016 surveys; the soybean data are from the 2006 and 2012 surveys; and the wheat data are from 2004 and 2009 surveys. Data were obtained from USDA ERS.

The specific questions on nitrogen application in the ARMS surveys that provided the data used in this report are listed in Appendix D (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2005; USDA ERS, 2006; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c) (USDA ERS, 2010b; USDA ERS, 2012b; USDA ERS, 2016a).

Data are presented in two ways: (1) mean nitrogen pounds per treated acre or per bushel by USDA region and (2) mean nitrogen pounds per treated acre or per bushel by farm size (<250 acres, 250–299 acres, 1,000+ acres) at the national level. The relative standard error was too high (>50 percent) to present data by both farm size and by USDA region.

[9] Total amount of nitrogen applied is determined by multiplying total applied acres x mean pounds/acre.
[10] Based on estimated yield.

Nitrogen Applied to Corn Crops

Based on ARMS data, 77.2 million acres of corn were planted in 2005, 81.9 million acres were planted in 2010, and 86.9 million acres were planted in 2016. The regions with the highest acreage were the Corn Belt, the Northern Plains, and the Lake States. On average between the 3 survey years, these regions made up approximately 90 percent of U.S. corn acreage.

FIGURE 9 shows a breakdown of nitrogen per treated acre for corn in eight of the production regions, aggregated by region or farm size. Key findings indicate:

- On corn acres where nitrogen was applied, mean application rates increased between 2005, 2010 and 2016 in the three major production regions.
- Mean nitrogen application rates increased from 2005 to 2016 in the Corn Belt, the Northern Plains, and the Lake States.
- In 2016, the Southeast had the highest mean nitrogen application rate (165 pounds/acre) and the Northeast had the lowest application rates (78 pounds/acre).
- Larger farms, on average, applied more nitrogen per acre in 2016 than medium or small farms. Small farms applied the least nitrogen per acre in that year, on average.
- Total nitrogen application (total applied acres times mean pounds/acre) for corn covered by ARMS was approximately 9.23×10^9 pounds in 2005, 9.79×10^9 pounds in 2010, and 1.1×10^{10} pounds in 2016.
- The average national rate for nitrogen applied to corn increased from 121 to 128 pounds per acre.

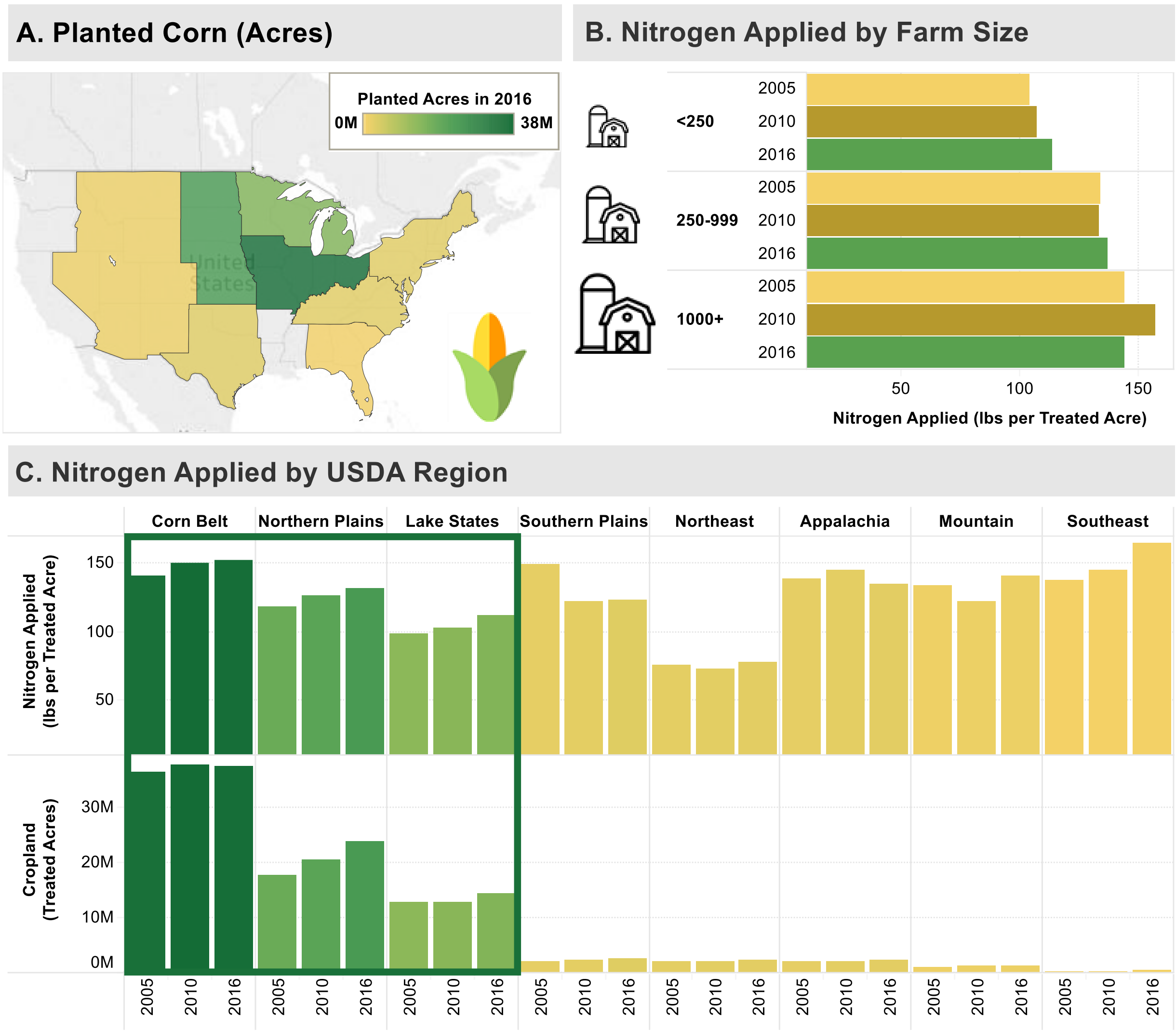
  See Appendix C for more detail.[11]

FIGURE 10 presents the nitrogen applied per expected yield in bushels. Key findings indicate:

- For nitrogen per bushel,[12] mean application rates decreased between 2005 and 2016 in the three major production regions (see FIGURE 10a).
- In 2016, the Southeast had the highest mean nitrogen application rates (1.20 pounds/bushel) and the Northeast had the lowest application rates (0.57 pounds/bushel).
- While total U.S. nitrogen application increased during the same period, the average pounds of nitrogen per bushel for corn decreased slightly from 0.84 in 2005 to 0.77 in 2016.
- Small farms, on average, applied slightly less nitrogen per bushel than medium or large farms in 2016.

[11] Appendix C presents the data tables used to generate the graphics provided throughout the report. Please see Appendix C for additional details for all the cropland conservation practices.
[12] Nitrogen per bushel is determined by dividing total amount of nitrogen applied by farmer estimated yield for nitrogen treated acres. Nitrogen per bushel values only apply to acres treated by nitrogen.

FIGURE 9. Nitrogen Applied to Treated Corn Crops



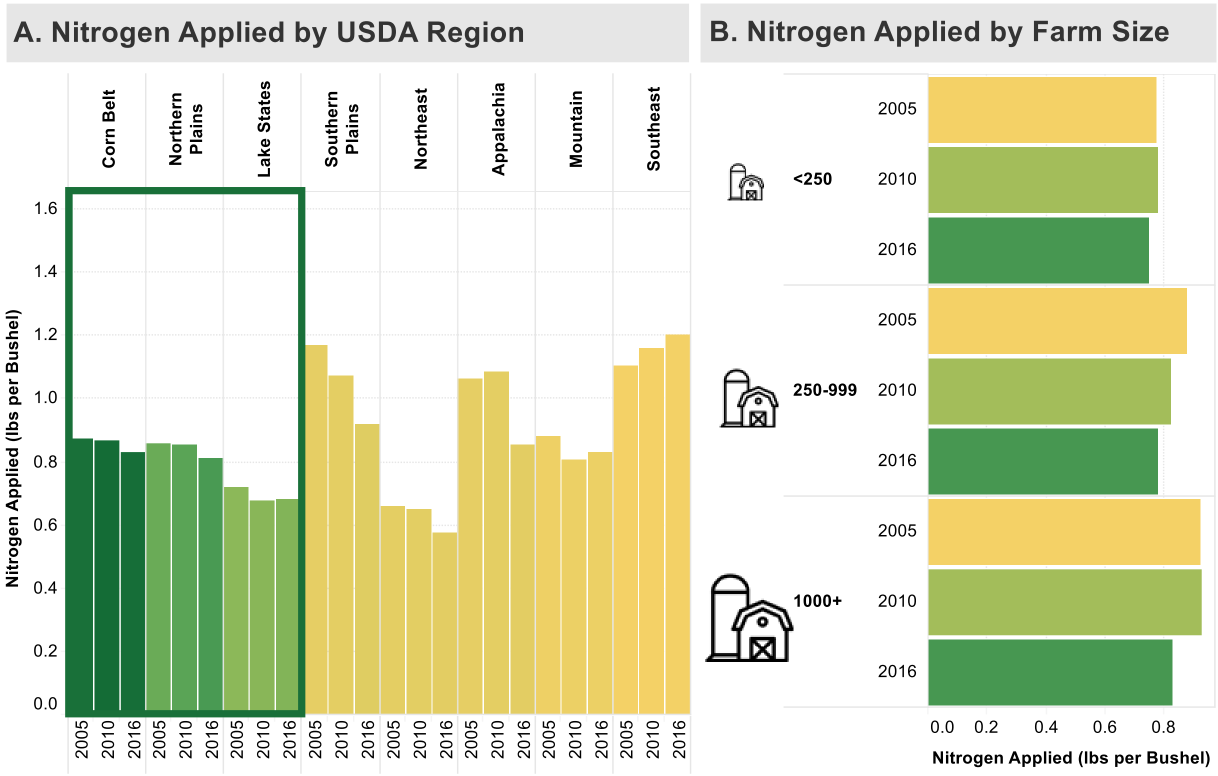
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. U.S. map showing planted acres of corn by U.S. State. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national average of applied pounds of nitrogen per treated acre by farm size. Lightest color indicates earliest timepoint (2005), medium color indicates mid timepoint (2010), and darkest color indicates latest time point (2016).

C. Graph of average applied pounds of nitrogen per treated acre by USDA region (upper graph) and total number of acres where nitrogen is applied by region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 10. Nitrogen Applied to Corn Crops by Yield



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. Graph of average applied pounds of nitrogen per bushel (based on farmer estimated yield) by USDA region. Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres.

B. Graph of national average applied pounds of nitrogen per bushel (based on estimated yield) by farm size. Lightest color indicates earliest timepoint (2005), medium color indicates mid timepoint (2010), and darkest color indicates latest time point (2016).

Nitrogen Applied to Soybean Crops

According to ARMS, approximately 15 percent of soybean acres had nitrogen applied in the Corn Belt, 37 percent in the Northern Plains, and 26 percent in the Lake States on average in 2006 and 2012. Nitrogen was applied to a much lower percentage of acres in soybean than corn (22 percent of acres vs. 97 percent of acres). The mean nitrogen application rate per acre for soybeans is much lower than the rate for corn because soybeans are a nitrogen-fixing crop. As indicated in FIGURE 11:

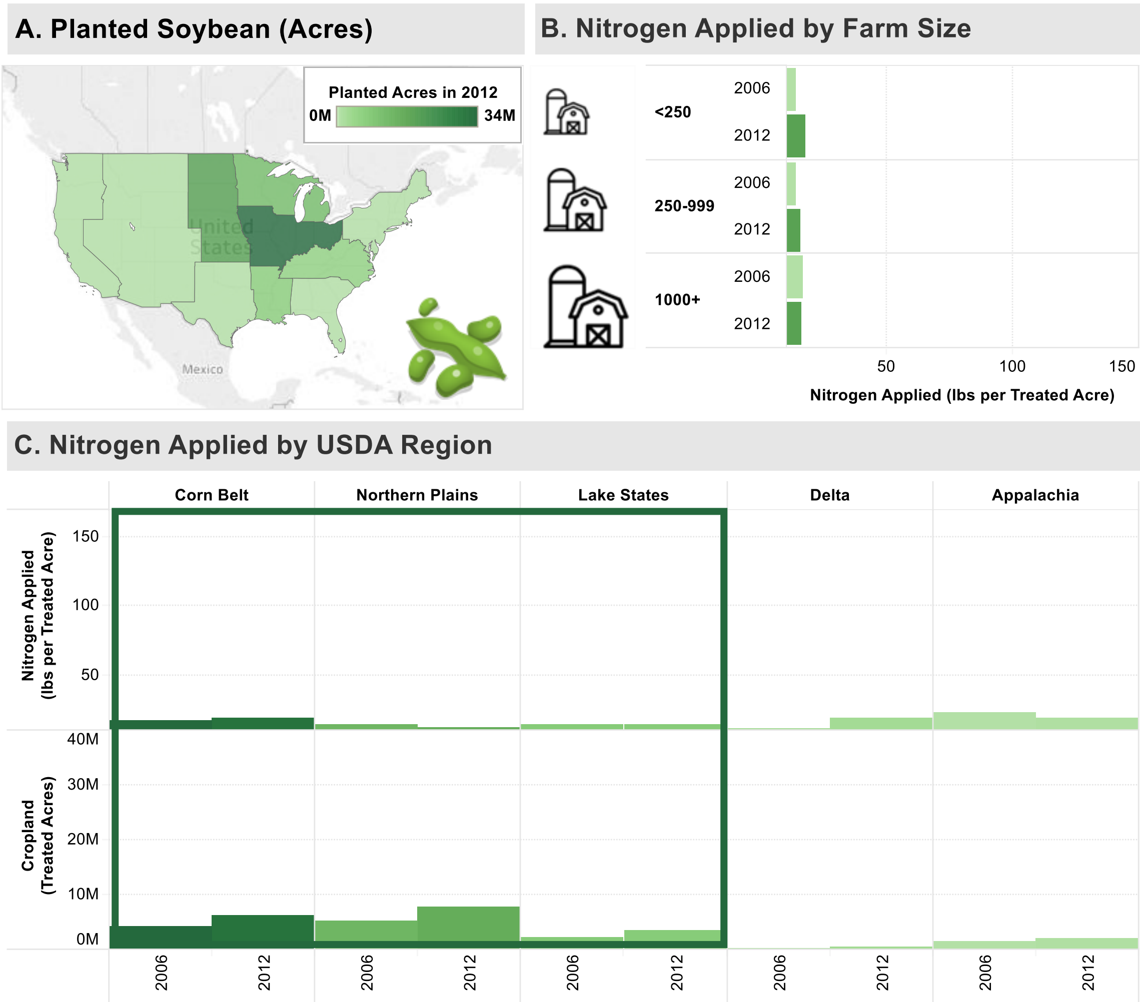
- On acres where nitrogen was applied, mean application rates increased slightly in the Corn Belt, stayed constant in the Lake States, and decreased in the Northern Plains from 2006 to 2012.
- The Corn Belt, Delta, and Appalachia regions all had the highest mean nitrogen application rates (19 pounds/acre), and the Northern Plains had the lowest application rate (12 pounds/acre).
- In 2012, small farms had the highest mean nitrogen application rate per treated acre (18 pounds), followed by large farms (16 pounds) and medium farms (15 pounds).
- The national average for nitrogen applied to soybeans remained constant from 2006 to 2012 at 17 pounds per acre.
- Total U.S. nitrogen application (total applied acres times mean pounds/acre) was approximately 2.17 X 10^8 pounds in 2006 and 3.45 X 10^8 pounds in 2012.

FIGURE 12 presents nitrogen application by yield. Key findings indicate:

- For nitrogen per bushel[13] for soybeans, application rates remained relatively constant in the main three soybean-growing regions (see FIGURE 12a).
- Mean nitrogen application rates per bushel increased slightly in the Corn Belt, decreased slightly in the Northern Plains, and increased slightly in the Lake States.
- In 2012, Appalachia again had the highest mean nitrogen application rate (0.46 pounds/bushel), and the Northern Plains had the lowest application rate (0.30 pounds/bushel).
- In 2012, medium farms had the lowest pounds per bushel application rate (0.34 pounds/bushel) followed by small farms (0.39 pounds/bushel) and large farms (0.41 pounds/bushel).
- The national average pounds of nitrogen per bushel for soybeans remained about the same at 0.39 in 2006 to 0.37 in 2012.

[13] Nitrogen per bushel is determined by dividing total amount of nitrogen applied by farmer estimated yield for nitrogen treated acres. Nitrogen per bushel values only apply to acres treated by nitrogen.

FIGURE 11. Nitrogen Applied to Treated Soybean Crops



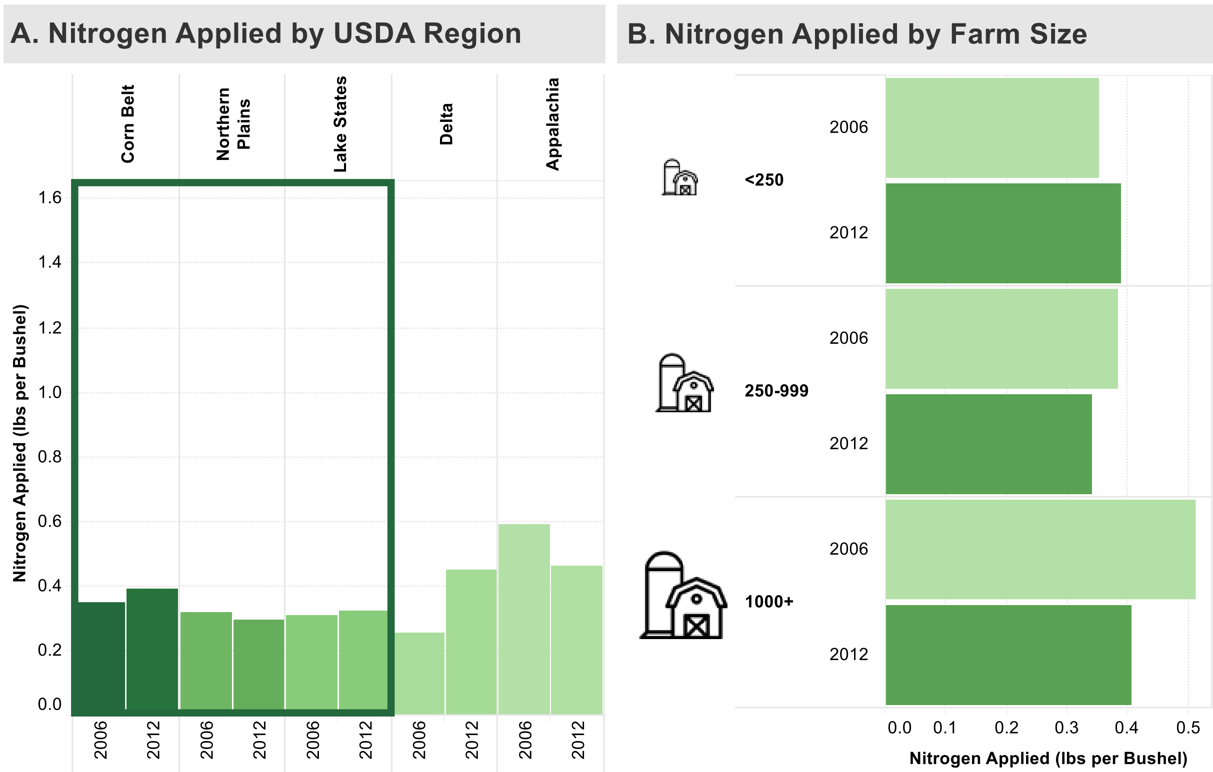
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006 and 2012.

A. U.S. map showing planted acres of soybeans by U.S. State. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national average of applied pounds of nitrogen per treated acre by farm size. Lighter color indicates earlier timepoint (2006), darker color indicates later timepoint (2012).

C. Graph of average applied pounds of nitrogen per treated acre by USDA region (upper graph) and total number of acres where nitrogen is applied by region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted soybean acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 12. Nitrogen Applied to Soybean Crops by Yield



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006 and 2012.

A. Graph of average applied pounds of nitrogen per bushel (based on farmer estimated yield) by USDA region. Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted soybean acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres.

B. Graph of national average applied pounds of nitrogen per bushel (based on estimated yield) by farm size. Lighter color indicates earlier timepoint (2006), darker color indicates later timepoint (2012).

Nitrogen Applied to Wheat Crops

Based on ARMS data, approximately 53.6 million acres of wheat were planted in 2004 and 52.2 million acres planted in 2009. The regions with the highest acreage were the Northern Plains, the Southern Plains, and the Mountain regions. Approximately 92 percent of wheat acres had nitrogen applied in the Northern Plains, approximately 75 percent in the Southern Plains, and approximately 59 percent in the Mountain region on average in 2004 and 2009. In total, these regions made up 84 percent of U.S. wheat acreage in 2004 and 85 percent of wheat acreage in 2009.

FIGURE 13 presents nitrogen applied by treated area. The key findings indicate:

- From 2004 to 2009, mean nitrogen application rates increased slightly from 63 to 65 pounds per acre in the Northern Plains, decreased from 70 to 55 pounds per acre in the Southern Plains, and increased from 55 to 62 pounds per acre in the Mountain region. In 2009, the Corn Belt had the highest mean nitrogen application rate (92 pounds/acre) and the Southern Plains had the lowest application rates (55 pounds/acre).

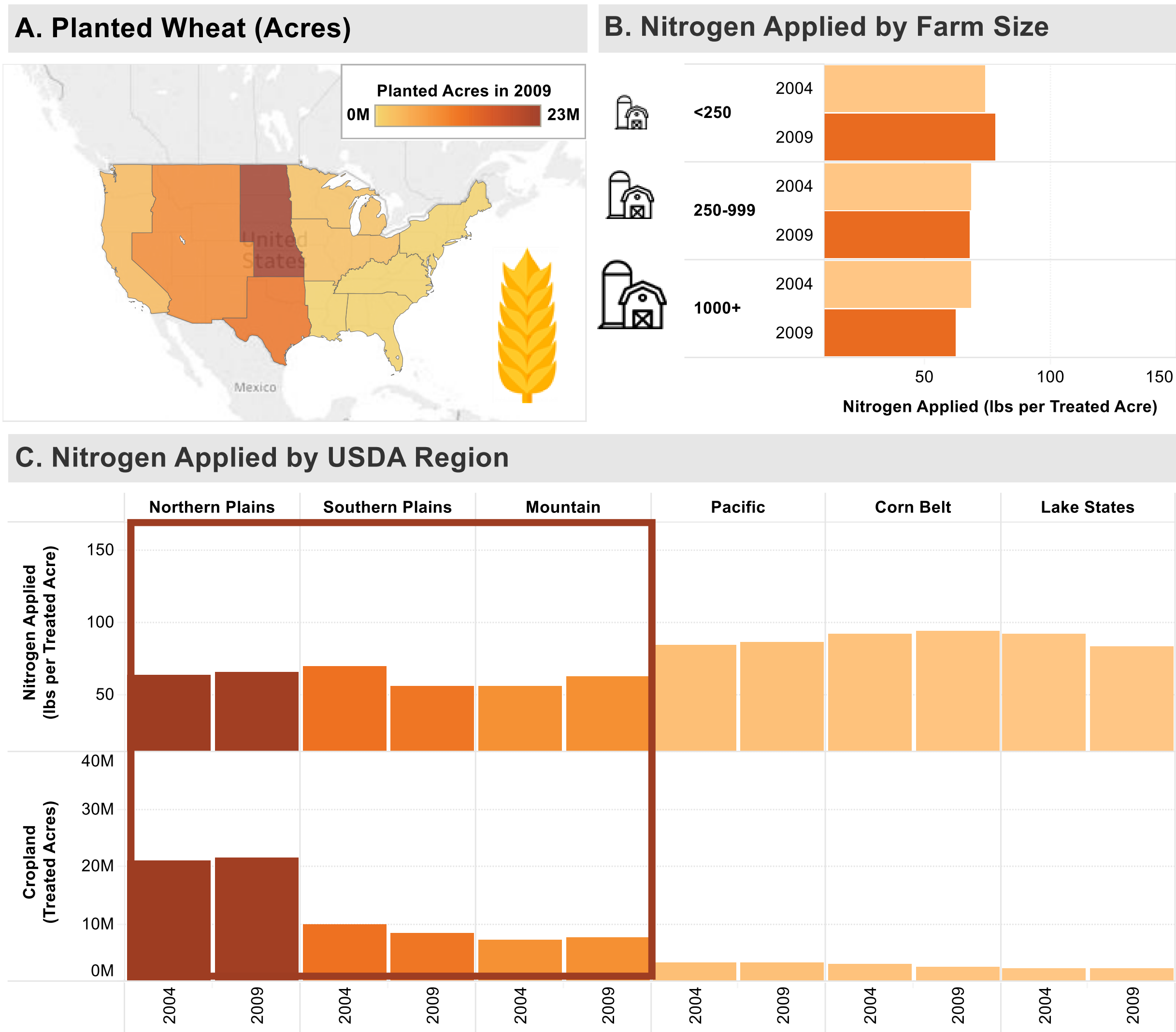
- Small farms had the highest average nitrogen usage rates and medium and large farms have lower rates.
- Total U.S. nitrogen application (total applied acres times mean pounds/acre) was approximately 3.55 X 10^9 pounds in 2004 and 3.36 X 10^9 pounds in 2009.
- The national average for nitrogen application for wheat remained about constant between 2004 and 2009.

FIGURE 14 presents nitrogen application by yield. Key findings indicate:

- For nitrogen per bushel[14], mean application rates decreased from 1.42 to 1.33 pounds in the Northern Plains, decreased from 1.58 to 1.46 pounds in the Southern Plains, and increased from 1.08 to 1.24 pounds in the Mountain region from 2004 to 2009 (see FIGURE 14a).
- In 2009, the Corn Belt and the Southern Plains had the highest mean nitrogen application rate (1.46 pounds/bushel) and the Pacific region had the lowest application rates (1.22 pounds/bushel).
- The amount of nitrogen per bushel decreased slightly for all three farm sizes, with negligible differences in nitrogen per bushel between the three farm sizes in 2009 (see FIGURE 14b).
- Consistent with the decrease in total nitrogen applied for wheat, the national average pounds of nitrogen per bushel slightly decreased from 1.40 pounds in 2004 to 1.34 pounds in 2009.

[14] Nitrogen per bushel is determined by dividing total amount of nitrogen applied by farmer estimated yield for nitrogen treated acres. Nitrogen per bushel values only apply to acres treated by nitrogen.

FIGURE 13. Nitrogen Applied to Treated Wheat Crops



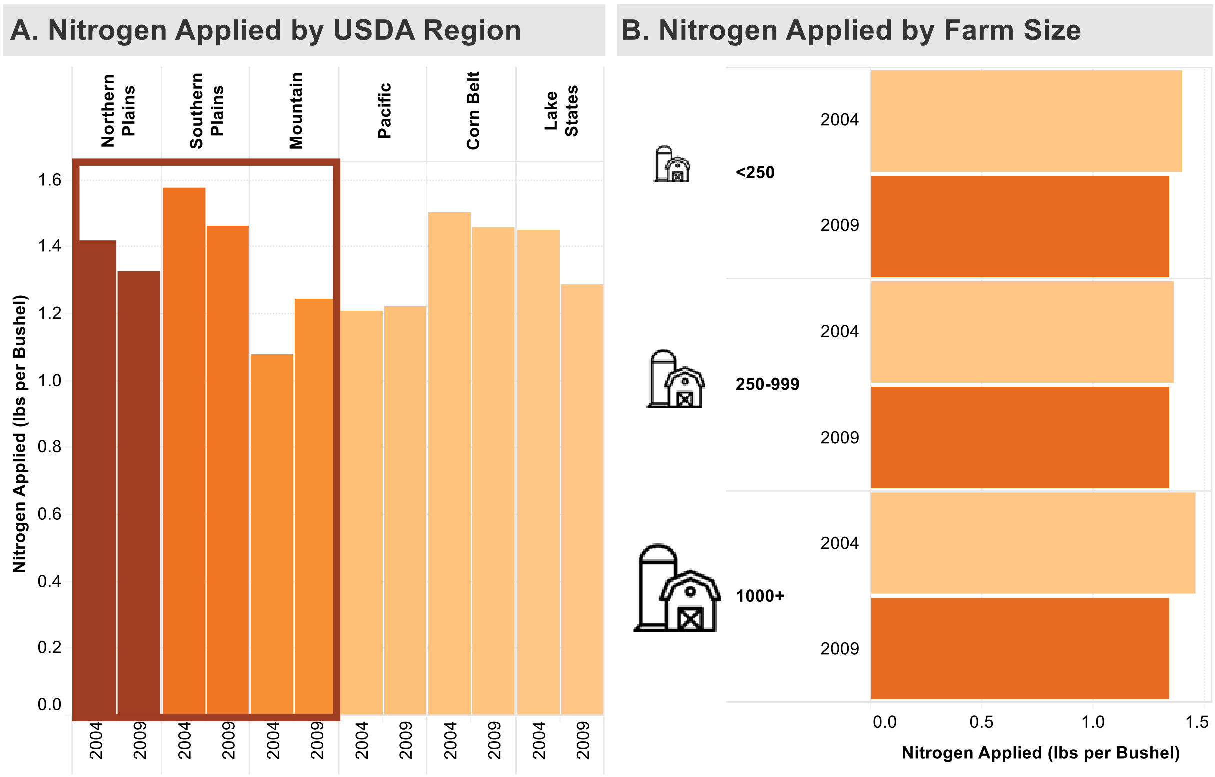
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004 and 2009.

A. U.S. map showing planted acres of wheat by U.S. State. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national average of applied pounds of nitrogen per treated acre by farm size. Lighter color indicates earlier timepoint (2004), darker color indicates later timepoint (2009).

C. Graph of average applied pounds of nitrogen per treated acre by USDA region (upper graph) and total number of acres where nitrogen is applied by region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted wheat acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 14. Nitrogen Applied to Wheat Crops by Yield



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004 and 2009.

A. Graph of average applied pounds of nitrogen per bushel (based on farmer estimated yield) by USDA region. Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted wheat acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres.

B. Graph of national average applied pounds of nitrogen per bushel (based on estimated yield) by farm size. Lighter color indicates earlier timepoint (2004), darker color indicates later timepoint (2009).

Nitrogen Application Timing and Method for Corn

In this report, data on nitrogen fertilizer application timing and method on corn acres are from USDA ARMS. Specifically, the corn data are from the 2005, 2010, and 2016 surveys.[15] The ARMS data on fertilizer timing are divided into three categories: (1) fertilizer applied in the fall, (2) fertilizer applied in the spring and/or at planting, and (3) fertilizer applied after planting. The USDA ERS has analyzed this data in terms of percentage of fertilizer applied. Thus, this analysis captures the overall timing of fertilizer application by quantity but does not describe the frequency of multiple fertilizer applications (sometimes called split application). As the data for application timing are expressed as a percentage of total amount of nitrogen applied (and not the percentage of acres grown using specific

[15] The specific questions on nitrogen application timing and method in the ARMS surveys that provided the data used in this report (USDA ERS, 2005; USDA ERS, 2010b; USDA ERS, 2016a) are listed in Appendix D.

application timing), it is not possible to determine how many corn acres were grown with each of the different nitrogen application timings.

The timing and application method data are presented in two ways:

- As indicated in FIGURE 15, for application timing, data are presented as (1) percent of total nitrogen applied at a given time (fall application, spring and/or at planting, and after planting) by USDA region, and (2) percent of total nitrogen applied at a given time by farm size (<250 acres, 250–299 acres, 1,000+ acres) at the national level.
- As indicated in FIGURE 16, for application method, data are presented as (1) percent of total nitrogen applied using a given application method (with or without incorporation into the soil) by USDA region, and (2) percent of total nitrogen applied using a given application method by farm size (<250 acres, 250–299 acres, 1,000+ acres) at the national level.

The relative standard error was too high (>50 percent) to present data by both farm size and by USDA region. Note that data for some region years[16] are not included due to relative standard error rates of greater than 50 percent.

Application Timing Key Findings:

- Around 80 percent of the total nitrogen applied to corn covered by ARMS was applied in the spring, at planting, or after planting in 2016. Timing of fertilizer remained relatively constant over the 3 survey years.
- In the three regions producing 90 percent of U.S. corn, the majority of nitrogen was applied in the spring, at planting, and/or after planting over the survey time series (see FIGURE 15c).
- In the Corn Belt, there was a slight increase in nitrogen applied after planting from 21 percent to 26 percent from 2005 to 2016.
- In the Northern Plains, nitrogen applied in the fall increased from 11 percent to 17 percent from 2005 to 2016. Application in the spring and at planting decreased and application after planting remained relatively stable.
- In the Lake States, nitrogen application in the fall decreased from 24 percent to 19 percent from 2005 to 2016. Application after planting increased from 19 percent to 24 percent over the same time period.
- In the Corn Belt and Northern Plains, the proportion of fertilizer applied in the fall remained constant or increased over the survey time series.
- Farm size appears to impact the timing of nitrogen application. In 2016, small farms had the lowest application of fertilizers in the fall, and large farms had the largest (see FIGURE 15b).

Application Method Key Findings:

- Approximately 77 percent of the nitrogen applied to corn was incorporated into the soil in 2016, a slight decrease from 81 percent in 2005.
- One of the three main production regions, the Northern Plains showed a slight increase in the percentage of nitrogen incorporated into the soil between 2005 and 2016, from 70 percent to 73 percent. Over the same period, the Corn Belt decreased slightly from 86

[16] A "region year" is a given region in a specific year. For example, data on the percent of corn acres fertilized in the fall in the Mountain region in 2005 and 2010 had an RSE > 50%. Therefore, the corn "region years" of Mountain, 2005 and 2010 are not included in this report.

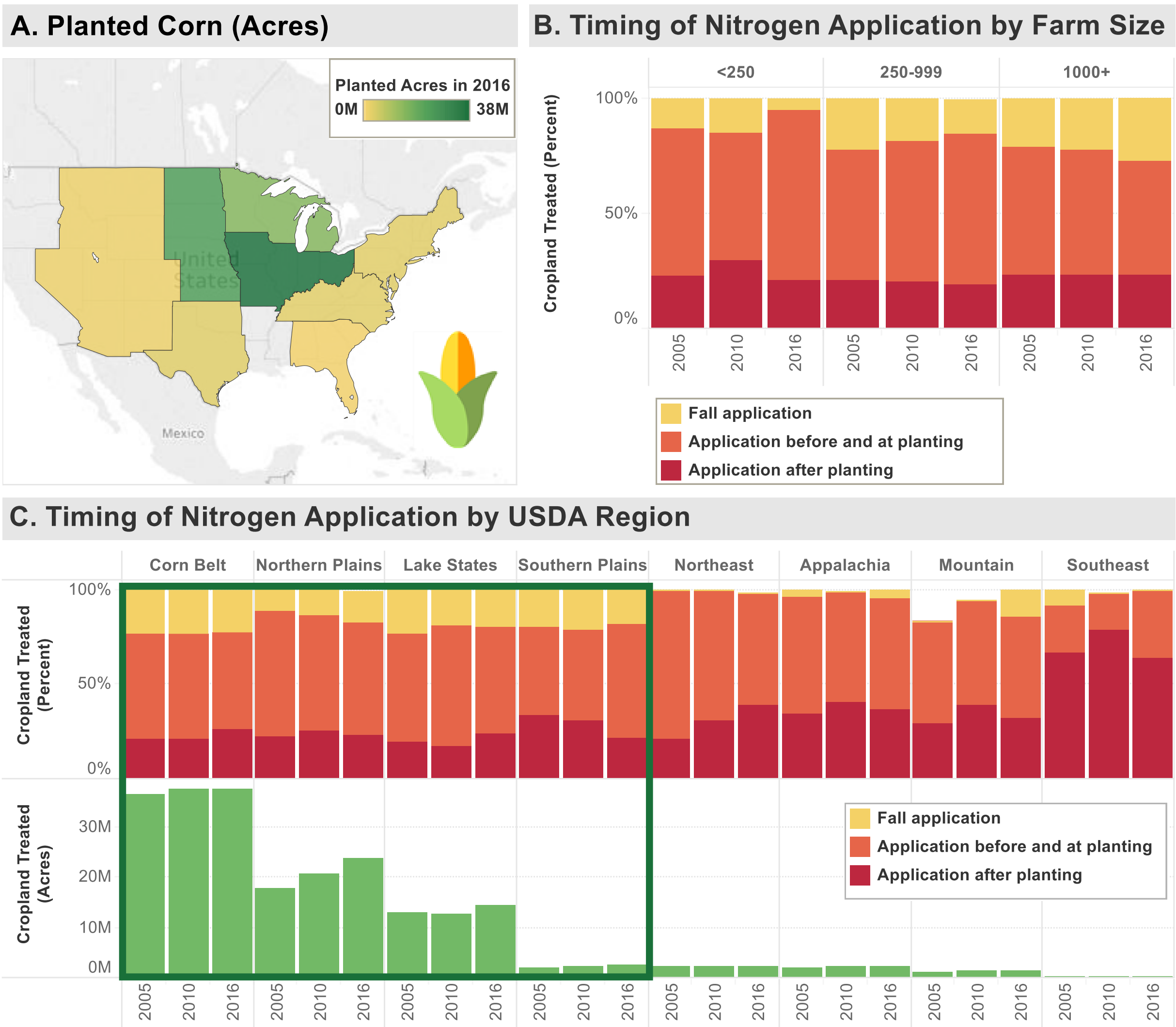
percent to 84 percent and the Lake States decreased from 85 percent to 69 percent of nitrogen incorporated into the soil.

- The percentage of total nitrogen applied with incorporation increased slightly (3 percent) from 70 percent in 2005 to 73 percent in 2016 in the Northern Plains, while it decreased slightly (2 percent) from 86 percent in 2005 to 84 percent 2016 in the Corn Belt and decreased (16 percent) from 85 percent in 2005 to 69 percent in 2016 in the Lake States.
- In lesser producing regions, the percentage total nitrogen applied and incorporated decreased (3 percent) in the Southern Plains from 87 percent in 2005 to 76 percent in 2010 to 84 percent in 2016 and decreased (22 percent) in the Northeast from 68 percent in 2005 to 48 percent in 2010 to 46 percent in 2016.
- Farm size appears to impact use of incorporation, where large farms have the highest percentage followed by mid-sized and small farms, all of which decreased over time (see FIGURE 16b).

Reason for Adoption Trends:

- Multiple public and private partnerships are working to improve fertilizer application methods and timing (including through 4R partnerships), which include improving application timing and methods (IPNI, 2017; The Fertilizer Institute, 2017; TNC, 2017; USDA NRCS, 2011).

FIGURE 15. Timing of Nitrogen Application for Corn



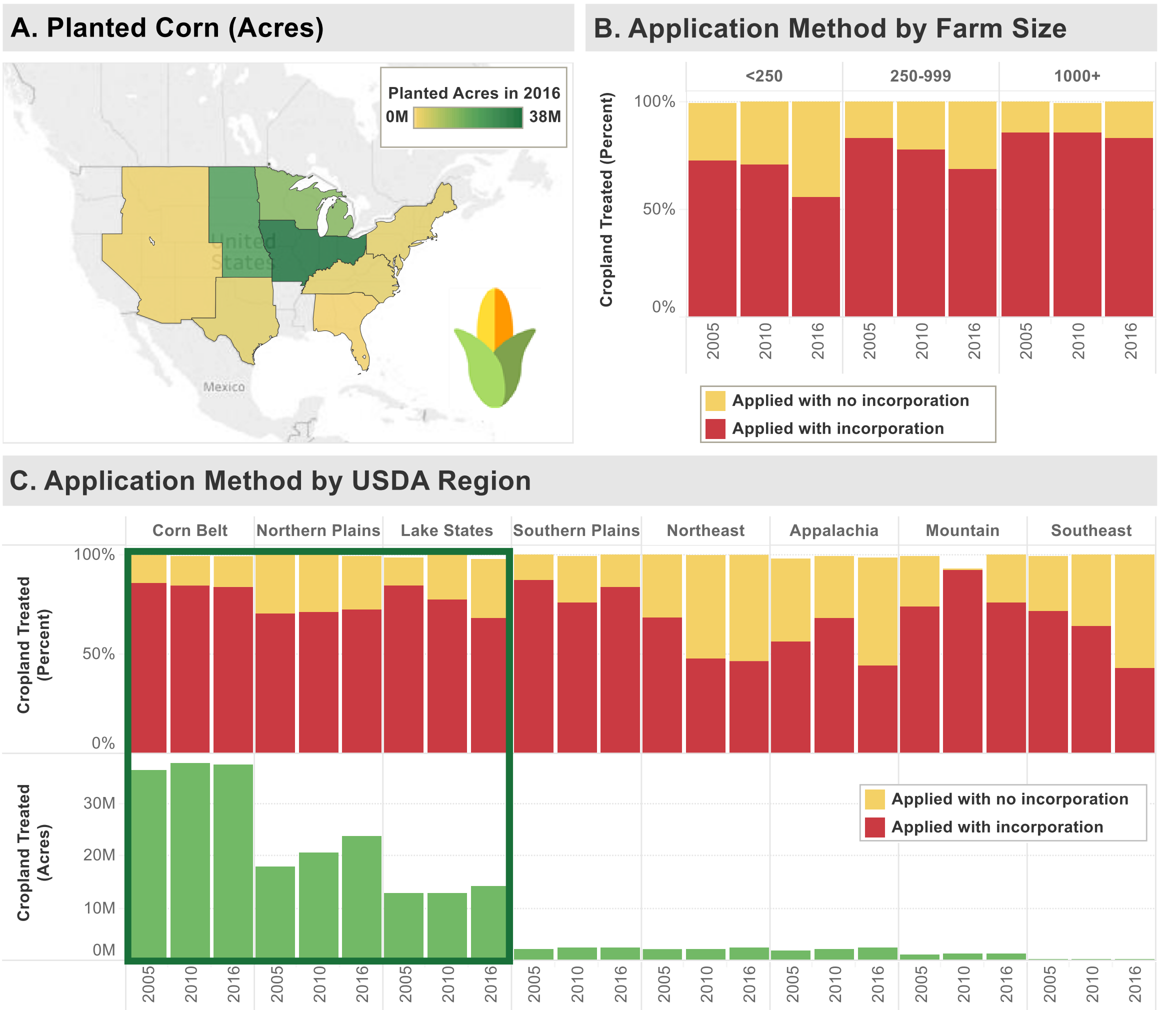
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. U.S. map showing planted acres of corn by U.S. State. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of the average percentage of total nitrogen applied at a given time by farm size at the national level. Red color indicates percentage of total nitrogen applied after planting, orange color indicates percentage of total nitrogen applied before and/or at planting, and yellow color indicates percentage of total nitrogen applied in the fall.

C. Graph of the average percentage total nitrogen applied at a given time by USDA region (upper graph) and total number of acres where nitrogen is applied by region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color indicates the percentage of total nitrogen applied at a given time as described above in b). M = million.

FIGURE 16. Method of Nitrogen Application for Corn Crops



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. U.S. map showing planted acres of corn by U.S. State. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of average percentage of total nitrogen applied using a given application method by farm size at the national level. Red color indicates the percentage of total nitrogen applied with incorporation into the soil; yellow color indicates the percentage of nitrogen applied with no incorporation into the soil.

C. Graph of the average percentage of total nitrogen applied using a given application method by USDA region (upper graph) and total number of acres where nitrogen is applied by region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color indicates the percentage of total nitrogen applied using a given method (with or without incorporation into the soil) as described above in b). M = million.

Enhanced Efficiency Fertilizers

One way to reduce the amount of nitrogen lost to the environment is by using enhanced efficiency fertilizers (EEFs),[17] which include nitrification inhibitors, urease inhibitors, and chemical-coated fertilizers (USDA ERS, 2016c). These products function by slowing the process through which fertilizers are broken down into byproducts that can be volatilized, leached, and/or are utilized by the plant. As such, EEFs have been shown to reduce both fertilizer quantities needed and GHG emissions (Smith, Martino, Cai, & Gwary, 2007). Use of EEFs is recommended by USDA NRCS as a part of the nutrient management conservation practice standard (USDA NRCS, 2012).

Chemicals included in this category include urease inhibitors (UIs), which block or slow the breakdown of urea to ammonia, and nitrification inhibitors (NIs), which block or slow the transformation of ammonia or ammonium N to nitrate or other byproducts. See TABLE 2 for common nitrogen byproducts.

Several UIs and NIs are available for use by U.S. farmers. These inhibitors include:

- N-(N-butyl)thiophosphoric triamide (NBPT), such as urease inhibitor Agrotain®
- 2-Chloro-6-(trichloromethyl)pyridine, also called nitrapyrin, such as nitrification inhibitors N-Serve® and Instinct®
- Dicyandiamide (DCD), such as nitrification inhibitors Agrotain Plus®, SuperU®, and Guardian®

In this report, data on the mean amount of EEF applied per acre to corn are from USDA ARMS. Specifically, the corn data are from the 2005 and 2010 surveys (USDA ERS, 2017a). The 2016 survey did not include a question on EEFs. The specific questions on EEF application in the ARMS surveys that provided the data used in this report (USDA ERS, 2005; USDA ERS, 2010b) are listed in Appendix D. Questions on EEF application from other sources (not included in this report) (USDA NRCS, 2003; USDA NRCS, 2004; USDA NRCS, 2005; USDA NRCS, 2006; USDA NRCS, 2015; Bierman, Rosen, Venterea, & Lamb, 2011; Arbuckle & Rossman, 2014) (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c) are also listed in Appendix D. As provided in TABLE 3, data are presented in a table rather than graphically as a majority of data points are statistically unreliable due to low sample size.

While several resources were found that contained limited information on NI or UI adoption rates, no readily available data sources of regional or national level NI or UI adoption rates over time were located (USDA NRCS, 2003; USDA NRCS, 2004; USDA NRCS, 2005; USDA NRCS, 2006; Bierman, Rosen, Venterea, & Lamb, 2011; Arbuckle & Rossman, 2014) (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2005; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c; USDA ERS, 2006). The most complete data set on EEF use is ARMS data on corn for 2005 and 2010 (TABLE 3). However, the vast majority of the data available are statistically unreliable at the State level (as indicated by the asterisks) and cannot be used to assess trends. For the States with data in 2005 and 2010 (Illinois, Indiana, Minnesota, Missouri, and Ohio), the percentage of planted acres treated with EEFs increased over time. However, given the unreliability of the

[17] In this report we refer specifically to EEFs used to slow the breakdown of nitrogenous fertilizers, also known as nitrogen inhibitors (NIs).

data for all of these States except Illinois, it is impossible to determine if there is an actual increase in EEF use or if the increase is an artifact of the unreliable data.

TABLE 3. Enhanced Efficiency Fertilizer Use in Corn (percent of planted acres)

State	2005	2010
All States	8.493	12.457
Colorado	---	---
Georgia	---	---
Illinois	27.619	27.885
Indiana	13.453*	43.818*
Iowa	---	13.149*
Kansas	---	---
Kentucky	6.498*	---
Michigan	6.205*	---
Minnesota	5.3*	8.303*
Missouri	2.739*	11.749*
Nebraska	---	6.285*
New York	5.729*	---
North Carolina	---	---
North Dakota	---	---
Ohio	7.406*	3.567
Pennsylvania	10.982*	---
South Carolina	---	---
South Dakota	---	---
Texas	---	---
Wisconsin	12.28*	---

*= Statistically unreliable due to low sample size

Source: (USDA ERS, 2017a)

Enhanced Efficiency Fertilizers (EEF) Key Findings:

- Insufficient data were available for EEFs used in wheat and soybean production, and limited data were available for corn production.
- Illinois was the only State that had statistically reliable data on EEF use on corn for both 2005 and 2010. Use of EEFs in Illinois remained at about 28 percent for both years.[18]
- At the national level, the use of EEFs in corn increased from 8.5 percent in 2005 to 12.5 percent in 2010.

[18] Data in TABLE 3 are specifically for “Nitrogen inhibitor used” for both 2005 and 2010 from the USDA ARMS Nutrient Use and Management Report.

- Approximately 10 percent of corn farmers adopted use of EEFs in 2010 (Weber & McCann, 2014).

Reason for Adoption Trends:

- Use of enhanced efficiency fertilizers has been correlated and/or shows a strong connection with:
  - farmer age (younger farmers are more likely to adopt EEFs);
  - use of other "current technologies" (e.g., precision agriculture);
  - region;
  - price (less likely to adopt when prices are higher);
  - irrigation use;
  - use of reduced tillage; and
  - access to information on EEFs (receiving "no recommendation" is negatively correlated to adoption) (Weber & McCann, 2014).

Precision Agriculture

Precision agriculture includes the use of various technologies, such as tractor guidance systems using a global positioning system (GPS), GPS soil sampling, and GPS yield mapping. These technologies help farms gather information on field conditions and site-specific within-field limitations and allow for adjustments to production practices, such as variable-rate technology (VRT) for the application of inputs (fertilizer, seeds, irrigation water, pesticides) (Schimmelpfennig, 2016b). Potential benefits of precision agriculture include reduced inputs resulting in cost reductions, more efficient use of production inputs, and significant environmental benefits such as improved soil and water quality and reduced GHG emissions (USDA NRCS, 2007). While there are numerous precision agriculture technologies, this report focuses on two of the key technologies: variable rate technology (VRT) used for nitrogen fertilizer application and guidance or auto steer using GPS.

Precision Agriculture Key Findings:

- Insufficient data resulted in limited analysis of VRT used in corn and wheat production, auto steer use in corn, and completely prevented analysis of VRT use in soybean production.
- Corn and wheat both had relatively low percentage of acres grown using VRT which increased over time. VRT used for corn increased 23 percent over 11 years and for wheat increased 4 percent over 4 years (from 7 percent in 2004 to 11 percent in 2009).
- Corn, soybeans, and wheat had relatively higher percentage of acres grown using auto steer than VRT, all of which increased over time. Auto steer used for corn increased 39 percent over 11 years (from 15 percent in 2005 to 45 percent in 2010 to 54 percent in 2016), for soybeans increased 25 percent over 6 years (from 20 percent in 2006 to 45 percent in 2012), and for wheat increased 26 percent in 4 years (from 16 percent in 2004 to 42 percent in 2009).
- For crops for which there were data available, farm size appeared to impact the percentage of acres grown using VRT and auto steer. Small farms had the lowest adoption percentage followed by mid-sized and large farms, all of which increased over time.

Reasons for Adoption Trends:

- Lower adoption of VRT (compared to auto steer) is consistent with the requirement for specialized equipment that must be tailored for each crop and the relatively low ease of use and functionality (Schimmelpfennig, 2016a).
- Higher adoption rates of auto steer are consistent with its ease of use, and the high functionality of yield and soil maps, which have increased along with adoption rates (Schimmelpfennig, 2016a).
- Higher adoption rates of VRT and auto steer by large farms compared to medium and small farms are consistent with the economies of scale, higher education rates, and comfort level of new technology adoption associated with large producers (USDA NIFA, 2017).

Variable Rate-Input Application Technology (VRT)

Variable rate technology (VRT) allows farmers to customize the application of inputs (fertilizer, seeds, irrigation water, and pesticides) using GPS data, often from yield and soil maps and guidance systems. The use of VRT requires specialized machinery with automated controls for specific input flow rates that are integrated into application equipment (Schimmelpfennig, 2016a). Use of VRT can improve input efficiency and reduce GHG emissions by reducing both fuel use and over-application of nitrogen fertilizer (USDA, 2016; Schimmelpfennig, 2016b).

In this report, data on the percentage of acres of corn and wheat where VRT is used for nitrogen fertilizer application are from USDA ARMS. Specifically, the corn data are from the 2005, 2010, and 2016 surveys and the wheat data are from the 2004 and 2009 surveys. There were not enough data points to analyze VRT use for production of soybeans over time.

The specific questions on VRT use in the ARMS surveys that provided the data used in this report (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2005; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c; USDA ERS, 2010b; USDA ERS, 2016a) are listed in Appendix D.

Data are presented in two ways, (1) percent of acres where VRT was used by production region; and (2) percent of acres where VRT was used by farm size (<250 acres, 250–299 acres, 1,000+ acres) at the national level. The relative standard error was too high (>50 percent) to present data by both farm size and by production region. Note that data for some region years are not included due to relative standard error rates of greater than 50 percent. See individual sections below for more details.

VRT Used on Corn Crops

The Corn Belt, the Northern Plains, and the Lake States regions had the highest corn production in 2005, 2010, and 2016 (see FIGURE 3 above and FIGURE 17 below). Data were available for all 3 survey years in these regions. Due to high relative standard error of available data, this report only presents 2016 data for the Southern Plains, Appalachia, and Southeast regions, and only 2010 and 2016 data for the Northeast and Mountain regions. FIGURE 17 presents the use of VRT on corn crops. Key findings indicate:

- The percentage of corn acres grown using VRT increased from 2005 to 2010 to 2016 in all regions for which there are multiple years of data.

- Rates increased from 6 to 8 to 35 percent in the Corn Belt, from 5 to 13 to 28 percent in the Northern Plains and from 2 to 11 to 21 percent in the Lake States.
- The Corn Belt had the most acres of corn grown using VRT (approximately 2.1 million acres in 2005, approximately 3.2 million acres in 2010, and 13.4 million acres in 2016).
- Farm size appears to impact the percentage of acres grown using VRT, where small farms have the lowest percentage followed by mid-sized and large farms, all of which have increased over time.
- Small farms (<250 acres) had the lowest percentage of corn acres grown using VRT in 2005, 2 percent, which increased to 6 percent in 2010 and 10 percent in 2016. Mid-sized farms (250–299 acres) grew 5 percent of acres with VRT in 2005, which increased to 11 percent in 2010 and 29 percent in 2016, and large farms (1,000+ acres) grew 7 percent of corn acres with VRT in 2005, which increased to 11 percent in 2010 and 40 percent in 2016.
- In total, VRT was applied to approximately 5 percent corn of acres in 2005, approximately 10 percent in 2010, and approximately 28 percent in 2016.

VRT Used on Soybean Crops

While the 2006 and 2012 ARMS surveys asked farmers about VRT use for soybean production, there were not sufficient data. Therefore, no data on VRT use for soybean production are included in this report.

VRT Used on Wheat Crops

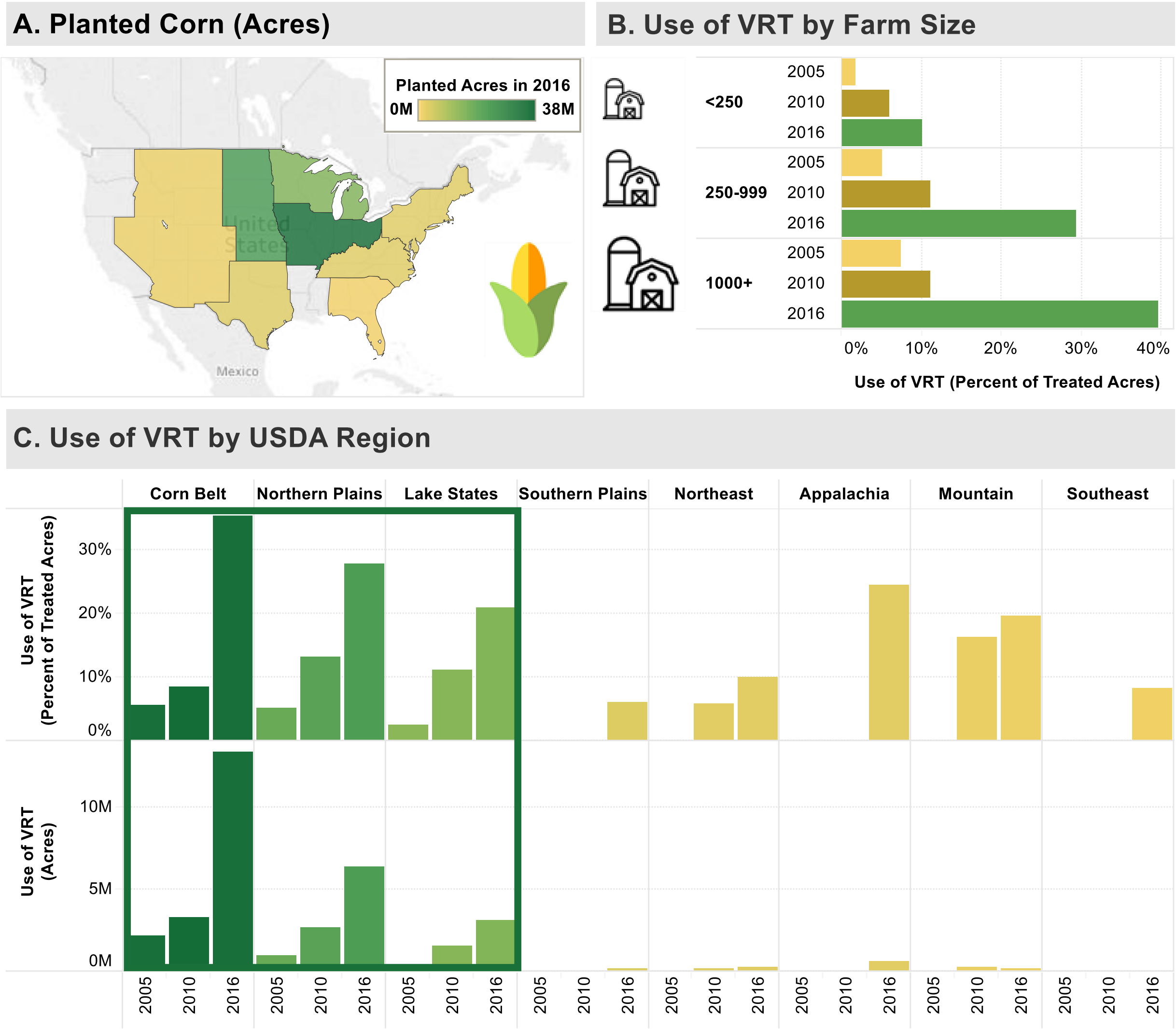
On average between 2004 and 2009, approximately 7 percent of acres utilized VRT in the Northern Plains, approximately 10 percent in the Southern Plains,[19] and approximately 8 percent in the Mountain region. There were not sufficient data to determine the percentage of wheat acres using VRT in the Southern Plains for both years, and only 2009 data for are presented for that region. Key findings as indicated in FIGURE 18 include:

- The percentage of wheat acres grown using VRT increased slightly from 2004 to 2009 in all regions for which there are sufficient data.
- Rates increased from 5 to 8 percent in the Northern Plains and from 5 to 10 percent in the Mountain region. There were not enough data to determine the percentage of acres grown using VRT in the Southern Plains in 2004, but VRT was used on 10 percent of acres in 2009.
- The Northern Plains had the most acres of wheat grown using VRT (approximately 1.2 million acres in 2004 and approximately 1.8 million acres in 2009).
- Farm size appears to impact the percentage of acres grown using VRT, where small farms have the lowest percentage followed by mid-sized and large farms, all of which have increased over time.
- Small farms (<250 acres) had the lowest percentage of wheat acres grown using VRT in 2004, 2 percent, which increased to 7 percent of acres in 2009. Mid-sized farms (250–299 acres) grew 5 percent of acres using VRT in 2004, which increased to 11 percent of acres in 2009, and large farms (1,000+ acres) grew 11 percent of wheat acres in 2005 and 2009.

[19] Only 2009 data are included for the Southern Plains as there were not enough data to determine percent of acres grown with VRT in 2004.

- In total, VRT was applied to approximately 7 percent of wheat acres in 2004, and approximately 11 percent of wheat acres in 2009.

FIGURE 17. Variable Rate Technology (VRT) Utilized on Corn Crops



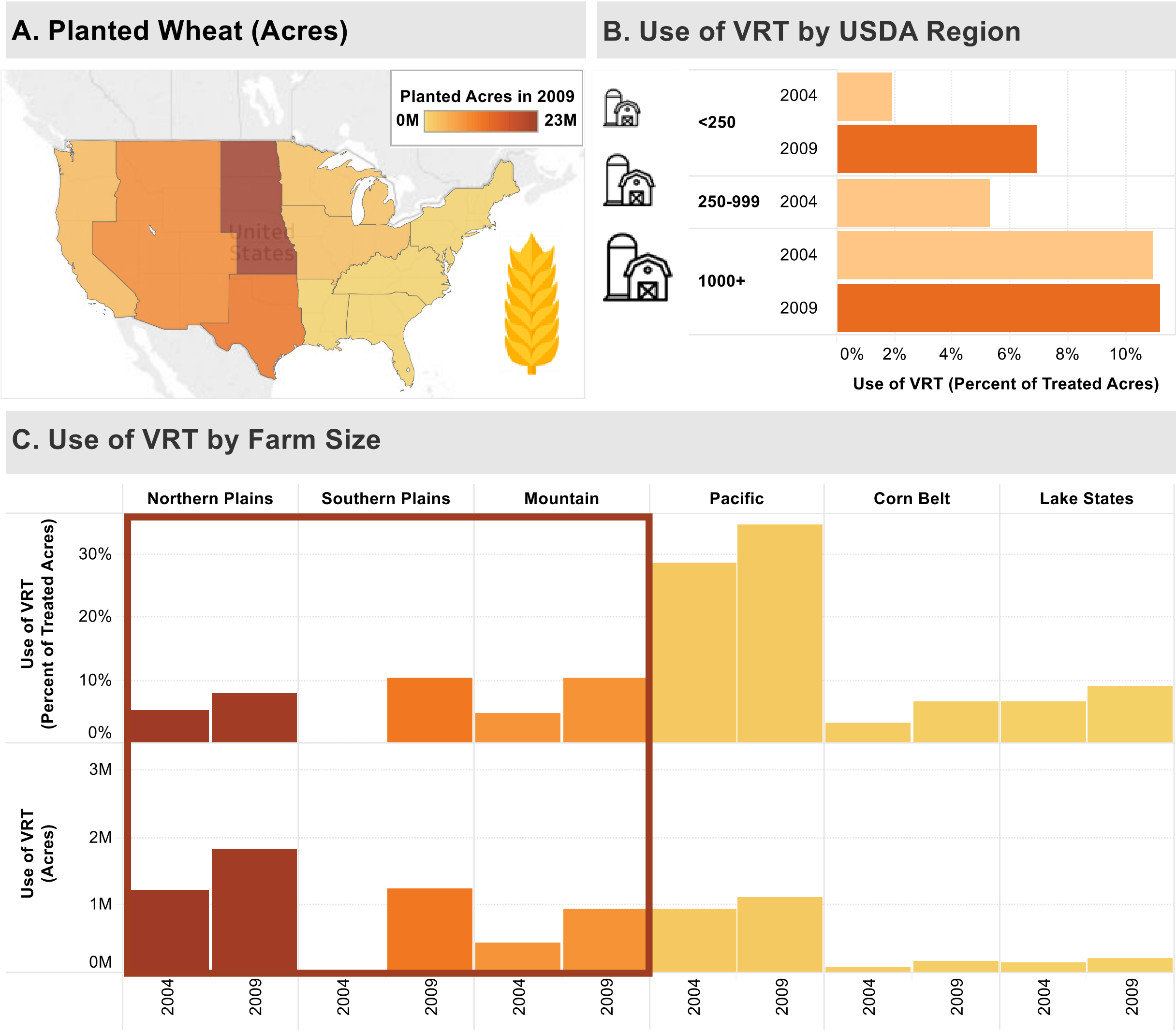
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. **Introduction** U.S. map showing planted acres of corn by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national percentage of acres where VRT is used by farm size. Lightest color indicates earliest timepoint (2005), medium color indicates mid timepoint (2010), and darkest color indicates latest time point (2016).

C. Graph of percentage of acres where VRT is used by USDA region (upper graph) and total number of acres where VRT is used by USDA region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres.

FIGURE 18. Variable Rate Technology (VRT) Utilized on Wheat Crops



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004 and 2009.

A. U.S. map showing planted acres of wheat by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national percentage of acres where VRT is used by farm size. Lighter color indicates earlier timepoint (2004), darker color indicates later timepoint (2009).

C. Graph of percentage of acres where VRT is used by USDA region (upper graph) and total number of acres where VRT is used by USDA region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted wheat acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

Guidance or Auto Steer

Auto (or assisted) steer is a GPS-based guidance system that provides centimeter-level accuracy of agricultural equipment. Auto steer functions though real time kinematic correction of GPS signals and requires three components:

1. GPS system (receive and process the signals)
2. Software (input of control maps)
3. Hardware (mechanical equipment to steer the tractor)

Auto-steering systems can either be added-on to existing equipment or may come included in the purchase of new equipment (USDA NRCS, 2007). The advantages of auto steer include reducing operator fatigue, improving efficiency and saving money by reducing over- and under-application of sprays (nutrients or pesticides), improving the seeding of field crop rows, and reducing GHG and water quality emissions by reducing both fuel use and over-application of nitrogen fertilizer (USDA, 2016; Schimmelpfennig, 2016b).

In this report, data on the percentage of acres of corn, soybean, and wheat crops where auto steer is used are from USDA ARMS. Specifically, the corn data are from the 2005, 2010, and 2016 surveys, the soybean data are from the 2006 and 2012 surveys and the wheat data are from 2004 and 2009 surveys. The specific questions on nitrogen application in the ARMS surveys that provided the data used in this report (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2005; USDA ERS, 2006; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c) (USDA ERS, 2010b; USDA ERS, 2012b; USDA ERS, 2016a) are listed in Appendix D.

Data are presented in two ways, (1) percent of acres where auto steer was used by USDA region and (2) percent of acres where auto steer was used by farm size (<250 acres, 250–299 acres, 1,000+ acres) at the national level. The relative standard error was too high (>50 percent) to present data by both farm size and by USDA region. Note that data for some region years are not included due to relative standard error rates of greater than 50 percent. See individual sections below for more details.

For all crop types, farm size appears to impact the percentage of acres grown using auto steer, where small farms have the lowest percentage followed by mid-sized and large farms, all of which have increased over time.

Use of Auto Steer on Corn Crops

There were not sufficient data to determine the percentage of corn acres grown using auto steer for all region years. Specifically, there are only 2010 and 2016 data for the Southeast region. As indicated in FIGURE 19, key findings indicate:

- The percentage of corn acres grown using auto steer increased overall from 2005 to 2016 in all regions, except for the Southeast region which decreased from 2010 to 2016.[20]
- Rates increased from 13 to 47 to 56 percent in the Corn Belt, from 23 to 51 to 67 percent in the Northern Plains and from 9 to 35 to 46 percent in the Lake States.

[20] Due to an RSE > 50 there are no data for the Southeast Region in 2005.

- The region producing the most corn, the Corn Belt, had the most acres of corn grown using auto steer (approximately 4.9 million acres in 2005, approximately 18.3 million acres in 2010 and approximately 20.9 million acres in 2016).
- Small farms (<250 acres) had the lowest percentage of corn acres grown using auto steer in 2005, 6 percent, increasing to 18 percent of acres in both 2010 and 2016. Mid-sized farms (250-299 acres) grew 13 percent of acres with auto steer in 2005, increasing to 41 percent in 2010 and 57 percent in 2016, and large farms (1,000+ acres) grew 33 percent of corn acres with auto steer in 2005, increasing to 74 percent in 2010 and 79 percent in 2016.
- In total, auto steer was used on approximately 15 percent of corn acres in 2005, 45 percent in 2010, and 54 percent in 2016.

Use of Auto Steer on Soybean Crops

On average, between 2006 and 2012, 33 percent of acres were produced with auto steer in the Corn Belt, 40 percent in the Northern Plains, and 31 percent in the Lake States. As indicated in FIGURE 20, key findings include:

- The percentage of soybean acres grown using auto steer increased from 2006 to 2012 in all regions.
- Rates increased from 18 to 47 percent in the Corn Belt, from 30 to 49 percent in the Northern Plains, and from 17 to 44 percent in the Lake States.
- The Corn Belt had the most acres of soybeans grown using auto steer (approximately 6.6 million acres in 2006 and approximately 15.7 million acres in 2012).
- Small farms (<250 acres) had the lowest percentage of soybean acres grown using auto steer in 2006, 6 percent, increasing to 28 percent of acres in 2012. Mid-sized farms (250-299 acres) grew 18 percent of acres with auto steer in 2006, increasing to 46 percent of acres in 2012, and large farms (1,000+ acres) grew 37 percent of soybean acres with auto steer in 2006, increasing to 59 percent in 2012.
- In total, auto steer was applied to approximately 20 percent of soybean acres in 2006 and 45 percent of acres in 2012.

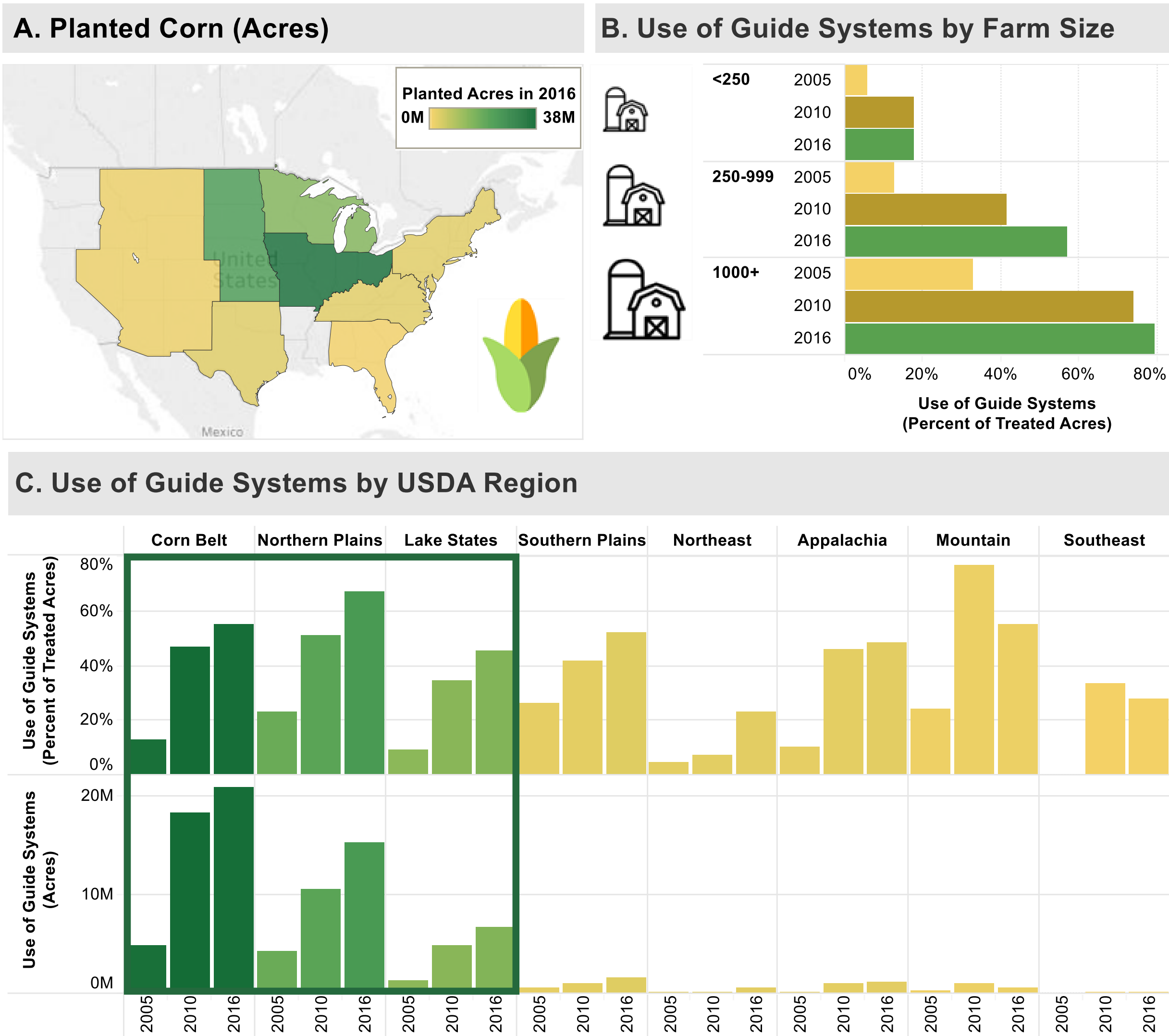
Use of Auto Steer on Wheat Crops

In the three regions with the most wheat acreage, 34 percent of acres were produced with auto steer in the Northern Plains, 19 percent in the Southern Plains, and 35 percent in the Mountain region on average between 2004 and 2009. As indicated in FIGURE 21, key findings include:

- The percentage of wheat acres grown using auto steer increased from 2004 to 2009 in all regions.
- Rates increased from 20 to 47 percent in the Northern Plains, from 10 to 27 percent in the Southern Plains, and from 17 to 53 percent in the Mountain region.
- The Northern Plains had the most acres of wheat grown using auto steer (approximately 4.7 million acres in 2004 and approximately 10.7 million acres in 2009).
- Small farms (<250 acres) had the lowest percentage of wheat acres grown using auto steer in 2004, 5 percent, increasing to 20 percent of acres in 2009. Mid-sized farms (250–299 acres) grew 13 percent of acres with auto steer in 2004, increasing to 36 percent in 2009, and large farms (1,000+ acres) grew 24 percent of wheat acres with auto steer in 2005, increasing to 54 percent in 2009.

- In total, auto steer was used on approximately 16 percent of wheat acres in 2004 and 42 percent of wheat acres in 2009.

FIGURE 19. Use of Auto Steer on Corn Crops



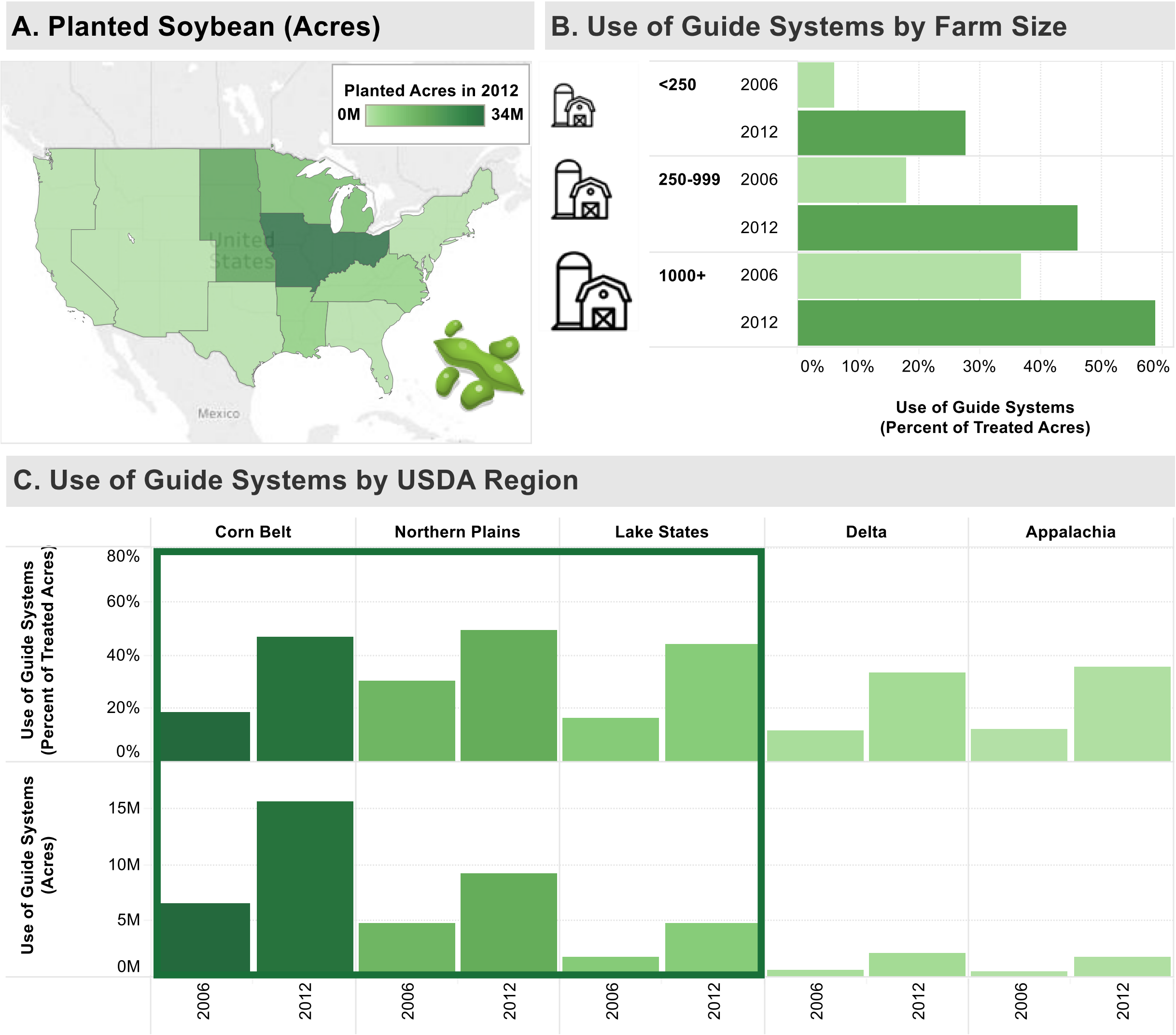
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. U.S. map showing planted acres of corn by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national percentage of acres where auto steer is used by farm size. Lightest color indicates earliest timepoint (2005), medium color indicates mid timepoint (2010), and darkest color indicates latest timepoint (2016).

C. Graph of percentage of acres where auto steer is used by USDA region (upper graph) and total number of acres where auto steer is used by USDA region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 20. Use of Auto Steer on Soybean Crops



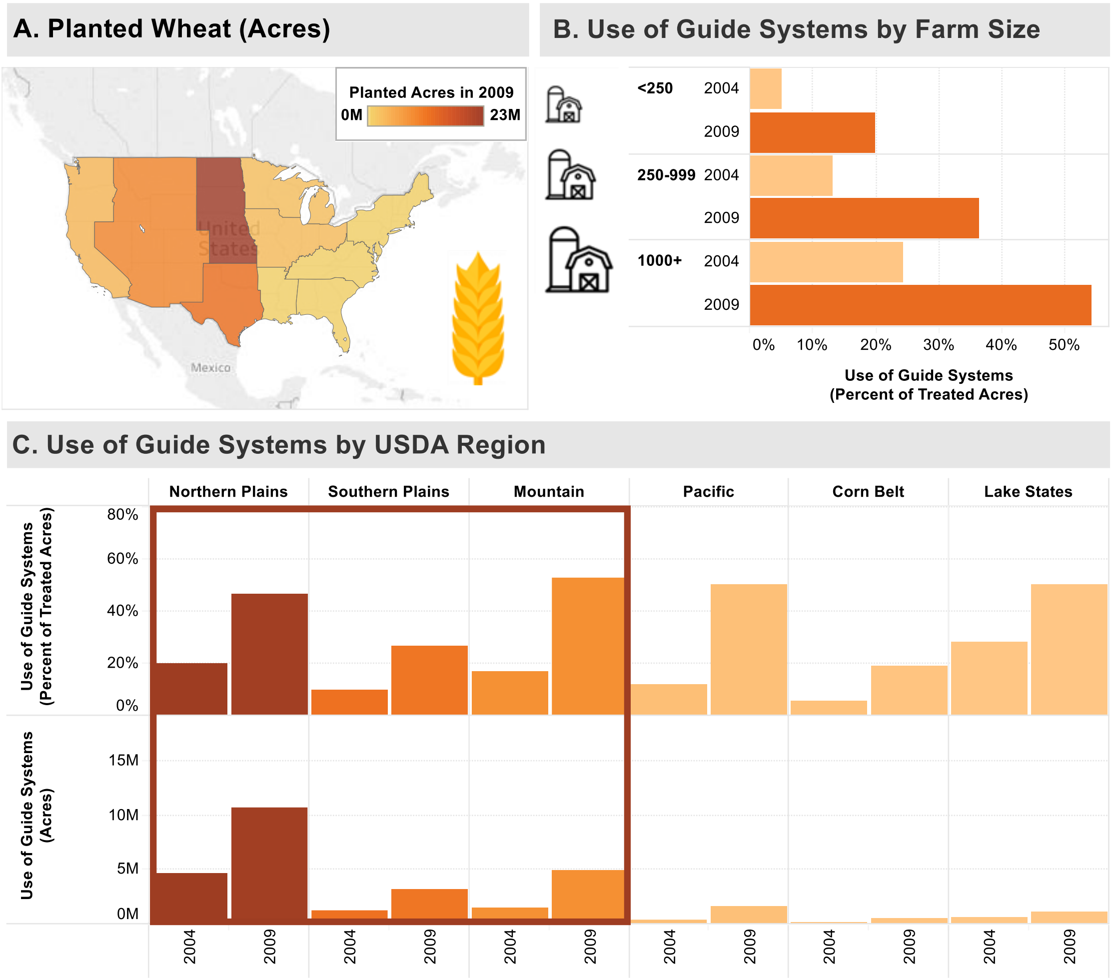
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006 and 2012.

A. U.S. map showing planted acres of soybeans by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national percentage of acres where auto steer is used by farm size. Lighter color indicates earlier timepoint (2006), darker color indicates later timepoint (2012).

C. Graph of percentage of acres where auto steer is used by USDA region (upper graph) and total number of acres where auto steer is used by USDA region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted soybean acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 21. Use of Auto Steer on Wheat Crops



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004 and 2009.

A. U.S. map showing planted acres of wheat by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of national percentage of acres where auto steer is used by farm size. Lighter color indicates earlier timepoint (2004), darker color indicates later timepoint (2009).

C. Graph of percentage of acres where auto steer is used by USDA region (upper graph) and total number of acres where auto steer is used by USDA region (lower). Box designates the three largest-producing regions. Regions sorted from left to right from most to least planted wheat acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

Cover Crops

Cover crops can contribute to conservation goals including reduced erosion, improved soil quality, and reduced GHG emissions. Depending on the specific conditions, management, and conservation objective, grasses, legumes, and brassicas are all commonly used as cover crops either as single species or mixes of multiple species (USDA NRCS, 2017f). Cover crops are not harvested and are typically grown either during fallow periods (when harvested crops are not grown) or grown simultaneously with main crops (such as in an orchard or vineyard, called intercropping). Benefits of adding cover crops to a system include: erosion control; improving soil structure, moisture, and nutrient content; reducing nitrate leaching; increasing beneficial soil biota; suppressing weeds; providing pollinators food; providing wildlife and pollinator habitat; and as forage for farm animals. Cover crops can also reduce GHG emissions and provide energy and cost savings by adding nitrogen to the system and increasing availability of soil nutrients, thereby reducing the need to apply fertilizer (USDA NRCS, 2017e; USDA NRCS, 2010; USDA NRCS, 2017f; USDA NRCS, 2010). Studies have also found that cover crops can help mitigate climate change by increasing soil carbon sequestration (Clark, 2012; Olson, Al-Kaisi, Lal, & Lowery, 2014; Eagle, et al., 2012). Cover crop data for the 2010, 2011, 2012, and 2015 USDA NASS/ERS ARMS were obtained from USDA ERS. Additional data on cover crop adoption were obtained from the Conservation Technology Innovation Center (CTIC) (see Appendix B). These data, however, were not collected in a statistically representative manner, so they are not included in the main report, but are available in the appendix.

In this report, data on the percentage of acres and the number of acres of cover crops grown are from USDA ARMS III CRR surveys in 2010, 2011, 2012, and 2015. The data include acreage from all types of farms, including those farms where crops are the main product and those where livestock are the main product.

FIGURE 22 presents the data in two ways, (1) percent of total acres of cover crops grown by USDA region, and (2) acres of cover crops grown by USDA region. Note that these data are not shown in some region years due to high relative standard errors (>50 percent). Specifically, the regions and years not included in the analysis due to RSE being greater than 50% include: 2010 Northern Plains, 2010 Southern Plains, 2010 Lake States, and 2010 and 2015 Delta regions.

Cover crops were grown on a very small percentage of acres in each of the five major regions. Some regions grew cover crops on a smaller area, but a slightly higher proportion of farms, than the main farm production regions.

Use of Cover Crops Key Findings:

- Both the percentage of acres grown with cover crops and the number of acres of cover crops grown increased from 2010 to 2015 in all but two regions.
- The Corn Belt had the largest increase in cover crops planted (approximately 3.3 million acres) from approximately 518,000 acres in 2010 to 3.8 million acres in 2015, followed by the Southern Plains, which increased approximately 1.6 million acres from approximately 758,000 acres in 2011 to approximately 2.3 million acres in 2015.
- Two regions showed decreases in the percentage of acres grown with cover crops and the number of acres planted with cover crops between 2010 and 2015. The Delta decreased approximately 309,000 acres from approximately 538,000 acres in 2011 to

approximately 230,000 acres in 2012, and the Mountain region decreased approximately 324,000 acres from approximately 1.2 million acres in 2010 to approximately 860,000 acres in 2015.[21]

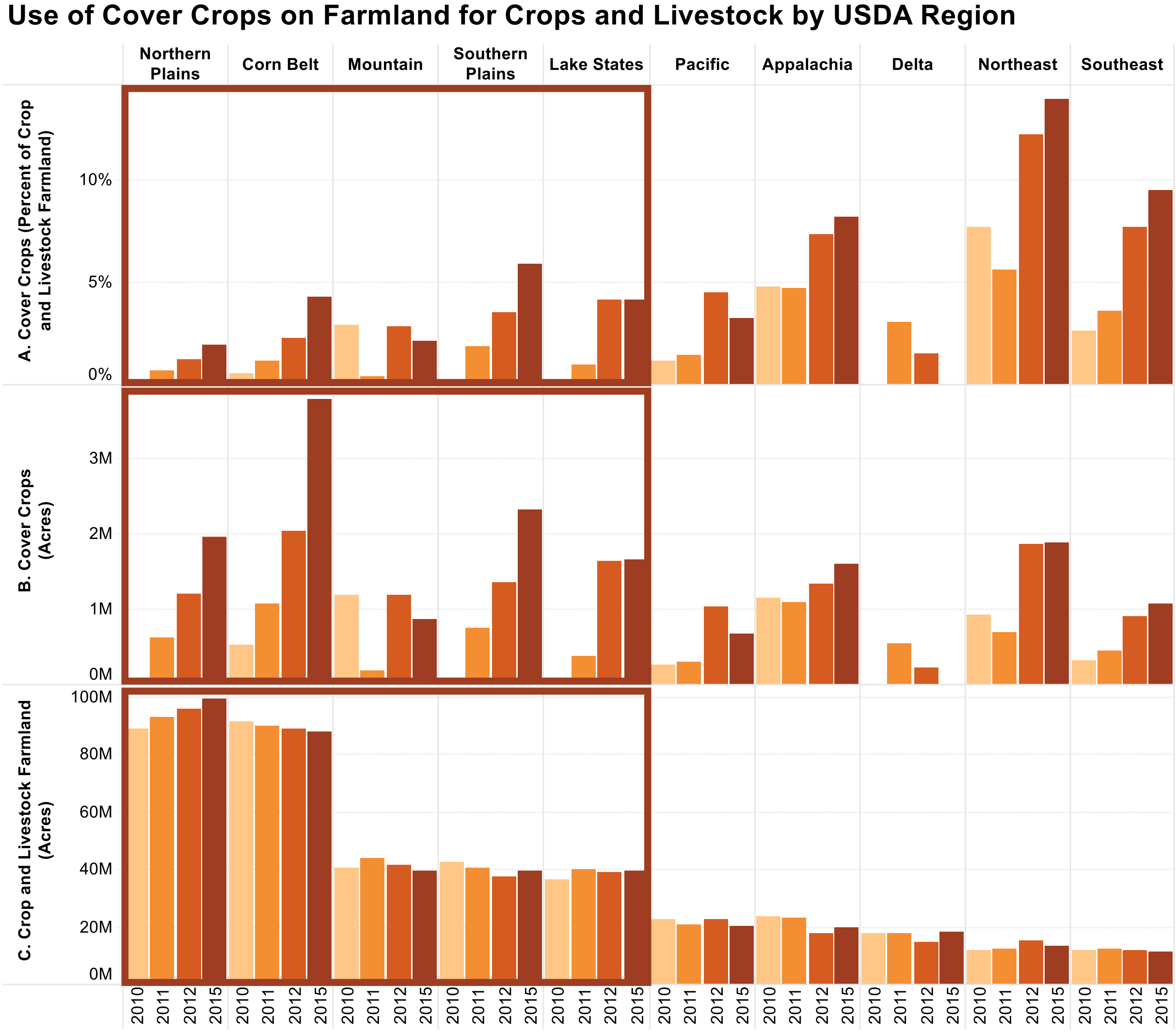
- Nationally, the acreage of cover crops planted was 7.7 million acres in 2010 (2 percent of all planted acres), 6.1 million acres in 2011 (2 percent of all planted acres), 12.8 million acres in 2012 (2 percent of all planted acres) to 16.3 million acres in 2015 (4 percent of all planted acres).

Reasons for Adoption Trends:

- Funding by Federal and State programs to encourage planting of cover crops (USDA NRCS IA, 2016; USDA NRCS, 2013).
- Positive impacts of cover crops on cash crop yield and soil, including increasing soil organic matter and moisture, reducing compaction, and capturing and recycling soil nutrients (CTIC, 2013; 2014; 2015; 2016; Taylor, 2015).

[21] Note that the Mountain region had the most complex pattern of cover crop acreage and percent of acres grown with approximately equal acreage in 2010 (1.2 million acres) and 2012 (1.1 million acres) and much lower levels in 2011 (approximately 189,000 acres) and 2015 (approximately 860,000 acres).

FIGURE 22. Use of Cover Crops on Farmland for Crops and Livestock by USDA Region



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010, 2011, 2012, and 2015.

A. Graph of the percentage of cover crops grown on total farmland acres (including land to grow crops and livestock) by USDA region and year. Box indicates the five largest-producing regions. Regions sorted from left to right from most to least total farmland acres. Color intensity is correlated to the year; the lighter the color, the earlier the year in the time series.

B. Graph of the number of acres grown with cover crops by USDA region and year. Box indicates five largest-producing regions. Regions sorted from left to right from most to least farmland acres. Color intensity is correlated to the year; the lighter the color the earlier the year in the time series. M = million.

C. Graph of the total number of farmland acres (including land to grow crops and livestock) by USDA region and year. Box indicates the five largest-producing regions. Regions sorted from left to right from most to least total farmland acres. Color intensity is correlated to the year; the lighter the color, the earlier the year in the time series. M = million.

Reduced Tillage

Tillage is the preparation of soil for seeding. It is also used to control weeds and pests and to incorporate fertilizers and manures. The more disruptive or intense the tillage, the higher the likelihood of soil erosion, nutrient runoff into nearby waterways, and the release of GHGs. A strong correlation exists between tillage intensity (i.e., amount of soil disturbed) and the amount of soil organic carbon lost to the atmosphere as carbon dioxide. Reducing tillage (by tilling less intensely or less frequently) enables the soil to retain organic matter, soil moisture, and potentially more soil carbon and can reduce costs and fuel use (USDA ERS, 2017e; USDA NRCS, 2016a). Studies have found that long-term no tillage (i.e., 10 or more years) results in increased soil carbon sequestration compared to shorter periods or seasonal no tillage (Abdalla, Chivenge, Ciais, & Chaplot, 2016).

Tillage can be categorized by the amount of residue left on the field and/or by Soil Tillage Intensity Rating (STIR). This report uses an older scale of STIR categories, which is consistent with analysis of the 2003 to 2006 CEAP study (USDA CEAP, 2011). General tillage categories included in this report are:

- **No tillage:** least intensive form of tillage. STIR rating less than 30 for all crops in a multi-year rotation.
- **Seasonal no tillage**: multi-year tillage rotation which includes at least one crop of no tillage (STIR rating less than 30) and other crops with mulch tillage (STIR rating less than 100).
- **Mulch tillage**: higher tillage rating than no-till, but lower intensity of tillage than conventional tillage. STIR rating between 30 and 100 for all crops in a multi-year rotation.
- **Seasonal mulch tillage:** multi-year tillage rotation which includes at least one crop of mulch tillage (STIR rating between 30 and 100) and other crops with conventional tillage (STIR rating greater than 100).
- **Conventional tillage:** most intensive form of tillage. STIR rating greater than 100 for all crops in rotation.

In this report, two different data sources were used to determine reduced tillage practices:

1. **USDA NASS/ERS ARMS** In this report, data on the percentage of acres of corn, soybean, and wheat crops where no tillage and mulch tillage were used are from 2005, 2010, and 2016 corn surveys, 2006 and 2012 soybean surveys, and 2004 and 2009 wheat surveys. As these data are each from independent, 1-year surveys, they offer a snapshot in time of which crop was grown and which tillage system was used in the year of the survey. For example, if a farmer grows a rotation of corn with mulch tillage and soybeans with no tillage, the survey will only capture one type of tillage. As such, the data do not capture crop rotations or multi-year tillage trends. The specific questions on tillage practices in the ARMS surveys that provided the data used in this report (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c; USDA ERS, 2005; USDA ERS, 2006; USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c) (USDA ERS, 2010b; USDA ERS, 2012b; USDA ERS, 2016a) are listed in Appendix D.
2. **USDA NRCS CEAP** In this report, data on the percentage of multi-year total cultivated cropland rotations grown under continuous no tillage, seasonal no tillage, continuous mulch tillage, seasonal mulch tillage, and continuous conventional tillage are from the

2003–2006 USDA CEAP national survey data. Unlike the ARMS surveys, the CEAP data capture a 3-year crop and tillage rotation, which gives a more nuanced understanding of farming practices in each USDA region. However, as this 3-year rotation is used as a single data point, it is not currently possible to determine changes in tillage over time. Future inclusion of 2015–2016 CEAP survey data (USDA NRCS, 2016b) will allow for this analysis. The specific questions on tillage practices in the CEAP surveys that provided the data used in this report (USDA NRCS, 2003; 2004; 2005; 2006) are listed in Appendix D.

Reduced Tillage Key Findings – ARMS Data:

- The proportion of acres grown using some type of reduced tillage (mulch tillage or no tillage) was relatively constant for corn for 2005 to 2016, decreased for soybeans, and increased for wheat. Wheat had the largest percentage increase and increase in acres.[22] The area of mulch tillage and no tillage is dependent on the total number of acres grown for those crops; thus, percentage is a more meaningful metric.
  - For corn, reduced tillage was used on 76 percent of acres in 2005 and 80 percent of acres in 2016.
  - For soybeans, reduced tillage was used on 82 percent of acres in 2006 and 82 percent of acres in 2012.
  - For wheat, reduced tillage was used on 46 percent of acres in 2004 and 66 percent of acres in 2009.
- For no tillage, wheat had the largest in percentage and in acres, from 22 percent of acres in 2004 to 41 percent of acres in 2009, followed by corn, which increased 29 percent of acres in 2005 to 33 percent of acres in 2016.
- Soybeans had a decrease in both percentage and total number of acres grown under no tillage, from 47 percent of acres in 2006 to 44 percent of acres in 2012.
- There were not sufficient data to determine the percentage of wheat acres grown using no tillage for all region years; there are only 2009 data for the Southern Plains.

Reduced Tillage Key Findings – CEAP Data:

- The vast majority of crops grown annually (93 percent) are grown using some type of reduced tillage.
  - No tillage (continuous or seasonal) was used on 122.4 million acres annually (43 percent) between 2003 and 2006.
  - Mulch tillage (continuous or seasonal) was used on 138.5 million acres annually (50 percent) between 2003 and 2006.
- More acres of crops were grown under continuous (long-term) no tillage or mulch tillage rotations than seasonal no tillage or mulch tillage rotations.
- 68.2 million acres (24 percent) were grown annually under continuous no tillage and 54.1 million acres (19 percent) were grown annually under seasonal no tillage between 2003 and 2006.
- 75.5 million acres (27 percent) were grown annually under continuous mulch tillage and 62.9 million acres (23 percent) were grown annually under seasonal mulch tillage between 2003 and 2006.

[22] These values do not include no tillage and total wheat acres grown in the Southern Plains region in 2004.

USDA ARMS Tillage Data

Data are presented individually (no tillage and mulch tillage are graphed separately) and in two ways, (1) percent of acres where a reduced tillage (mulch or no-till) practice was used by USDA region; and (2) percent of acres where a reduced tillage practice was used by farm size (<250 acres, 250–299 acres, 1,000+ acres) at the national level. The relative standard error was too high (>50 percent) to present data by both farm size and by USDA region. Note that data for some crop region years are not included due to relative standard error rates of greater than 50 percent. Please see individual sections for more details.

No Tillage and Mulch Tillage Used on Corn Crops

In the three regions producing 90 percent of U.S. corn, 26 percent of acres were produced with no tillage and 58 percent were produced with mulch tillage in the Corn Belt (84 percent reduced tillage overall), 51 percent with no tillage and 37 percent with mulch tillage in the Northern plains (88 percent reduced tillage overall), and 14 percent with no tillage and 47 percent with mulch tillage in the Lake States (61 percent reduced tillage overall) on average between 2005, 2010, and 2016.

FIGURE 23 presents use of no tillage on corn crops. Key findings indicate:

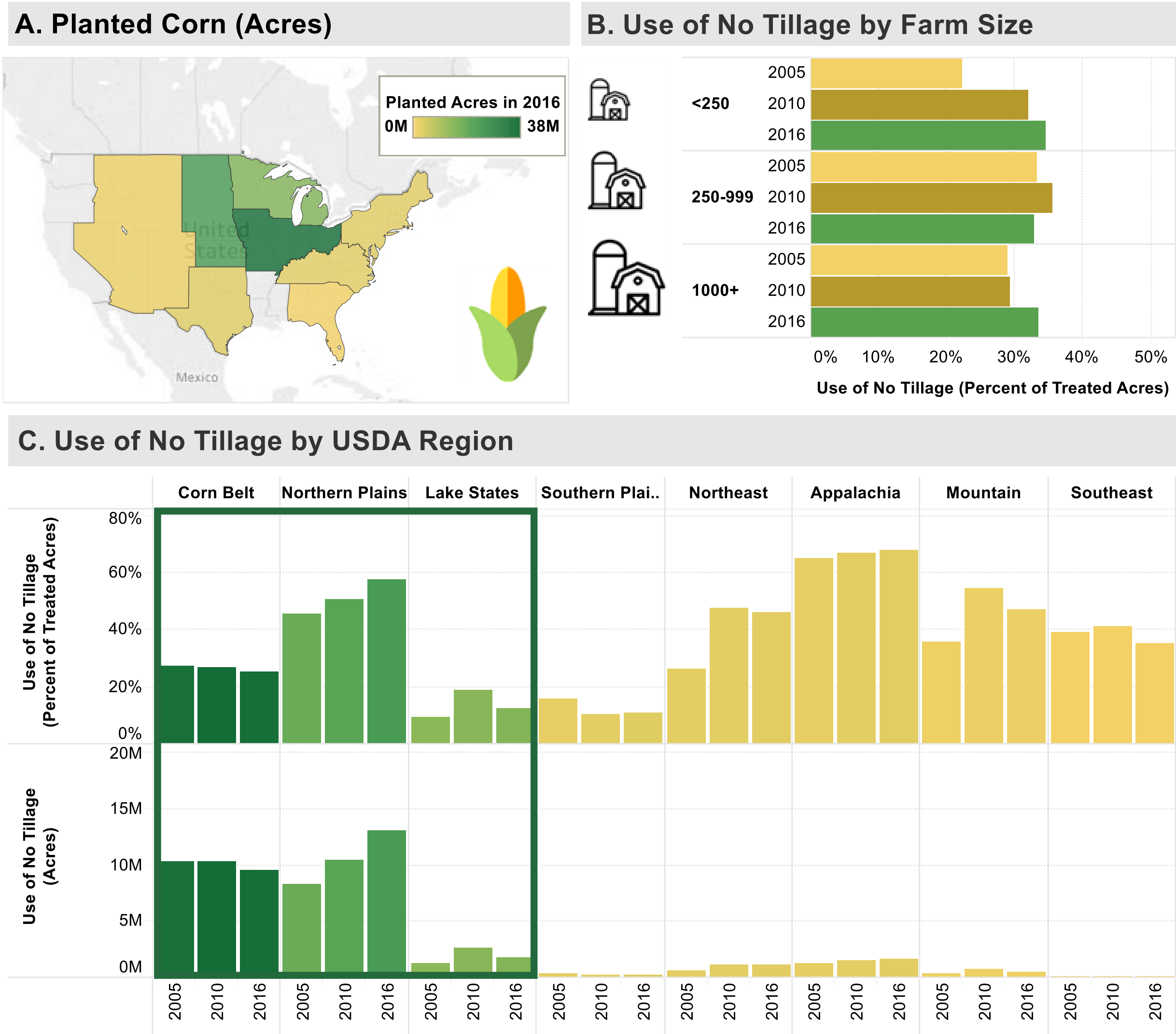
- The percent of corn acres grown using no tillage increased in five out of eight regions from 2005 to 2016 and decreased in three regions.
- Rates of no tillage remained about constant in the Corn Belt at 27 percent in 2005 and 25 percent in 2016, increased from 46 to 57 percent in the Northern Plains, and remained about constant in the Lake States at 10 percent in 2005 and 12 percent in 2016.
- Farm size does not appear to have a clear impact on the percentage of acres grown using no tillage, where all farm sizes have around one-third of acres grown using no tillage in 2016.
- Small farms (<250 acres) had the lowest percentage of corn acres grown using no tillage in 2005, 22 percent, which increased to 34 percent in 2016. Mid-sized farms (250–299 acres) grew 33 percent of acres with no tillage, which remained about constant. Large farms (1,000+ acres) grew 29 percent of corn acres with no tillage in 2005, which increased to 34 percent of acres in 2016.
- In total, approximately 29 percent of corn acres were grown using no tillage in 2005, 33 percent in 2010, and 33 percent in 2016.

FIGURE 24 presents use of mulch tillage on corn crops. Key findings indicate:

- The percentage of corn acres grown using mulch tillage increased in seven out of eight regions and decreased in one region from 2005 to 2016 (see FIGURE 24b).
- Rates in the Corn Belt increased from 57 percent in 2005 to 61 percent in 2016, decreased from 42 to 30 percent in the Northern Plains, and increased from 40 to 51 percent in the Lake States.
- Farm size appears to impact the percentage of acres grown using mulch tillage. Whereas small farms remained relatively constant in the percentage of acres grown with mulch tillage, mid-sized farms had increased percentage of land grown under mulch tillage, and large farms had decreases in the percentage of acres grown using mulch tillage (see FIGURE 24c).

- In total, approximately 47 percent of corn acres were grown using mulch tillage in 2005, 48 percent in 2010, and 47 percent in 2016.

FIGURE 23. Use of No Tillage on Corn Crops



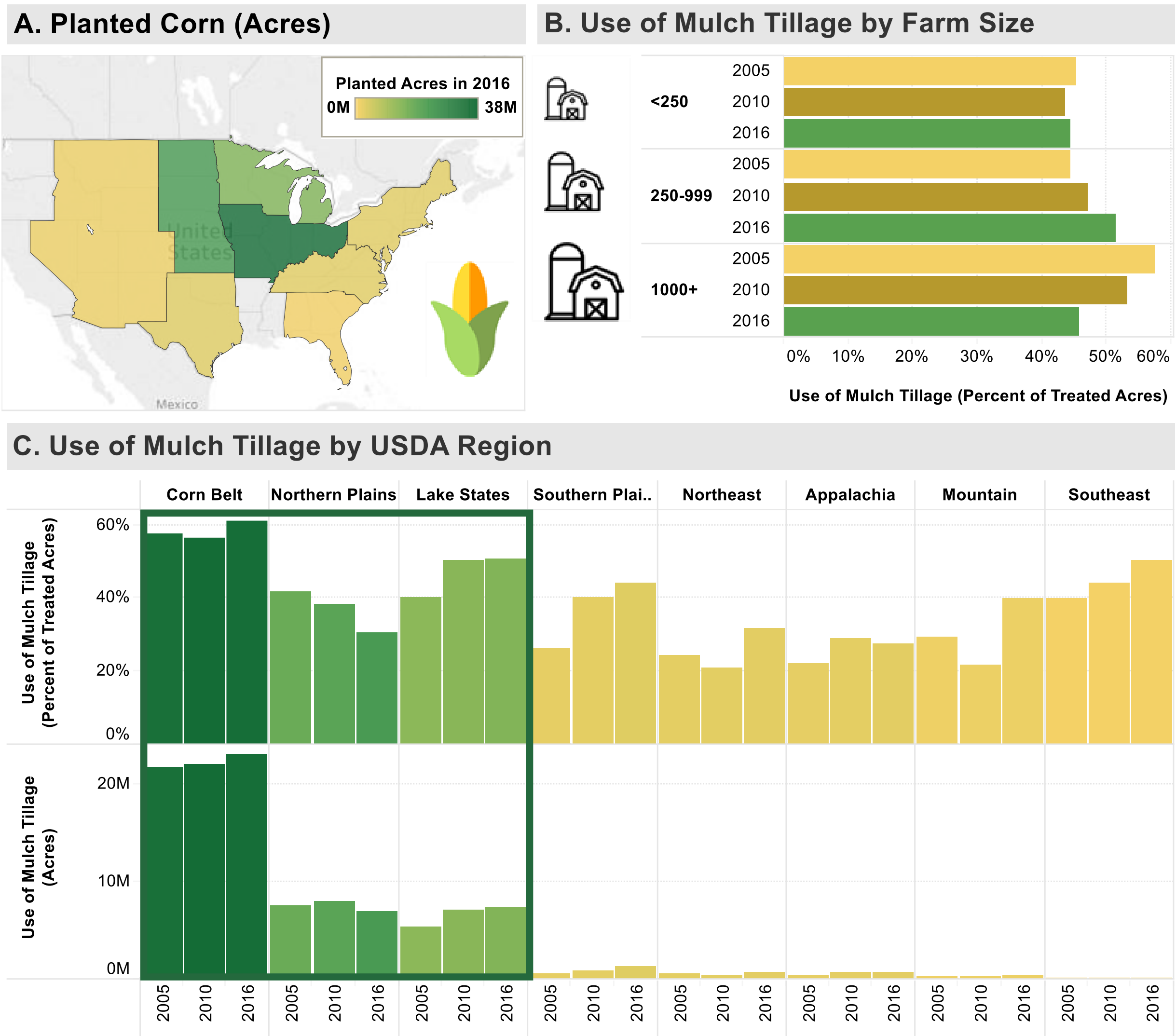
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. U.S. map showing planted acres of corn by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of percentage of acres produced using no tillage by farm size and year. Lightest color indicates earliest timepoint (2005), medium color indicates mid-timepoint (2010), and darkest color indicates latest time point (2016). M = million.

C. Graph of percentage of corn acres using no tillage by USDA region and year (upper graph) and total number of acres where no tillage was used by USDA region and year (lower). Box indicates three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres.

FIGURE 24. Use of Mulch Tillage on Corn Crops



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

A. U.S. map showing planted acres of corn by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of percentage of acres produced using mulch till by farm size and year. Lightest color indicates earliest timepoint (2005), medium color indicates mid-timepoint (2010), and darkest color indicates latest time point (2016).

C. Graph of percentage of corn acres using mulch till by USDA region and year (upper graph) and total number of acres where mulch till was used by USDA region and year (lower). Box indicates three largest-producing regions. Regions sorted from left to right from most to least planted corn acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

No Tillage and Mulch Tillage Used on Soybean Crops

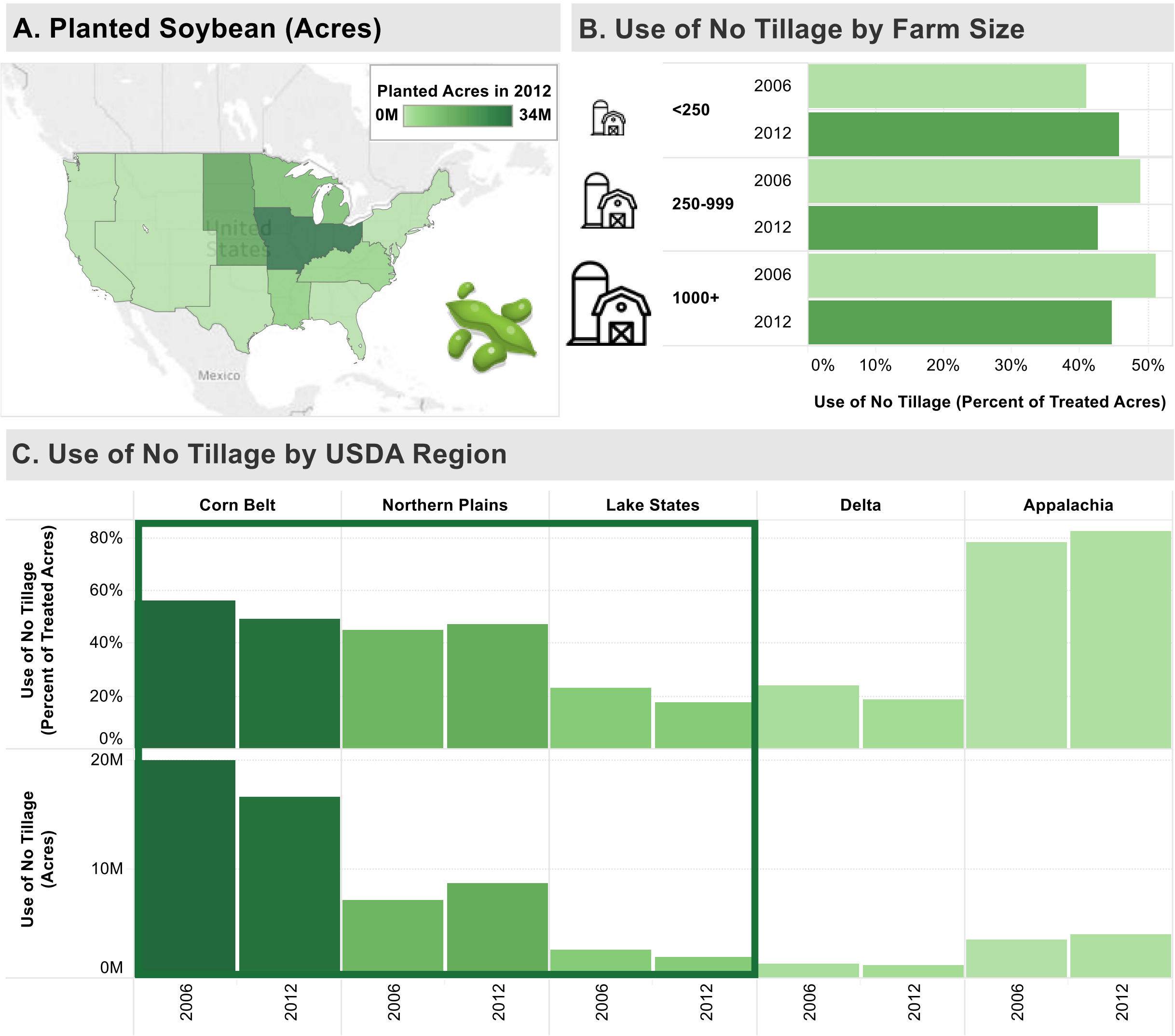
FIGURE 25 presents the use of no tillage on soybean crops. Key findings indicate:

- The percentage of soybean acres grown using no tillage increased in 2 of 5 regions from 2006 to 2012.
- Rates decreased from 56 to 50 percent in the Corn Belt, remained about constant from 45 to 47 percent in the Northern Plains, and decreased from 23 to 18 percent in the Lake States.
- Farm size appears to impact the percentage of acres grown using no tillage, where small farms had the lowest percentage in 2005, but all three farm sizes had similar percentage in 2012.
- Small farms (<250 acres) had the lowest percentage of soybean acres grown using no tillage in 2006, 40 percent, which remained about constant at 41 percent of acres in 2012. Mid-sized farms (250–299 acres) grew 47 percent of acres with no tillage in 2006, which decreased to 40 percent of acres in 2012, and large farms (1,000+ acres) grew 50 percent of soybean acres with no tillage in 2006, which decreased to 42 percent in 2012.
- In total, approximately 47 percent of soybean acres were grown using no tillage in 2006 and 44 percent in 2012.

FIGURE 26 presents the use of mulch tillage on soybean crops. Key findings indicate:

- The percentage of soybean acres grown using mulch tillage increased in two regions and decreased slightly in three regions from 2006 to 2012 (see FIGURE 26b).
- Rates increased from 32 to 38 percent in the Corn Belt, remained about the same from 38 to 36 percent in the Northern Plains, and were stable from 45 percent to 47 percent in the Lake States.
- Farm size appears to have little impact the percentage of acres grown using mulch tillage, where all farm sizes have similar percentage of use (34–40 percent) (see FIGURE 26c).
- Small farms (<250 acres) had the highest percentage of soybean acres grown using mulch tillage in 2006, 36 percent, which remained constant in 2012. Mid-sized farms (250–299 acres) grew 35 percent of acres with mulch tillage in 2006, which increased to 40 percent of acres in 2012, and large farms (1,000+ acres) grew 35 percent of soybean acres with mulch tillage in 2006, which remained about the same at 34 percent in 2012.
- In total, 35 percent of soybean acres were grown using mulch tillage in 2006 and 38 percent in 2012.

FIGURE 25. Use of No Tillage on Soybean Crops



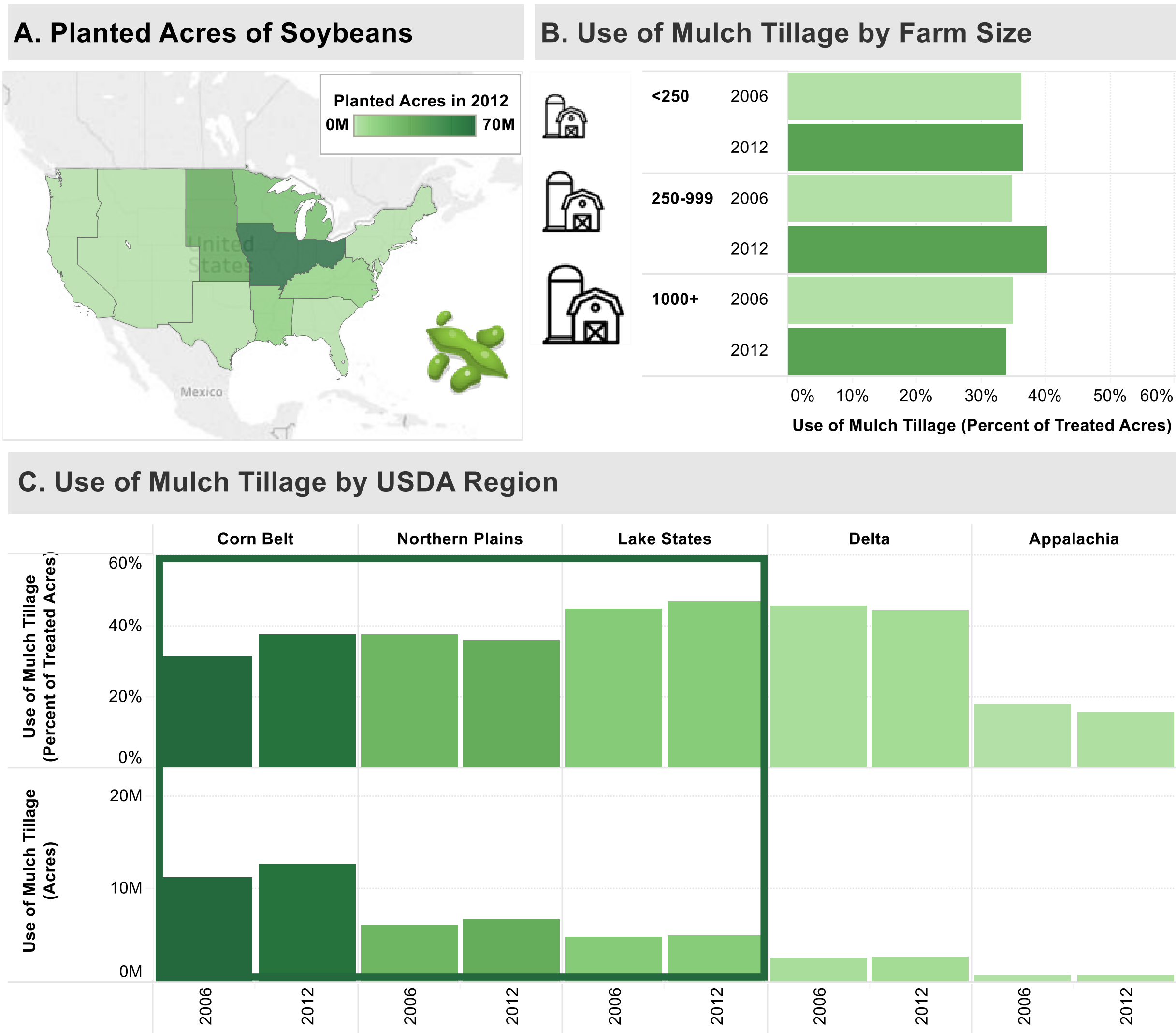
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006 and 2012.

A. U.S. map showing planted acres of soybeans by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of percentage of acres produced using no tillage by farm size and year. Lighter color indicates earlier timepoint (2006), darker color indicates later timepoint (2012).

C. Graph of percentage of soybean acres using no tillage by USDA region and year (upper graph) and total number of acres where no tillage was used by USDA region and year (lower). Box indicates three largest-producing regions. Regions sorted from left to right from most to least planted soybean acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 26. Use of Mulch Tillage on Soybean Crops



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006 and 2012.

A. U.S. map showing planted acres of soybeans by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of percentage of acres produced using mulch till by farm size and year. Lighter color indicates earlier timepoint (2006), darker color indicates later timepoint (2012).

C. Graph of percentage of soybean acres using mulch till by USDA region and year (upper graph) and total number of acres where mulch till was used by USDA region and year (lower). Box indicates three largest-producing regions. Regions sorted from left to right from most to least planted soybean acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

Use of No Tillage and Mulch Tillage on Wheat Crops

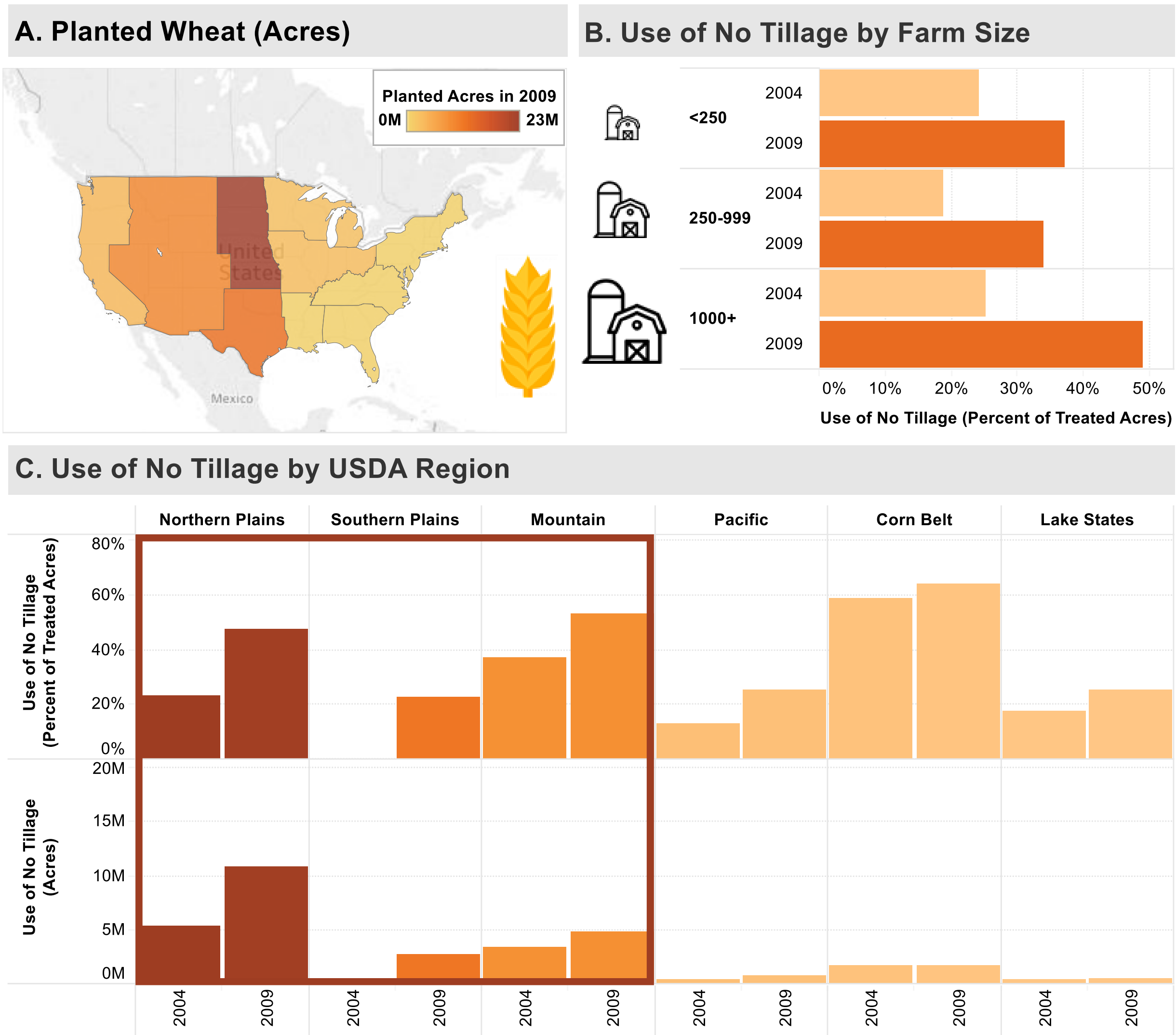
FIGURE 27 presents the use of no tillage on wheat crops. Key findings indicate:

- The percentage of wheat acres grown using no tillage increased from 2004 to 2009 in all regions for which there are data.
- Rates increased from 23 to 48 percent in the Northern Plains, and from 37 to 53 percent in the Mountain region. There were not enough data to determine the percentage of acres grown using no tillage in the Southern Plains in 2004, but it was used on 23 percent of acres in 2009.
- Farm size appears to impact the percentage of acres grown using no tillage.
- Small farms (<250 acres) had the mid-range percentage of wheat acres grown using no tillage 24 percent, which increased to 37 percent of acres in 2009. Mid-sized farms (250–299 acres) had the lowest percentage in both years, 19 percent of acres with no tillage in 2004, which increased to 34 percent of acres in 2009, and large farms (1,000+ acres) grew the highest percentage of acres with no tillage in both years, 25 percent in 2005, which increased to 49 percent in 2009.
- In total, approximately 22 percent of wheat acres were grown using no tillage in 2004 and 41 percent in 2009.

FIGURE 28 presents the use of mulch tillage on wheat crops. Key findings indicate:

- The percentage of wheat acres grown using mulch tillage increased from 2004 to 2009 in three regions, remained constant in one region, and decreased in two regions.
- Rates decreased from 22 to 19 percent in the Northern Plains, increased from 24 to 33 percent in the Southern Plains, and remained stable from 25 to 26 percent in the Mountain region.
- Farm size appears to impact the percentage of acres grown using mulch tillage, where small farms have the highest percentage followed by mid-sized and large farms.
- Small farms (<250 acres) had the highest percentage of wheat acres grown using mulch tillage in 2004, 29 percent, which increased slightly to 31 percent of acres in 2009. Mid-sized farms (250–299 acres) grew 25 percent of acres with mulch tillage in 2004, which increased to 29 percent of acres in 2009, and large farms (1,000+ acres) grew 21 percent of wheat acres with mulch tillage in 2005, which remained about the same at 20 percent in 2009.
- In total, approximately 24 percent of wheat acres were grown using mulch tillage in 2004 and 25 percent in 2009.

FIGURE 27. Use of No Tillage on Wheat Crops



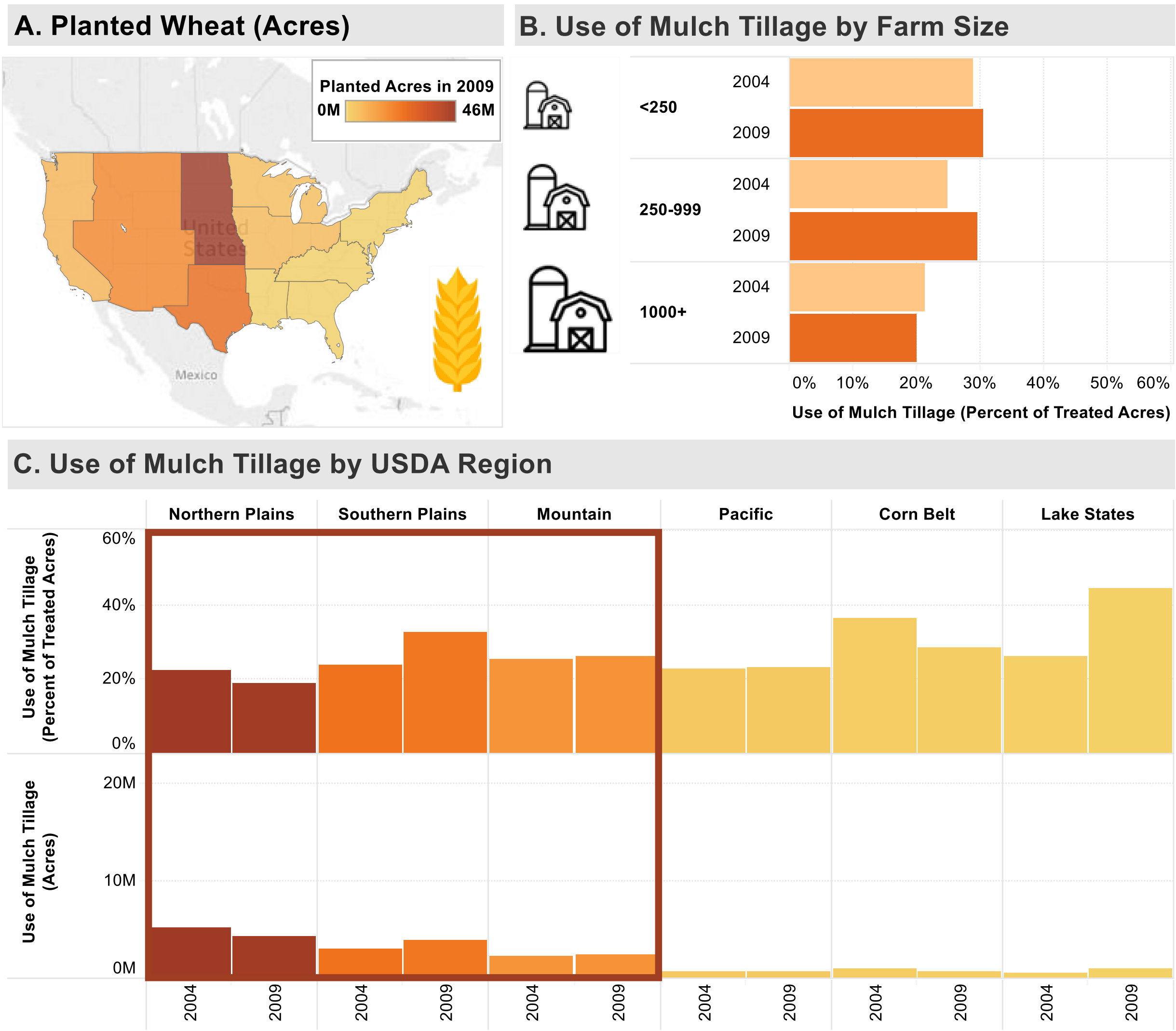
Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004 and 2009.

A. U.S. map showing planted acres of wheat by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of percentage of acres produced using no tillage by farm size and year. Lighter color indicates earlier timepoint (2004), darker color indicates later timepoint (2009).

C. Graph of percentage of wheat acres using no tillage by USDA region and year (upper graph) and total number of acres where no tillage was used by USDA region and year (lower graph). Box indicates three largest-producing regions. Regions sorted from left to right from most to least planted wheat acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

FIGURE 28. Use of Mulch Tillage on Wheat Crops



Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004 and 2009.

A. U.S. map showing planted acres of wheat by USDA region. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. Grey color indicates no data. M = million.

B. Graph of percentage of acres produced using mulch till by farm size and year. Lighter color indicates earlier timepoint (2004), darker color indicates later timepoint (2009).

C. Graph of percentage of wheat acres using mulch till by USDA region and year (upper graph) and total number of acres where mulch till was used by USDA region and year (lower). Box indicates three largest-producing regions. Regions sorted from left to right from most to least planted wheat acres. Color intensity is correlated to number of planted acres; darker colors indicate more planted acres, lighter colors indicate fewer planted acres. M = million.

USDA CEAP Tillage Data

Data are sorted in two ways, (1) by tillage practice (percent of acres grown using a given tillage practice over a crop rotation) in each production region; and (2) by production region (percent of acres grown using each type of tillage practice over a crop rotation). The relative standard error is too high (>50 percent) to present data by farm size. Differences in results between the CEAP and ARMS data are due to differences in sampling methods, sample sizes, and crop types.

Simple Cropland Rotation Graph

To simplify the data, the graph in this section has grouped 3-year tillage categories to be similar to those used in the ARMS data. They include:

- **No tillage:** comprised of the continuous no tillage category (STIR rating < 30 for all crops in a multi-year rotation) and the seasonal no tillage category (at least one crop of no tillage (STIR rating< 30) and other crops with mulch tillage (STIR rating <100)).[23]
- **Mulch tillage**: comprised of the continuous mulch tillage category (STIR rating between 30 and 100 for all years in a multi-year rotation) and the seasonal mulch tillage category (multi-year tillage rotation that has at least 1 year of mulch tillage (STIR rating between 30 and 100) and other years with conventional till (STIR rating >100)).
- **Continuous conventional tillage:** STIR rating > 100 for all years in rotation.

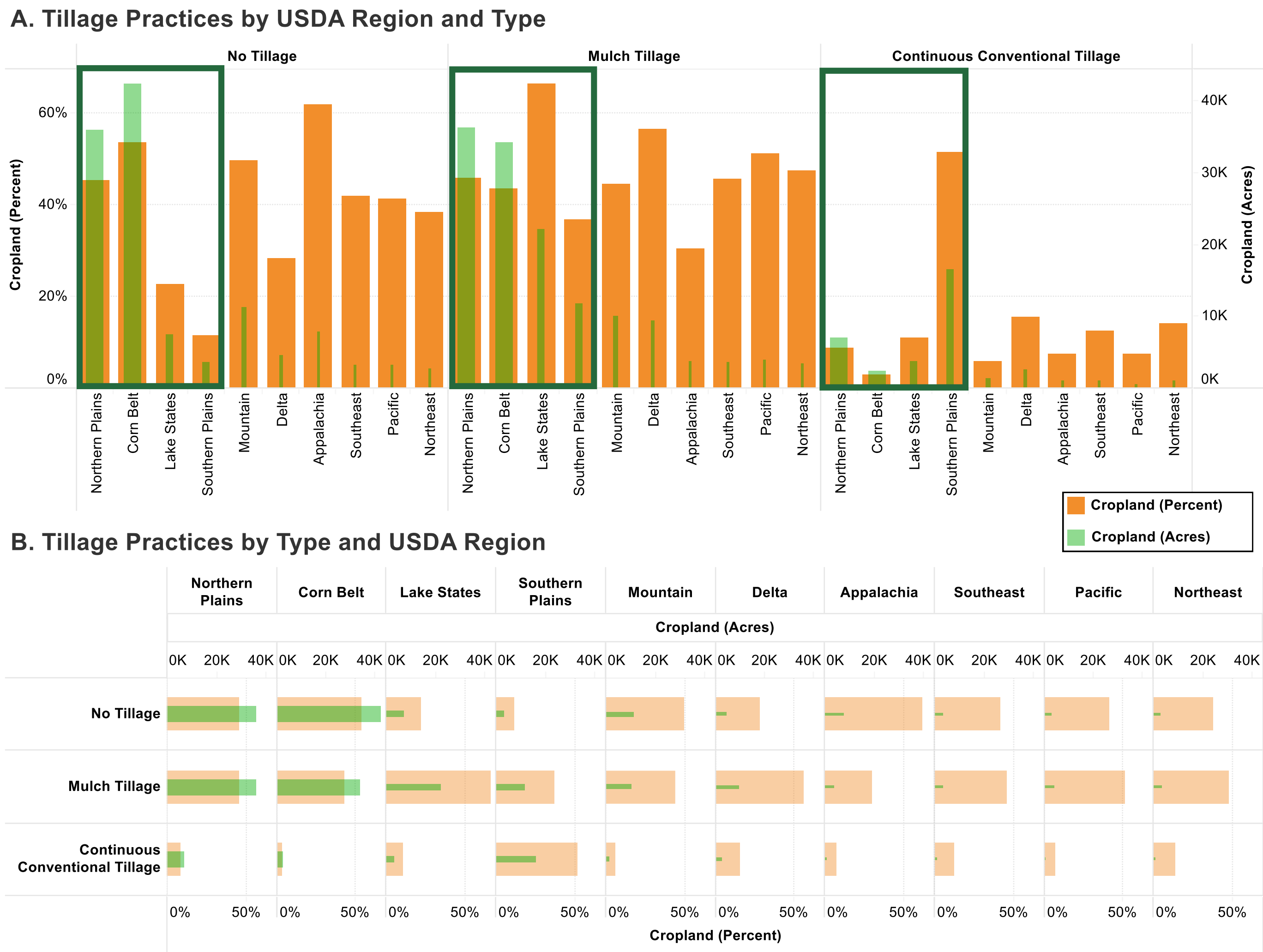
Total cropland during this period was approximately 279.7 million acres annually between 2003 and 2006. (The combined acres of corn, soybean and wheat from ARMS was approximately 208.4 million acres around the same time period). The four major producing regions are the Northern Plains (79.128 million acres), the Corn Belt (78.8 million acres), the Lake States (33.4 million acres) and the Southern Plains (31.9 million acres), which comprised approximately 80 percent of total U.S. cropland annually from 2003 to 2006.

As indicated in FIGURE 29, findings include:

- No tillage and mulch tillage were used on the vast majority of acres in three of the four major production regions, with 45 percent no tillage and 46 percent mulch tillage used in the Northern Plains (91 percent total reduced till), 54 percent no tillage and 43 percent mulch tillage used in the Corn Belt (97 percent total reduced till), and 23 percent no tillage and 66 percent mulch tillage used in the Lake States (89 percent total reduced till). In the Southern Plains, 11 percent of acres used no-till and 37 percent used mulch tillage (48 percent total reduced till).
- The areas with the largest percent of acres grown using no tillage (from highest to lowest percent) are: Appalachia (62 percent), Corn Belt (54 percent), Mountain (50 percent), Northern Plains (45 percent), Southeast (42 percent), Pacific (41 percent), Northeast (38 percent), Delta (28 percent), Lake States (23 percent), and Southern Plains (11 percent). Combined, 122.4 million acres were grown annually under no tillage from 2003 to 2006.
- The areas with the largest percentage of acres grown using mulch tillage (from highest to lowest percentage) are: Lake States (66 percent), Delta (56 percent), Pacific (51 percent), Northeast (48 percent), Northern Plains (46 percent), Southeast (45 percent), Mountain (44 percent), Corn Belt (43 percent), Southern Plains (37 percent), and Appalachia (30 percent). Combined, 138.5 million acres were grown annually under mulch tillage from 2003 to 2006.

[23] Note: Data for determining tillage categories were not taken directly from survey questions. Each field operation was assigned a STIR rating using operation-specific STIR ratings provided by NRCS.

FIGURE 29. Crop Rotations Split Into Three Tillage Categories for 2003 to 2006



Source: USDA Economic Research Service analysis based on Conservation Effects Assessment Project (CEAP) data for 2003, 2004, 2005, and 2006.

A. Graph of percentage and number of planted acres grown using a given tillage type (no tillage, mulch tillage, and continuous conventional till) for all cropland acres by USDA region. Graph is sorted by acres grown under no tillage (left), mulch tillage (center), and continuous conventional till (right). Orange bars indicate percentage of cropland acres grown using a given tillage type by region (units on left axis). Length of the green bars indicate number of acres grown using a given tillage type by USDA region (units on right axis). Width of green bars is correlated to number of total planted acres; thicker bars indicate more planted acres; thinner bars colors indicate fewer planted acres. Regions sorted from left to right from most to least planted cropland acres. Box indicates the four largest-producing regions. K = thousand.

B. Graph of percentage and number of planted acres grown using a given tillage type (no tillage, mulch tillage, and continuous conventional till) for all cropland acres by USDA region. Graph is sorted by USDA region. Identical to the graph above, orange bars indicate percentage of cropland acres grown using a given tillage type by region (units on bottom axis). Length of green bars indicate number of acres grown using a given tillage type by USDA region (units on top axis). Width of green bars is correlated to number of total planted acres; thicker bars indicate more planted acres; thinner bars colors indicate fewer planted acres. Regions sorted from left to right from most to least planted cropland acres. K = thousand.

Complex Cropland Rotation Graph

To get a deeper understanding of multi-year tillage trends, the graph in this section has categorized the data to include continuous no tillage, mulch tillage, and conventional till as well as seasonal no tillage and seasonal mulch till. By dividing the data into “continuous” and “seasonal” categories, it is possible to see multi-year tillage management trends, which may include no tillage for some years but mulch tillage other years. As many of the environmental and climate benefits of no tillage and mulch tillage result from continuous use of these production methods, it is important to understand multi-year tillage management trends (Grandy, 2006; Stavi, 2011).

General tillage categories included in this section are:

- **Continuous no tillage:** least intensive form of tillage. STIR rating < 30 for all years in a multi-year rotation.
- **Seasonal no tillage**: multi-year tillage rotation that has at least 1 year of no till (STIR rating< 30) and other years with mulch tillage (STIR rating between 30 and 100).
- **Continuous mulch tillage**: mid-range intensity of tillage. STIR rating between 30 and 100 for all years in a multi-year rotation.
- **Seasonal mulch tillage**: multi-year tillage rotation that has at least 1 year of mulch tillage (STIR rating between 30 and 100) and other years with conventional till (STIR rating >100).
- **Continuous conventional tillage:** most intensive form of tillage. STIR rating > 100 for all years in rotation.

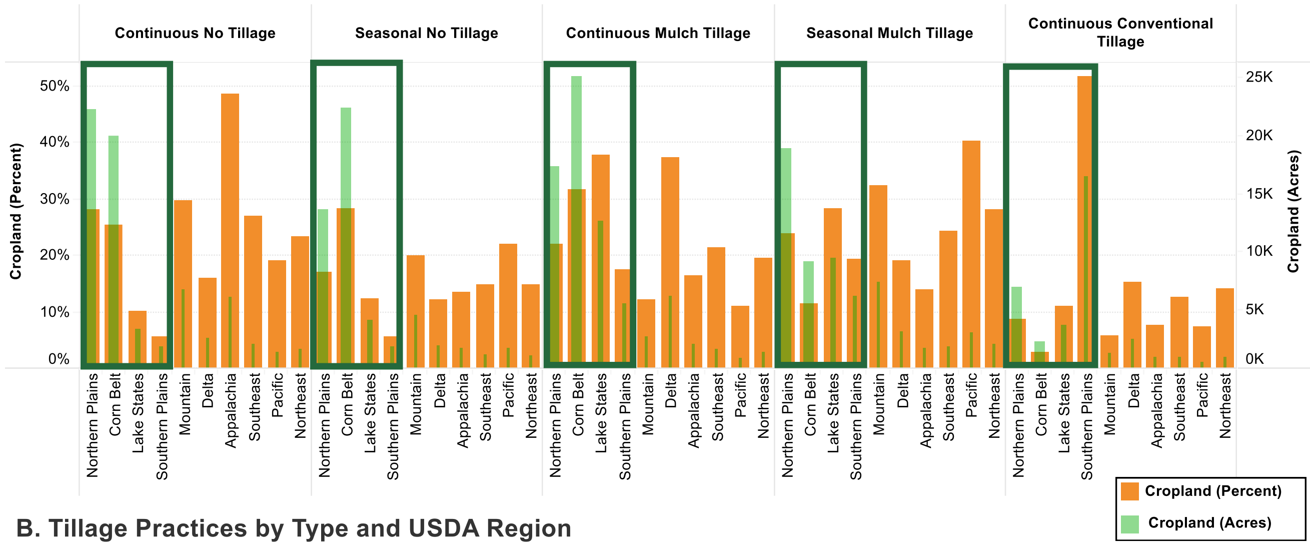
FIGURE 30 indicates the following findings:

- Continuous no tillage, seasonal no tillage, continuous mulch tillage, and seasonal mulch tillage are used on the vast majority of acres grown in three of the four major producing regions.
- In the Northern Plains, 28 percent of acres are grown using continuous no tillage, 17 percent of acres are grown using seasonal no tillage, 22 percent of acres are grown using continuous mulch tillage, and 24 percent are grown using seasonal mulch tillage (91 percent total reduced till).
- In the Corn Belt, 25 percent of acres are grown using continuous no tillage, 28 percent of acres are grown using seasonal no tillage, 32 percent of acres are grown using continuous mulch tillage, and 12 percent are grown using seasonal mulch tillage (97 percent total reduced till).
- In the Lake States, 10 percent of acres are grown using continuous no tillage, 12 percent of acres are grown using seasonal no tillage, 38 percent of acres are grown using continuous mulch tillage, and 28 percent are grown using seasonal mulch tillage (89 percent total reduced till).
- In the Southern Plains, 6 percent of acres are grown using continuous no tillage, 6 percent of acres are grown using seasonal no tillage, 18 percent of acres are grown using continuous mulch tillage, and 19 percent are grown using seasonal mulch tillage (48 percent total reduced till).
- Overall, continuous mulch tillage was used for crop production on the most acres (75.5 million), followed by continuous no tillage (68.2 million acres), seasonal mulch tillage (62.9 million acres), seasonal no tillage (54.1 million acres), and continuous conventional till (36.9 million acres).

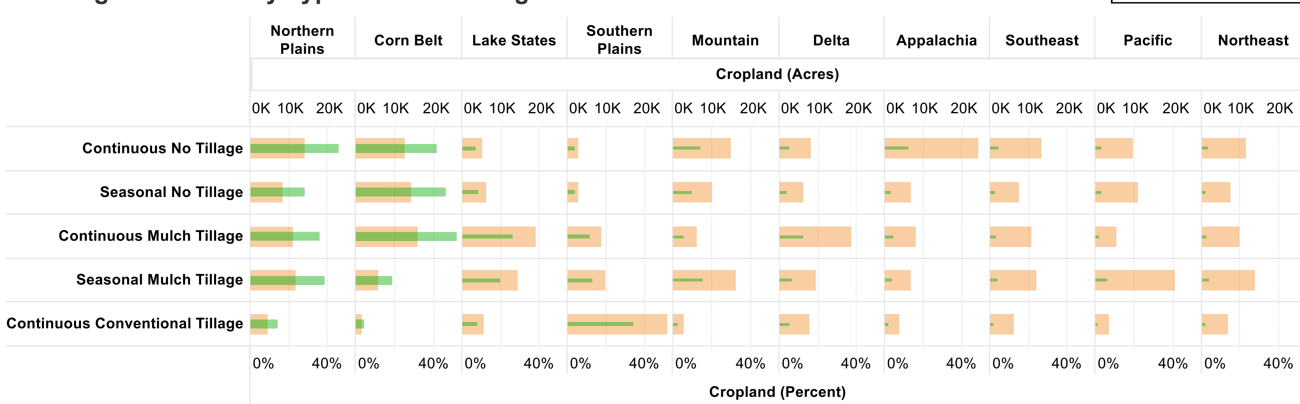
- The data indicate that between 2003 and 2006, 55 percent of crops grown using reduced-till were grown using continuous reduced-till (i.e., continuous no tillage or continuous mulch tillage) and 45 percent of crops using reduced-till were grown using seasonal reduced till (i.e., seasonal no tillage or seasonal mulch tillage) annually.

FIGURE 30. Crop Rotations Split Into Five Tillage Categories for 2003 to 2006

A. Tillage Practices by USDA Region and Type



B. Tillage Practices by Type and USDA Region



Source: USDA Economic Research Service analysis based on Conservation Effects Assessment Project (CEAP) data for 2003, 2004, 2005, and 2006.

A. Graph of percentage and number of planted acres grown using a given tillage type (continuous no tillage, seasonal no tillage, continuous mulch tillage, seasonal mulch tillage, and continuous conventional till) for all cropland acres by USDA region. Graph is sorted by acres grown under the different tillage types; from left to right continuous no tillage, seasonal no tillage, continuous mulch tillage, seasonal mulch tillage, and continuous conventional till. Orange bars indicate percentage of cropland acres grown using a given tillage type by region (units on left axis). Length of green bars indicate number grown using a given tillage type by USDA region (units on right axis). Width of green bars is correlated to number of total planted acres; thicker bars indicate more planted acres; thinner bars colors indicate fewer planted acres. Regions sorted from left to right from most to least planted cropland acres. Box indicates the four largest-producing regions. K = thousand.

B. Graph of percentage and number of planted acres grown using a given tillage type (continuous no tillage, seasonal no tillage, continuous mulch tillage, seasonal mulch tillage, and continuous conventional till) for all cropland acres by USDA region. Graph is sorted by USDA region. Identical to the graph above, orange bars indicate percentage of cropland acres grown using a given tillage type by region (units on bottom axis). Length of green bars indicate number grown using a given tillage type by USDA region (units on top axis). Width of green bars is correlated to number of total planted acres; thicker bars indicate more planted acres; thinner bars colors indicate fewer planted acres. Regions sorted from left to right from most to least planted cropland acres. K = thousand.

RECOVERY AND USE OF BIOGAS FROM ANAEROBIC DIGESTERS FOR MANURE MANAGEMENT

Overview of Anaerobic Digesters

When stored or treated in anaerobic conditions (without oxygen), livestock manure decomposes to produce biogases. Biogases are comprised of between 60 and 80 percent methane (CH_4) which is both a potential energy source and a potent greenhouse gas (EPA, 2017b; EPA, 2004). In 2015, most of the emissions from livestock manure, 66.3 million metric tons of CO_2 equivalent, came from anaerobic decomposition (EPA, 2017b).

Anaerobic digester systems can reduce biogas (and methane emissions) by capturing the emitted gases and using them to generate electricity and/or heat or converting them to CO_2 (Pape, 2016). Anaerobic digesters can also reduce water contamination risks, improve nutrient recovery and recycling, reduce odors during storage and decomposition, and may increase net farm income as gas can be used on-site or sold off-site (EPA, 2004; USDA, EPA, & DOE, 2014).

Farmers generally select a specific digester technology based on which digester will work best with their existing manure handling system. The three most commonly used types of anaerobic digester technologies are:

- **Covered lagoon**: used to treat and produce biogas from liquid manure with less than 3 percent solids. Generally, large lagoon volumes are required, preferably with depths greater than 12 feet. The typical volume of the required lagoon can be roughly estimated by multiplying the daily manure flush volume by 40 to 60 days. Covered lagoons for energy recovery are compatible with flush manure systems in warm climates. Covered lagoons may be used in cold climates for seasonal biogas recovery and odor control (gas flaring). There are two types of covers, bank-to-bank and modular. A bank-to-bank cover is used in moderate to heavy rainfall regions. A modular cover is used for arid regions (EPA, 2004).
- **Complete mix**: engineered tanks, above or below ground, that treat slurry manure with a solids concentration in the range of 3 to 10 percent. These structures are heated and require less land than lagoons. Complete mix digesters are compatible with combinations of scraped and flushed manure (EPA, 2004).
- **Plug flow system**: engineered, heated, rectangular tanks that treat scraped dairy manure with a range of 11 to 13 percent total solids. Swine manure cannot be treated with a plug flow digester due to its lack of fiber (EPA, 2004).

Anaerobic Digester Key Findings:

- The total number of operational digesters in the United States increased from 63 in 2004 to 248 in 2017 (EPA, AgSTAR Livestock Anaerobic Digester Database, 2018).
- Plug flow and complete mix digesters were the most common type of technology in operation, representing nearly 80 percent of all digesters in the AgStar program.

- One-third of operational digesters are located in the Northeast. Between 2004 and 2017, this region also had the greatest increase in digesters, with 68 new systems coming online.
- The majority of digesters were fed by dairy cattle manure. Between 2004 and 2017, the proportion of digesters fed by dairy cattle manure increased from 65 percent to 79 percent.

Reasons for Adoption Trends:

- Plug flow and complete mix digesters provide greater potential to generate electricity than covered anaerobic lagoon digesters, and thus may be a more popular option in States that have renewable energy portfolio standards or other renewable energy incentives.
- Adoption of State renewable energy portfolio standards can increase the adoption of anaerobic digesters, as was seen in Pennsylvania, Wisconsin, and New York (Sam, 2017; Simmons, 2016; Wheeler, 2015; NYSERDA, 2016).
- In Vermont, the Green Mountain Power Renewable Development Fund provided farmers financial incentives for anaerobic digesters (EPA, 2016a).
- Growth in the number of digesters may be attributable to demonstrated production and reliability, State and Federal funding programs, energy utility interest, and revenue potential (Zaks, 2011).

Application

Data on the adoption of anaerobic digesters analyzed in this report were collected from the AgSTAR Database of Livestock Digesters (EPA, 2018). AgSTAR is a voluntary effort sponsored by the U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), and the U.S. Department of Energy (DOE), which encourages the use of biogas capture and use at animal feeding operations that manage manure (EPA, 2004). Data for each digester that began operation between 2004 and 2017 were collected by operating year, State, population number feeding digesters (used to determine farm size), and type of animal feeding the digester.

The data are represented in three ways: (1) number of digesters by digester type, (2) number of digesters by farm size, and (3) number of digesters by USDA farm production region.

Digester Adoption between 2004 and 2017

Between 2004 and 2017, the number of operational digesters increased at an average annual rate of 11 percent, increasing from 63 in 2004 to 248 in 2017. The largest number of new installations occurred in 2008, with 34 new digesters coming online. Wisconsin, New York, Pennsylvania, and Vermont accounted for nearly 50 percent of newly installed digesters that came online during this time period (EPA, AgSTAR Livestock Anaerobic Digester Database, 2018). Wisconsin, New York, and Pennsylvania had renewable energy portfolio standards that were signed into law in the 2004 to 2006 timeframe, which may have encouraged the development of anaerobic digesters in each State (NYSERDA, 2018; Wisconsin Public Service, 2018; Pennsylvania General Assembly, 2004). Similarly, Vermont's Clean Energy Development Fund, established in 2005, may have encouraged digester development during this timeframe.

Between 2004 and 2017, 37 digesters were initiated but have since shut down. These digesters went out of operation due to bankruptcies declared by the operation (not necessarily related to the digester), operational challenges, or loss of staff to continue maintenance.

The number of new digesters coming online decreased significantly after 2013, with fewer than 10 digesters coming online annually between 2014 and 2017. Market trends during this time period may have impacted the adoption of digesters.[24]

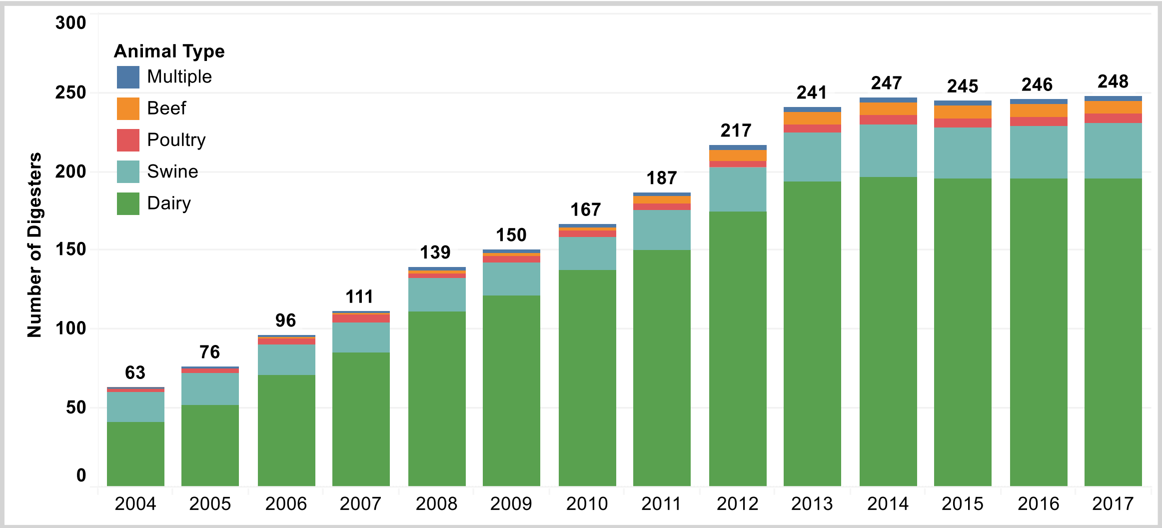
Digester Adoption by Animal Type and Farm Size

Between 2004 and 2017, the majority of operational digesters were fed by dairy cattle manure (FIGURE 31). According to the EPA AgStar database, the operational digesters in 2017 managed manure from approximately 458,000 dairy cattle (i.e., approximately 4.9 percent of the total dairy cattle population) (EPA, 2018) (USDA NASS, 2018). Of this total, approximately 35 percent of dairy cattle manure managed with an anaerobic digester is from New York, Pennsylvania, Wisconsin, or Vermont. Another 27 percent of total dairy cattle manure managed by an aerobic digester is from cattle in the Pacific region (California, Washington, and Oregon). Sixty-five percent of the dairy anaerobic digesters were installed on operations with 1,000 head of dairy cattle or more (FIGURE 32).

Eight digesters installed between 2004 and 2017 manage manure from beef cattle. Beef cattle are kept generally on pastures or feedlots, where manure collection is more challenging than collection from dairy farms. All beef digesters are located on operations with 2,500 head of cattle or more. Six digesters were installed on poultry farms in the same time period, with animal populations ranging from 84,000 to 600,000.

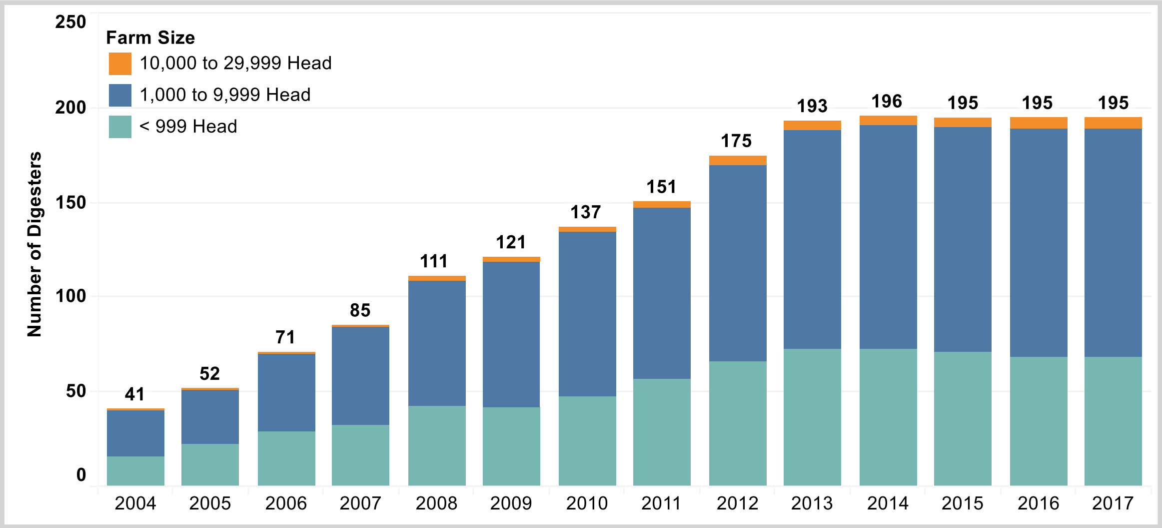
[24] Natural gas electric power prices experienced a sharp and sustained price drop beginning in 2009, which may have impacted new digester systems coming online. Alternatively, the generation costs associated with solar photovoltaic systems fell by 65 percent between 2010 and 2017, which may have made the technology more attractive to farmers than digesters. The information on natural gas prices was obtained from (U.S. EIA, 2018) and the information on solar PV generation costs is from (Fu, Feldman, Margolis, Woodhouse, & Ardani, 2017).

FIGURE 31. Number of Operational Digesters by Animal Type and by Year



Graph showing the number of operational digesters by animal type from 2004 to 2017. Each color within a bar represents a different animal type. Digesters that were reported as under construction were omitted. In cases where systems are no longer operational but the closure date is not provided, ICF conservatively assumed that the digester went offline in the same year. Source: (EPA, 2018)

FIGURE 32. Number of Operational Dairy Digesters by Farm Size

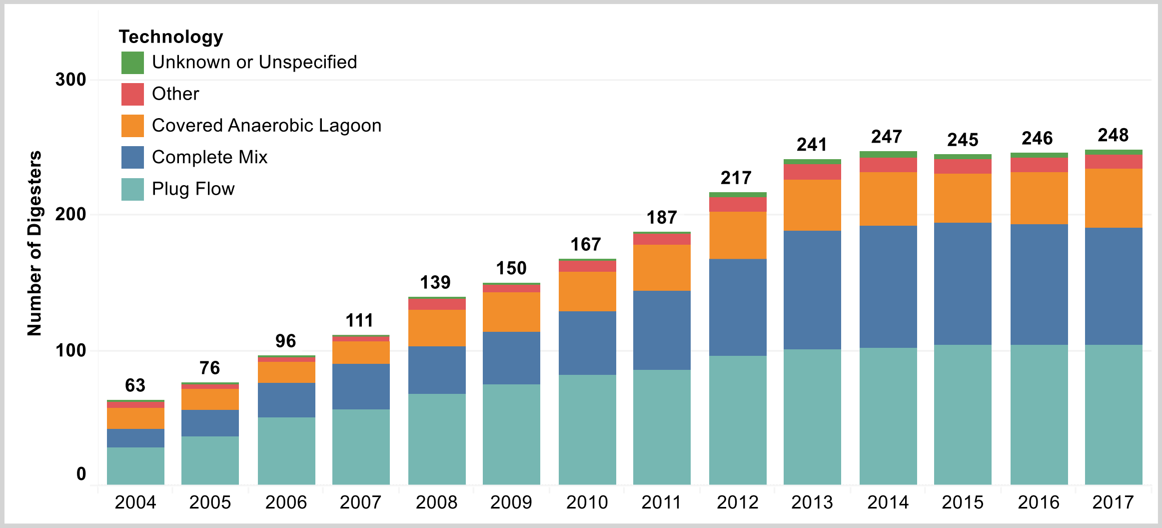


Graph showing the number of operational dairy digesters between 2004 and 2017 by farm size. Each color within a bar represents a different farm size. Digesters that were reported as under construction were omitted. In cases where systems are no longer operational, but the closure date is not provided, ICF conservatively assumed that the digester went offline in the same year. Source: (EPA, 2018)

Digester Types

FIGURE 33 presents the distribution of digesters by technology. In 2017, the majority of operational digesters were complete mix digesters (35 percent of digesters) and plug flow digesters (42 percent of digesters). Although the absolute number of plug flow digesters was higher, the rate of increase for complete mix digesters was higher, growing 15 percent annually compared to 11 percent over the 13-year period. The number of operational covered anaerobic lagoons increased at an annual rate of 8 percent between 2004 and 2017, increasing from 15 to 43 covered lagoons during this time period. Covered anaerobic lagoons represent 17 percent of all mitigation technologies installed and registered by AgStar. The type of technology used for the remainder of AgStar projects was either unknown or uncommon (e.g., fixed film technology).

FIGURE 33. Number of Operational Digesters by Technology and by Year

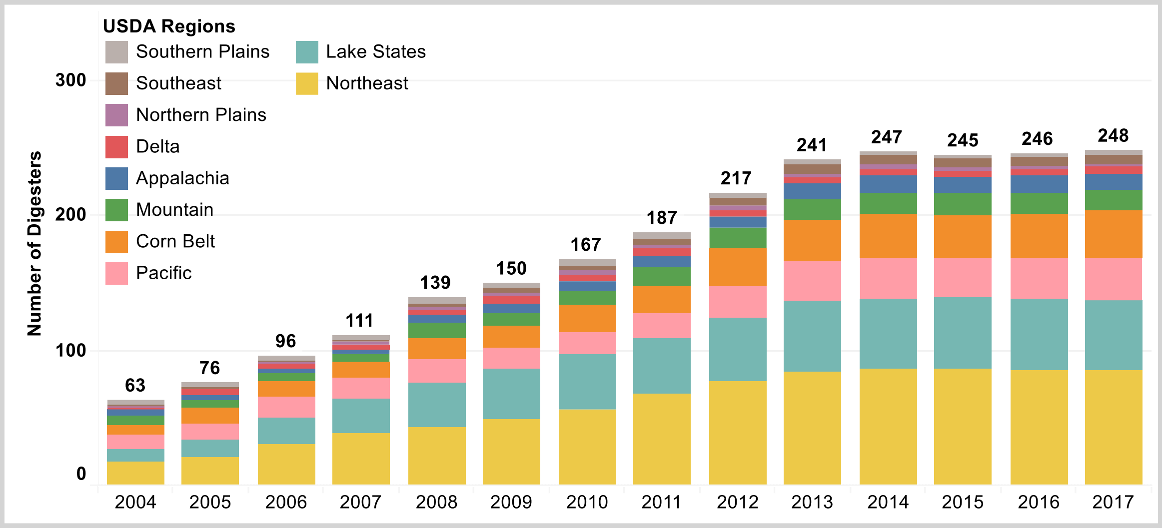


Graph showing the cumulative number of digesters in operation between 2004 and 2017 by type of digester. Each color within a bar represents a different technology. Digesters that were reported as under construction were omitted. In cases where systems are no longer operational, but the closure date is not provided, ICF conservatively assumed that the digester went offline in the same year. Source: (EPA, 2018)

Digesters by USDA Farm Production Region

Approximately one-third of all digesters are located in the Northeast region, which includes New York, Pennsylvania, Vermont, New Hampshire, Maine, Maryland, Rhode Island, Massachusetts, Delaware, Connecticut, and New Jersey. Between 2004 and 2017, 68 digesters came online in the Northeast, the most of any region. The Lake States, driven by strong representation by Wisconsin, has the second largest number of digesters, with approximately 21 percent of all operational digesters at the end of 2017. The Northern Plains and Southern had the fewest number of operational digesters in the country, with two and three digesters in 2017, respectively. FIGURE 34 presents the distribution of operational digesters by USDA production region.

FIGURE 34. Number of Operational Digesters by USDA Farm Production Region



The graph shows the cumulative number of digesters that were operational between 2004 and 2017 by USDA region. Each color within a bar represents a different USDA region. Digesters that were reported as under construction were omitted. In cases where systems are no longer operational, but the closure date is not provided, ICF conservatively assumed that the digester went offline in the same year. Source: (EPA, 2018)

Observed Trends

Overall, 256 digesters were installed from 2004 to 2017.[25] However, the rate of increase in both the number of new digesters and the population feeding digesters has declined since 2013.

The growth in the number of new digesters in operation has mostly come from dairy operations (155 new digesters), while the number of new digesters in operation fed by swine increased by 16 from in 2004 to 2017, new digesters in operation fed by beef cattle increased by eight, new digesters in operation fed by poultry increased by three, and new digesters in operation fed by multiple animal types increased by three. The population of animals feeding digesters has grown along with the increase in the total number of operational digesters. The number of digesters in operation has grown the most in the Northeast region since 2004 and the least in the Northern and Southern Plains.

[25] This count includes digesters that came online and went offline within this 13-year span.

SUMMARY AND CONCLUSIONS

This report was developed to evaluate U.S. adoption of selected agricultural conservation practices that both reduce GHG emissions and provide additional environmental benefits between 2004 and 2016 (see

TABLE 1 for a full list of practices). By conducting a literature search to find data for the practices of interest, USDA established where further research is required to fill data gaps for some practices, and, where data are available, set baselines and established processes for tracking progress on further adoption rates. By identifying current adoption rates and trends of adoption at the regional and national levels, USDA and other farming- and food-related entities can better understand farmers' actions today and develop strategies to increase future adoption of these practices.

Results from the literature search indicated that the desired granularity of data was not available for most of the agricultural practices or categories listed in

TABLE 1. For example, limited data on the use of enhanced efficiency fertilizers were available at the national level, and there were no data that covered all States in the United States for multiple years.

Practices Included in the Report

The practices for which enough data were found to either determine a change in practice over time or establish a baseline of current practice are:

Cropland

- Nitrogen application
- Enhanced efficiency fertilizers
- Precision agriculture (VRT and auto steering)
- Use of cover crops
- Reduced tillage (mulch till and no till)

Recovery and Use of Biogas From Anaerobic Digesters for Manure Management

- Anaerobic digesters

Summary of Cropland Data

Adoption of the conservation practices on working lands reviewed in this report is variable. Continued data collection on these practices will allow for more robust analyses in the future.

Practices that increased over time include precision agriculture and use of cover crops. For example, use of precision agriculture (VRT and auto steer) increased over time for all crops for which there are data. Specifically, VRT use increased from 5 percent in 2005 to 28 percent in 2016 for corn, and from 7 percent in 2004 to 11 percent in 2009 for wheat. Auto steer increased from 15 percent in 2005 to 54 percent in 2016 for corn, from 20 percent in 2006 to 45 percent in 2012 in soybeans, and from 16 percent in 2004 to 42 percent in 2009 in wheat, based on ARMS data. Despite the increases in use, the overall relatively low percent of adoption of these technologies shows that there is opportunity for substantial increases in adoption.

The data for cover crops showed increased use over time, but overall had very low adoption rates. Cover crops were grown on approximately 2 percent of farmland acres in 2010, and 4 percent of farmland acres in 2015 (including for both crop and livestock production).

Trends in the use of reduced tillage varied by specific crop and tillage type. The proportion of acres grown using no tillage showed the greatest increase for wheat (from 22 percent in 2004 to 41 percent in 2009), increased slightly for corn (from 29 percent in 2005 to 33 percent in 2016) and decreased slightly for soybeans (at 47 percent in 2006 and 44 percent in 2012) based on ARMS data.

While there were no ARMS trend data for all cropland acres combined, the CEAP data show that more acres of crops were grown under continuous no tillage or mulch tillage rotations than seasonal no tillage or mulch tillage rotations for the 2003 to 2006 timespan. While the data indicate that the majority of farmers are using reduced tillage practices, a further shift from seasonal practices to continuous practices would result in additional soil and climate benefits (Abdalla, Chivenge, Ciais, & Chaplot, 2016). Once released, the next series of CEAP data will allow for a more nuanced analysis of tillage trends.

Nitrogen management practices are complex and can be analyzed a variety of ways. In this report, we presented the data as fertilizer rate (pounds per treated acre) and fertilizer per yield (pounds per bushel). For corn, the total amount of nitrogen applied increased from approximately 9.23×10^{9} pounds in 2005 to 1.1×10^{10} pounds in 2016, but the average pounds of nitrogen per bushel decreased slightly from 0.84 in 2005 to 0.77 in 2016 based on ARMS data. This means that while the absolute amount of nitrogen applied increased, the amount applied per yield decreased. For wheat, both total nitrogen applied and the national average pounds of nitrogen/bushel decreased slightly from approximately 3.55×10^{9} pounds (1.40 pounds/bushel) in 2004 to 3.36×10^{9} pounds (1.34 pounds/bushel) in 2009. Soybeans had the largest increase in total nitrogen applied nationally (60 percent). The increase in applied nitrogen, from approximately 2.17×10^{8} pounds in 2006 to 3.45×10^{8} pounds in 2012, was due to an increase in applied acres from 18 percent in 2006 to 27 percent in 2012. The national average pounds of nitrogen per bushel for soybeans decreased slightly from 0.39 in 2006 to 0.37 in 2012. The cause of the increase in applied acres could be due to newer production practices which encourage nitrogen fertilization to increase soybean yield (La Menza, Monzon, Specht, & Grassini, 2017; Mourtzinis, et al., 2018).

In terms of nitrogen application timing and method for corn production, results were mixed based on analysis of the ARMS data. The timing of nitrogen application was relatively constant from 2005 to 2016, with most (around 80 percent) applied in the spring, at or after planting. The percentage of total nitrogen applied with incorporation has decreased over time from 81 percent in 2005 to 79 percent in 2010 to 77 percent in 2016. Improved nitrogen application timing could be the result of multiple public and private partnerships working to improve plant Nitrogen Use Efficiency (including through 4R partnerships), which includes improved fertilizer timing and application methods (IPNI, 2017; The Fertilizer Institute, 2017; TNC, 2017; USDA NRCS, 2011).

Lack of sufficient data meant that many desired practices could not be included in this report, that national or regional trends could not be determined, that trends in that some practices could not be included for all crops, and for numerous practices, some years could not be included. While the CEAP data allowed for a detailed understanding of tillage during a multi-year crop rotation, access to additional multi-year rotations is required to determine trends in these practices.

Summary of Anaerobic Digester Data

Overall, the cumulative number of digesters in operation and the cumulative number of animals feeding those digesters has increased from 2004 to 2017, however the rate of increase slowed between 2013 to 2017 compared to the rate from 2005 to 2013 (EPA, 2018)

- The total number of digesters in the United States increased from 63 in 2004 to 248 in 2017.
- Complete mix (35 percent) and plug flow digesters (42 percent) are the two most common types of anaerobic digesters built between 2004 and 2017.
- The Northeast region had the greatest increase in the number of digesters with 68 new digesters coming online from 2004 to 2017.
- Most digesters were fed by dairy cow manure (196 out of 248 operational digesters in 2017).
- The increase in adoption of digesters was likely in part due to the adoption of State renewable energy portfolio standards in Pennsylvania, Wisconsin, and New York (Sam, 2017; Simmons, 2016; Wheeler, 2015; NYSERDA, 2016).
- Growth in the number of digesters may also be attributable to demonstrated production and reliability, State and Federal funding programs, energy utility interest, and revenue potential (Zaks, 2011).

Next Steps

The data collected in this report are a first attempt to aggregate publicly available data and determine baselines and adoption trends for the selected practices in Table 2. As stated previously, publicly available data are insufficient to determine baselines or track adoption trends for the following practices:

- Erosion control measures
- Double cropping
- Enhanced efficiency fertilizers
- Compost additions
- Manure additions
- Slow-release fertilizers
- Nitrogen use efficiency

- Tree planting on sensitive lands
- Water table management on sensitive lands
- Re-flooding of set-aside lands on sensitive lands
- Management of hydric soils on sensitive lands
- Percentage of livestock managed by each manure management system (by State, livestock type)
- Methane capture
- Land application of manure
- Per unit GHG intensity of manure

To determine baselines and adoption trends for these missing practices, new survey questions or research projects will need to be initiated to collect data over time.

For the conservation practices reviewed in this report, continued collection of data or enhanced/improved collection of data will further the understanding of adoption of these practices over time. Areas where data collection could be improved include:

- Enhanced efficiency fertilizer uses in corn, soy, and wheat (improved data for corn and data for soy and wheat)
- VRT use in corn, soy, and wheat (improved data in corn and wheat and data in soy)
- Auto steer in corn (improved data)
- Cover crop use in all crops (improved data)
- No till use in wheat (improved data)
- Reduced tillage in all agriculture (additional data points)

Further analysis of the data collected in this report may also lead to a better understanding of areas where conservation performance could be improved.

WORKS CITED

AAPFCO. (2013). *Official publication number 65.* Association of American Plant Food Control Officials. Retrieved from http://www.aapfco.org/publications.html

Abdalla, K., Chivenge, P., Ciais, P., & Chaplot, V. (2016, June 21). No-Tillage Lessens Soil CO2 Emissions the Most Under Arid and Sandy Soil Conditions: Results from a Meta-Analysis. *Biogeosciences, 13*, 3619-3633. doi:10.5194/bg-13-3619-2016

Aillery, M., Gollehon, N., Johansson, R., Kaplan, J., Key, N., & Rihaudo, M. (2005). Managing manure to improve air and water quality. *Agricultural Economics Report, 6*, 65.

Arbuckle, J., & Rossman, H. (2014). *Iowa Farmers' Nitrogen Management Practices and Perspectives.* Iowa State University. Retrieved from http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1026&context=extension_communities_pubs

Balafoutis, A., Koundouras, S., Anastasiou, E., Fountas, S., & Arvanitis, K. (2017). Life Cycle Assessment of Two Vineyards after the Application of Precision Viticulture Techniques: A Case Study. *Sustainability, 9*(11).

Bierman, P., Rosen, C., Venterea, R., & Lamb, J. (2011). *Survey of Nitrogen Fertilizer Use on Corn in Minnesota.* Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27883_W_2010_Corn_Phase2_Questionnaire_Production_Practices_And_Costs_Q_COP_CPP.pdf?v=40877

Boyle, K. P. (2006). *The Economics of On-site Conservation Tillage.* Portland, OR: West National Technology Support Center. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/nrcs143_009593.doc

Butchee, K., May, J., & Arnall, B. (2011). Sensor based nitrogen management reduced nitrogen and managed yield. *Crop Management, 10*(1).

Carlisle, L. (2016). Factors influencing farmer adoption of soil health practices in the United States: a narrative review. *Agroecology and Sustainable Food Systems, 40*(6), 583-613. Retrieved from https://www.tandfonline.com/doi/full/10.1080/21683565.2016.1156596

Cavigelli, M., Del Grosso, S., Liebig, M., & al., e. (2012). US Agricultural Nitrous Oxide Emissions: Context, Status, and Trends. *Frontiers in Ecology and the Environment, 10*, 537-546.

Clark, A. (2012). *Managing Cover Crops Profitably.* Sustainable Agriculture Research and Education (SARE). Retrieved from http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

Congress of the United States. (1996). Federal Agriculture Improvement and Reform Act . *Public Law 104-127*. Retrieved from https://www.congress.gov/104/plaws/publ127/PLAW-104publ127.pdf

Congress of the United States. (2002). Farm Security and Rural Investment Act of 2002. *Public Law 107-171*. Retrieved from https://www.gpo.gov/fdsys/pkg/PLAW-107publ171/pdf/PLAW-107publ171.pdf

Congress of the United States. (2008). Food, Conservation, and Energy Act of 2008. *Public Law 110-246*. Retrieved from https://www.agriculture.senate.gov/imo/media/doc/pl110-246.pdf

Congress of the United States. (2014). Agricultural Act of 2014. *H.R. 2542*. Retrieved from https://www.gpo.gov/fdsys/pkg/BILLS-113hr2642enr/pdf/BILLS-113hr2642enr.pdf

CTIC. (2013). *2012-13 Cover Crop Survey.* Conservation Technology Information Center (CTIC), Conservation Technology Information Center. Sustainable Agriculture Research & Education. Retrieved from http://www.ctic.org/media/pdf/Cover%20Crops/SARE-CTIC%20Cover%20Crop%20Survey%202013.pdf

CTIC. (2014). *2013-14 Cover Crop Survey.* Joint publication of the Conservation Technology Information Center and the North Central Region Sustainable Agriculture Research and Education Program. Retrieved from http://www.ctic.org/media/CoverCrops/CTIC_04_Cover_Crops_report.pdf

CTIC. (2015). *2014-15 Cover Crop Survey.* Conservation Technology Information Center. Joint publication of the Conservation Technology Information Center and the North Central Region Sustainable Agriculture Research & Education Program. Retrieved from http://www.ctic.org/media/pdf/20142015CoverCropReport_Draft6.pdf

CTIC. (2016). *2015-16 Cover Crop Survey.* Conservation Technology Information Center. Joint publication of the Conservation Technology Information Center and the North Central Region Sustainable Agriculture Research and Education Program. Retrieved from http://www.ctic.org/media/CoverCrops/2016CoverCropSurvey_Final.pdf

Eagle, A. J., Olander, L. P., Henry, L. R., Haugen-Kozyra, K., Millar, N., & Robertson, G. P. (2012). *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature.* Durham, NC: Nicholas Institute Environmental Policy Solutions. Retrieved from https://nicholasinstitute.duke.edu/sites/default/files/publications/ni_r_10-04_3rd_edition.pdf

EPA. (2004). *AgSTAR Handbook – A Manual For Developing Biogas Systems at Commercial Farms in the U.S.* EPA.

EPA. (2016a). *Improving Project Outcomes & Growing the Anaerobic Digestion Industry.* Washington, D.C.: EPA.

EPA. (2016b). *U.S. Greenhouse Gas Emissions and Sinks: 1990-2014 - Annex 3, Part B.* Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/production/files/2016-04/documents/us-ghg-inventory-2016-annex-3-additional-source-or-sink-categories-part-b.pdf

EPA. (2017b). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015.* United States Environmental Protection Agency. Retrieved from https://www.epa.gov/sites/production/files/2017-02/documents/2017_complete_report.pdf

EPA. (2018, April). AgSTAR Livestock Anaerobic Digester Database. Washington, D.C., U.S.

Eve, M., Pape, D., Flugge, M., Steele, R., Man, D., Riley-Gilbert, M., & Biggar, S. (2014). *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory.* Washington, DC: Office of the Chief Economist, U.S. Department of Agriculture.

Fu, R., Feldman, D., Margolis, R., Woodhouse, M., & Ardani, K. (2017). *U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017.* Golden, CO: National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/docs/fy17osti/68925.pdf

Grandy, A. S. (2006). Do productivity and environmental trade-offs justify periodically cultivating no-till cropping systems? *Agronomy Journal, 98(6)* , 1377-1383.

Hauck, R. (1990). Agronomic and Public Aspects of Soil Nitrogen Research. *Soil Use and Management, 6*(2), 66-70.

ICF International. (2013). *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States.* Washington, DC. Retrieved from https://www.usda.gov/oce/climate_change/mitigation_technologies/GHG_Mitigation_Options.pdf

ICF International. (2016). *Managing Agricultural Land for Greenhouse Gas Mitigation within the United States.* Report prepared for USDA, Climate Change Program Office.

IPNI. (2017). *4 Nutrient Stewardship*. Retrieved from International Plant Nutrition Institute: http://www.ipni.net/4R

Johnson, R. (2011). *The Nitrogen Cycle.* Boise, Idaho: United States Department of Agriculture. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_046108.pdf

La Menza, N., Monzon, J., Specht, J., & Grassini, P. (2017). Is soybean yield limited by nitrogen supply? *Field Crops Research, 213*, 204-212.

Millar, N., Robertson, G., Grace, P., Gehl, R., & Hoben, J. (2010). Nitrogen Fertilizer Management for Nitrous Oxide (N2O) Mitigation in Intensive Corn (Maize) Production: An Emissions Reduction Protocol for US Midwest Agriculture. *Mitigation and Adaptation Strategies for Global Change, 15*(2), 185-204.

Mitchell, P. D., & Moore, V. (2014). Economics of Cover Crops. *Wisconsin Cover Crops Conference.* Madison, WI. Retrieved from http://www.aae.wisc.edu/pdmitchell/Production/EconomicsCoverCrops.pdf

Mourtzinis, S., Kaur, G., Orlowski, J. M., Shapiro, C. A., Lee, C. D., Wortmann, C., . . . Conley, S. P. (2018). Soybean response to nitrogen application across the United States: A synthesis-analysis. *Field Crops Research, 215*, 74-82. Retrieved from https://www.sciencedirect.com/science/article/pii/S037842901731033X

Naidoo, R., Balmford, A., Ferraro, P. J., Polasky, S., Ricketts, T. H., & Rouget, M. (2006). Integrating economic costs into conservation planning. *Trends in Ecology and Evolution, 21*(12). Retrieved from http://www.uvm.edu/giee/pubpdfs/Naidoo_2006_TRENDS_in_Ecology_and_Evolution.pdf

NRCS, NHCP. (2012). *Natural Resources Conservation Services Conservation Practice Standard Nutrient Management.* Code 590. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046433.pdf

NYSERDA. (2016). *New York State Renewable Portfolio Standard Annual Performance Report through December 31, 2015.* Albany, NY: New York State Energy Research and Development Authority.

NYSERDA. (2018). *Renwable Portfolio Standard.* Retrieved 07 18, 2018, from Clean Energy Standard: https://www.nyserda.ny.gov/All-Programs/Programs/Clean-Energy-Standard/Renewable-Portfolio-Standard

Olson, K. R., Al-Kaisi, M., Lal, R., & Lowery, B. (2014). Examining the paired comparison method approach for determining soil organic carbon sequestration rates. *Journal of Soil and Water Conservation, 69*(6), 193A-197A.

Osteen, C., Gottlieb, J., & Vasavada (eds.), U. (2012). *Agricultural Resources and Environmental Indicators, 2012 Edition.* Economic Information Bulletin Number 98, Economic Research Service, United States Department of Agriculture. Retrieved from http://ageconsearch.umn.edu/record/132048/files/EIB98.pdf

Pape, D. J.-G. (2016). *Managing Agricultural Land for Greenhouse Gas Mitigation within the United States. Report prepared by ICF International under USDA Contract No. AG-3144-D-1.* USDA.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G., & Smith, P. (2016). Climate-Smart Soils. *Nature, 532*(7597), 49-57.

Pennsylvania General Assembly. (2004). *Alternative Energy Portfolio Standards Act - Enactment.* 2004 Act 213. Retrieved from http://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2004&sessInd=0&act=213

Ribaudo, M., Delgado, J., Hansen, L., Livingston, M., Mosheim, R., & Williamson, J. (2011). *Nitrogen In Agricultural Systems: Implications for Conservation Policy.* United States Department of Agriculture Economic Research Service.

Robertson, G., Bruulsema, T., Gehl, R., Kanter, D., Mauzerall, D., Rotz, C., & Williams, C. (2013). Nitrogen-Climate Interactions in US Agriculture. *Biogeochemistry, 114*(1-3), 41-70.

Sam, A. B. (2017). How Incentives Affect the Adoption of Anaerobic Digesters in the United States. *Sustainability*, 11-12.

Schahczenski, J. (2014). *Federal Conservation Resources for Sustainable Farming.* NCAT. Retrieved from https://attra.ncat.org/attra-pub/download.php?id=280

Schimmelpfennig, D. (2016a). *Precision Agriculture Technologies and Factors Affecting Their Adoption*. Retrieved 2017, from https://www.ers.usda.gov/amber-waves/2016/december/precision-agriculture-technologies-and-factors-affecting-their-adoption/

Schimmelpfennig, D. (2016b). *Farm Profits and Adoption of Precision Agriculture, ER-217.* USDA, ERS. Retrieved from https://www.ers.usda.gov/amber-waves/2016/december/precision-agriculture-technologies-and-factors-affecting-their-adoption/

Simmons, R. T. (2016). *Renewable Portfolio Standards: Pennsylvania.* Logan, UT: Institute of Political Economy, Utah State University.

Smith, P., Martino, D., Cai, Z., & Gwary, D. (2007). Chapter 8: Agriculture in Climate Change 2007: Mitigation. *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*.

Snyder, C. (2016). Reducing Nitrogen Losses from Fields with the 4Rs: A Focus on Nitrous Oxide Emissions. *Nitrogen Program Director*. Conway, Arkansas, USA: International Plant Nutrition Institute.

Snyder, C., & Fixen, P. (2012). Plant Nutrient Management and Risks of Nitrous Oxide Emission. *J Soil Water Conserv, 67*, 137A-144A.

Stavi, I. L. (2011). On-farm effects of no-till versus occasional tillage on soil quality and crop yields in eastern Ohio. *Agronomy for sustainable development, 31(3),*, 475-482.

Stubbs, M. (2016). *Emergency Assistance for Agricultural Land Rehabilitation.* Congressional Research Service. Retrieved from http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R42854.pdf

Stute, J. (2013). *Cover Crop Economics: The green behind the green.* UW Extension. Retrieved from http://fyi.uwex.edu/sustag/files/2013/02/Economics-of-Cover-Crops.pdf

Swinton, S., Rector, N., Robertson, G., Jolejole-Foreman, C., & Lupi, F. (2015). Farmer decisions about adopting environmentally beneficial practices. In S. Hamilton, J. Doll, & G. Robertson, *The Ecology of Agricultural Landscapes: Long-Term Research on the Path to Sustainability* (pp. 340-359). New York, NY: Oxford University Press.

Taylor, C. (2015, January 21). Cover Crops Provide Multiple Benefits, Higher Yields. *National Resources Conservation Service*. Retrieved September 11, 2017, from https://www.usda.gov/media/blog/2015/01/21/cover-crops-provide-multiple-benefits-higher-yields

The Fertilizer Institute. (2017). *What are the 4Rs*? (T. F. Institute, Producer) Retrieved from 4 Nutrient Stewardship: http://www.nutrientstewardship.com/4rs/

TNC. (2017). *Western Lake Erie Basin. Working with Agriculture: the 4Rs of Nutrient Stewardship*. Retrieved from The Nature Conservancy: https://www.nature.org/ourinitiatives/regions/northamerica/areas/greatlakes/explore/nutrient-stewardship-4rs.xml

U.S. EIA. (2018). *U.S. Price of Natural Gas Sold to Commercial Consumers.* U.S. Energy Information Administration. Retrieved from https://www.eia.gov/dnav/ng/hist/n3020us3a.htm

USDA. (2011b). *USDA Consensus Statement*. (O. Economist, Producer) Retrieved from United States Department of Agriculture: https://www.usda.gov/oce/sustainable/definitions.htm

USDA. (2014). *Farms and Farmland: Numbers, Acreage, Ownership, and Use.* 2012 Census of Agriculture. U.S. Department of Agriculture. Retrieved from https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Highlights/Farms_and_Farmland/Highlights_Farms_and_Farmland.pdf

USDA. (2016). *USDA Building Blocks for Climate Smart Agriculture and Forestry: Implementation Plan and Progress Report.* U.S. Department of Agriculture. Retrieved from https://www.usda.gov/sites/default/files/documents/building-blocks-implementation-plan-progress-report.pdf

USDA. (2017). *Conservation*. Retrieved August 31, 2017, from https://www.usda.gov/topics/conservation

USDA. (2018). *Conservation*. Retrieved September 18, 2018, from https://www.usda.gov/topics/conservation

USDA. (2018, 05 04). *Surveys*. Retrieved from Agricultural Resource Management (ARMS): https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Ag_Resource_Management/index2.php

USDA CEAP. (2011). *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region.* Conservation Effects Assessment Project (CEAP). Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042076.pdf

USDA CEAP. (2017a). *Conservation Effects Assessment Project.* United States Department of Agriculture Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/#

USDA CRP. (2017a). *Conservation Reserve Program*. Retrieved from United States Department of Agriculture: Farm Service Agency: https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index

USDA ERS. (2004a). *Durum Wheat Production Practices and Costs Report.* Agricultural Resource Management Survey, U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27986_w_5e2004_5edurum_20wheat_5ephase2_20questionnaire_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2004b). *Spring Wheat Production Practices and Costs Report.* Agricultural Resource Management Survey, U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27990_w_5e2004_5espring_20wheat_5ephase2_20questionnaire_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2004c). *Winter Wheat Production Practices and Costs Report.* Agricultural Resource Management Survey, U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27992_w_5e2004_5ewinter_20wheat_5ephase2_20questionnaire_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2005). *Corn Production Practices and Costs Report.* Agricultural Resource Management Survey (ARMS), U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27972_w_5e2005_5ecorn_5ephase2_20questionnaire_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2006). *Soybean Production Practices and Costs Report.* Agricultural Resource Management Survey (ARMS), U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27960_w_5e2006_5esoybeans_5ephase2_20questionnaire_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2009a). *Durum Wheat Production Practices and Costs Report.* Agricultural Resource Management Survey, U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27901_w_5e2009_5edurum_20wheat_5ephase2_20questionnaire_20production_20practices_20__20costs_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2009b). *Spring Wheat Production Practices and Costs Report.* Agricultural Resource Management Survey, U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27906_w_5e2009_5espring_20wheat_5ephase2_20questionnaire_20production_20practices_20__20costs_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2009c). *Winter Wheat Production Practices and Costs Report.* Agricultural Resource Management Survey, U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27908_w_5e2009_5ewinter_20wheat_5ephase2_20questionnaire_20production_20practices_20__20costs_5eq_5ecop_cpp_1_.pdf?v=40877

USDA ERS. (2010a). *Agricultural Resource Management Survey: Costs and Returns Report.* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27878_W_2010_CRR_Phase3_Questionnaire_Q_FOH.pdf?v=40877

USDA ERS. (2010b). *Corn Production Practices and Costs Report.* Agricultural Resource Management Survey (ARMS), United States Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/27883_W_2010_Corn_Phase2_Questionnaire_Production_Practices_And_Costs_Q_COP_CPP.pdf?v=40877

USDA ERS. (2011). *Agricultural Resource Management Survey: Costs and Returns Report.* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/33836_W_2011_CRR_Phase3_Questionnaire_Q_FOH.pdf?v=41241

USDA ERS. (2012a). *Agricultural Resource Management Survey: Costs and Returns Report.* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/33795_W_2012_CRR_Phase3_Questionnaire_Q_FOH.pdf?v=41241

USDA ERS. (2012b). *Soybean Production Practices and Costs Report.* Agricultural Resource Management Survey (ARMS), U.S. Department of Agriculture. Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/33801_W_2012_Soybean_Phase2_Questionnaire_Production_Practices_And_Costs_Q_COP_CPP.pdf?v=41740

USDA ERS. (2015). *Agricultural Resource Management Survey: Costs and Returns Report.* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/52816/54266_W_2015_CRR_Phase3_Questionnaire_Q_FOH.pdf?v=42299

USDA ERS. (2016a). *Corn Production Practices and Costs Report for 2016.* Agricultural Resource Management Survey (ARMS), U.S. Department of Agriculture. St. Louis, MO: National Agricultural Statistics Service. Retrieved from https://www.ers.usda.gov/webdocs/DataFiles/83637/W%5E2016%5ECorn%5EPhase2%20Questionnaire%20Production%20Practices_Costs%5EQ%5ECOP_CPP.pdf?v=42877

USDA ERS. (2016c). *Chemical Inputs Overview.* United States Department of Agriculture Economic Research Service. Retrieved from https://www.ers.usda.gov/topics/farm-practices-management/chemical-inputs/

USDA ERS. (2016d, October 12). *Nutrient Management*. Retrieved September 10, 2017, from U.S. Department of Agriculture, Economic Research Service: https://www.ers.usda.gov/topics/farm-practices-management/crop-livestock-practices/nutrient-management/

USDA ERS. (2017a). *Agricultural Resource Management Survey (ARMS) Tailored Reports: Crop Production Practices*, Nutrient Use and Management, Corn. Retrieved from United States Department of Agriculture Economic Research Services: https://data.ers.usda.gov/reports.aspx?ID=17883

USDA ERS. (2017b, July 26). *Background*. Retrieved from United States Department of Agriculture Economic Research Service: https://www.ers.usda.gov/topics/crops/soybeans-oil-crops/background/

USDA ERS. (2017c). *Corn and Other Feed Grains: Overview*. Retrieved from United States Department of Agriculture Economic Research Service: https://www.ers.usda.gov/topics/crops/corn/

USDA ERS. (2017d). *Overview*. Retrieved from United States Department of Agriculture Economic Research Service: https://www.ers.usda.gov/topics/crops/wheat/

USDA ERS. (2017e, April). *Soil Tillage and Crop Rotation*. Retrieved 2017, from https://www.ers.usda.gov/topics/farm-practices-management/crop-livestock-practices/soil-tillage-and-crop-rotation/

USDA FS. (2017). *Conservation Education: Programs*. Retrieved August 31, 2017, from https://www.fs.usda.gov/main/conservationeducation/programs

USDA FSA. (2017a). *Conservation Programs*. Retrieved August 31, 2017, from https://www.fsa.usda.gov/programs-and-services/conservation-programs/

USDA NASS. (2018, May 4). *Statistics by Subject*. Retrieved from National Agricultural Statitstics Service: https://www.nass.usda.gov/Statistics_by_Subject/result.php?551C6376-6206-3DB1-A353-92605E21EAE3&sector=ANIMALS%20%26%20PRODUCTS&group=LIVESTOCK&comm=CATTLE

USDA NIFA. (2017). *Adoption of Precision Agriculture*. (U. D. Agriculture, Producer, & National Institute of Food and Agriculture) Retrieved August 28, 2017, from Precision, Geospatial & Sensor Technologies Programs: https://nifa.usda.gov/adoption-precision-agriculture

USDA NRCS. (2003). *Conservation Effects Assessment Project (CEAP).* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_013508.pdf

USDA NRCS. (2004). *Conservation Effects Assessment Project (CEAP).* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_013394.pdf

USDA NRCS. (2005). *Conservation Effects Assessment Project (CEAP).* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1041940.pdf

USDA NRCS. (2006). *Conservation Effects Assessment Project (CEAP).* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1041938.pdf

USDA NRCS. (2006). *Soil Tillage Intensity Rating (STIR).* Minnesota: Natural Resources Conservation Service United States Department of Agriculture. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022735.pdf

USDA NRCS. (2007). *Precision Agriculture: NRCS Support for Emerging Technologies.* United States Department of Agriculture, Natural Resources Conservation Service. Greensboro, NC: United States Department of Agriculture Natural Resources Conservation Services. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043474.pdf

USDA NRCS. (2008). *Soil Tillage Intensity Rating.* United States Department of Agriculture. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_010153.pdf

USDA NRCS. (2009). Anaerobic Digeser - 366 Information Sheet. *Conservation Practice Information Sheet*. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026500.pdf

USDA NRCS. (2010). *Conservation Practice Standard: Cover Crop.* Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_025656.pdf

USDA NRCS. (2011). *4Rs Right for Nutrient Management*. Retrieved from USDA Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ia/home/?cid=nrcs142p2_008196

USDA NRCS. (2012). *Natural Resources Conservation Service Conservation Practice Standard: Nutrient Management.* Washington, DC: USDA NRCS. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046896.pdf

USDA NRCS. (2013). *Cover Crop Benefits and Opportunities.* Washington, DC: Natural Resources Conservation Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1082778.pdf

USDA NRCS. (2015). *Conservation Effects Assessment Project (CEAP).* Washington, DC: National Agricultural Statistics Service. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd386209.pdf

USDA NRCS. (2016a). *Reduction in Annual Fuel Use from Conservation Tillage.* Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1258255.pdf

USDA NRCS. (2016b). *Surveys - Conservation Effects Assessment Project.* Retrieved 2017, from CONSERVATION EFFECTS ASSESSMENT PROJECT (CEAP) - 2016: https://www.nass.usda.gov/Surveys/Conservation_Effects_Assessment_Project/2016/2016CEAPQuestionnareFinal.pdf

USDA NRCS. (2017a). *4R Nutrient Stewardship.* Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&ved=0ahUKEwiTJfzweTXAhVGyWMKHa2DCUwQFghPMAc&url=https%3A%2F%2Fwww.researchgate.net%2Ffile.PostFileLoader.html%3Fid%3D575e7f57eeae3958857833b3%26assetKey%3DAS%253A372451541307395%254014658107

USDA NRCS. (2017c). *Conservation Innovation Grants*. Retrieved August 31, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/cig/

USDA NRCS. (2017d). *Conservation Planning*. Retrieved August 31, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/

USDA NRCS. (2017e). *Cover Crops*. Retrieved August 25, 2017, from https://plants.usda.gov/about_cover_crops.html

USDA NRCS. (2017f). *Cover Crops and Soil Health*. Retrieved August 25, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/climatechange/?cid=stelprdb1077238

USDA NRCS. (2017g). *GHG and Carbon Sequestration Ranking Tool*. Retrieved August 31, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/air/?cid=stelprdb1044982

USDA NRCS. (2017h). *NRCS Practice Standards for Greenhouse Gas Emission Reduction and Carbon Sequestration*. Retrieved August 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/air/?cid=stelprdb1044982

USDA NRCS. (2018a). *Environmental Quality Incentives Program*. Retrieved 06 04, 2018, from USDA NRCS Financial Assistance: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

USDA NRCS. (2018b, September). *History of NRCS*. Retrieved from USDA Natural Resources Conservation Service: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/about/history/

USDA NRCS IA. (2016, August 16). State, Federally Funded Cover Crop Acres Increase 22 Percent. Retrieved September 11, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ia/newsroom/releases/?cid=NRCSEPRD1258613

USDA OCE. (2014a). *United States: Corn*. Retrieved from United States Department of Agriculture Office of the Chief Economist:

https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/USA/US_Corn_2010_to_2014.pdf

USDA OCE. (2014b). *United States: Durum Wheat*. Retrieved from United States Department of Agriculture Office of the Chief Economist: https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/USA/US_WheatDurum_2010_to_2014.pdf

USDA OCE. (2014c). *United States: Soybeans*. Retrieved from United States Department of Agriculture Office of the Chief Economist: https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/USA/US_Soybeans_2010_to_2014.pdf

USDA OCE. (2014d). *United States: Spring Wheat*. Retrieved from United States Department of Agriculture Office of the Chief Economist: https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/USA/US_WheatSpring_2010_to_2014.pdf

USDA OCE. (2014e). *United States: Winter Wheat*. Retrieved from United States Department of Agriculture Office of the Chief Economist: https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/USA/US_WheatWinter_2010_to_2014.pdf

USDA RMA. (2016). *2016 Cover Crops Crop Insurance, Cover Crops and NRCS Cover Crop Termination Guidelines.* Retrieved from Risk Management Agency FAQs: https://www.rma.usda.gov/help/faq/covercrops2016.html

USDA, EPA, & DOE, U. (2014). *Biogas Opportunities Roadmap: Voluntary Actions to Reduce Methane Emissions and Increase Energy Independence.* U.S. Department of Agriculture, U.S. Environmental Protection Agency, U.S. Department of Energy. Retrieved from https://www.usda.gov/oce/reports/energy/Biogas_Opportunities_Roadmap_8-1-14.pdf

Wade, T., Claassen, R., & Wallander, S. (2015). *Conservation-Practice Adoption Rates Vary Widely by Crop and Region.* United States Department of Agriculture. Economic Research Service. Retrieved from https://www.ers.usda.gov/webdocs/publications/44027/56332_eib147.pdf?v=42403

Watts, C. (2017, June 9). (P. communication, Interviewer)

Weber, C., & McCann, L. (2014, November 11). Adoption of Nitrogen-Efficient Technologies by U.S. Corn Farmers. *Journal of Environmental Quality Abstract - Special Section: Improving Nitrogen Use Efficiency in Crop and Livestock Production Systems, 44*(2), 391-401. doi:10.2134/jeq2014.02.0089

Wheeler, J. P. (2015). *2014 Reneable Portfolio Standard Summary Report.* Public Service Commission of Wisconsin. Retrieved from Wisconsin Public Service: http://www.wisconsinpublicservice.com/environment/renewable_standards.aspx

Wisconsin Public Service. (2018). *Renewable Standards for Wisconsin*. Retrieved from https://accel.wisconsinpublicservice.com/environment/renewable_standards.aspx

Zaks, D. P. (2011). Contribution of Anaerobic Digesters to Emissions Mitigation and Electricity Generation Under U.S. Climate Policy. *Environmental Science & Technology*, 2.

APPENDIX A: USDA DATA SOURCES ON AGRICULTURAL CONSERVATION PRACTICES

Additional USDA Sources for Agricultural Conservation Data are briefly outlined below. This list is not meant to be exhaustive but provides background on a variety of USDA sources where readers can find additional agricultural conservation data and information.

Census of Agriculture[26]

The Census of Agriculture (Census), administered by USDA's National Agricultural Statistics Service (NASS), is a complete count of U.S. farms and ranches and the people who operate them. All plots of land growing fruit, vegetables, or some food animals count if $1,000 or more of such products were raised and sold, or normally would have been sold, during the Census year.

The Census is taken once every 5 years, and collects data on land use and ownership, operator characteristics, production practices, income and expenditures. The Census collects some information on agricultural conservation practices, including the following:

- *Cover crops*: total acres used for cover crops at the national and State level. Data available from 2012.
- *Manure management*: percentage of livestock managed by each manure management system by State and livestock type. Data available from 2007.
- *Tillage*: total acres farmed using mulch tillage and no-till. Data available from 2012.

Conservation Effects Assessment Program (CEAP) National Assessments[27]

CEAP is a multi-USDA agency effort to quantify the environmental effects of conservation practices and programs and develop the science base for managing the agricultural landscape for environmental quality. Assessments in CEAP are carried out at national, regional, and watershed scales on cropland, grazing lands, wetlands, and for wildlife.

The purpose of the National Assessment for Cropland (CEAP-Cropland) is to estimate the environmental benefits and effects of conservation practices applied to cultivated cropland and cropland enrolled in long-term conserving cover (e.g., the Conservation Reserve Program). The first CEAP assessment (CEAP-1) was from farmer survey data collected between 2003 and 2006 with data from the National Resources Inventory (NRI), NRCS field office records, and the Farm Service Agency. The second CEAP assessment (CEAP-2) data was collected in 2015 and 2016.

[26] USDA 2012 Census of Agriculture Reports are available here: https://www.agcensus.usda.gov/
[27] USDA NRCS CEAP Data available in report-form here: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/

As part of CEAP-Cropland, NASS conducts surveys with a randomly selected set of farmers nationwide every 10 years. NASS interviews cooperating farmers to obtain current information on farming practices (e.g., crops grown, tillage practices, and nutrient and pesticide application) at NRI statistical sample points for the sample year and the previous 2 years. Data are run through APEX, a water quality model, to estimate nutrient and sediment savings. The CEAP program also produces regional reports, available on the USDA Natural Resources Conservation Service (NRCS) website.[28]

CEAP collects a wide variety of data on agricultural conservation practices, including:

- *Cover crops*: planting date and type of cover crop.
- *Nitrogen inhibitors*: whether inhibitors were used.
- *Manure management*: date and amount applied, method of application, manure storage method.
- *Reduced tillage*: number and percentage of acres using continuous and seasonal no till and mulch tillage. Uses the Soil Tillage Intensity Rating (STIR) to evaluate tillage, where a STIR < 30 indicates no till, a STIR between 30 and 100 indicates mulch till, and a STIR > 100 indicates conventional tillage.

Conservation Reserve Program (CRP)[29]

The Conservation Reserve Program (CRP) is a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10-15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and enhance wildlife habitat (USDA CRP, 2017a). As part of the program, USDA FSA tracks the location, number of acres, and the conservation practice in which the acres are enrolled.

Monthly and annual statistics on CRP enrollment are available online.[30] In addition to the CRP program, data on a variety of CRP Initiatives are available online, including:

- Bottomland Hardwoods Initiative
- Duck Habitat Initiative
- Floodplain Wetland Initiative
- Highly Erodible Land Initiative
- Honeybee Habitat Initiative
- Longleaf Pine Initiative
- Non-Floodplain and Playa Lakes Wetland Initiative
- Pollinator Habitat Initiative

---

[28] See https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/pub/

[29] Information on CRP can be found here: https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/

[30] See https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index

- State Acres for Wildlife Enhancement (SAFE) Initiative
- Upland Bird Habitat Initiative

National Animal Health Monitoring System (NAHMS)[31]

USDA Animal and Plant Health Inspection Service (APHIS) initiated the National Animal Health Monitoring System (NAHMS) to collect, analyze, and disseminate data on the health, management, and productivity of domestic livestock populations across the United States. These studies are designed to meet the information needs of the industries associated with these commodities. NAHMS collects information on livestock such as dairy, swine, beef cow-calf, poultry, equine, sheep, and goats.

Conservation-related information covered by NAHMS includes data on manure management systems, which are split into categories (e.g., lagoon, deep pit, liquid/slurry, solid storage, and pasture/paddock).

National Resources Inventory (NRI)[32]

The National Resources Inventory (NRI) is a statistical study of land use and natural resource conditions and trends on U.S. non-Federal lands. The NRI is conducted by USDA NRCS in cooperation with the Iowa State University Statistical Laboratory.

The 2012 NRI is the latest in a series of natural resource inventories conducted by NRCS. It provides updated information on the status, condition, and trends of land, soil, water, and related resources on the Nation's non-Federal lands. Non-Federal lands include privately owned lands, Tribal and trust lands, and lands controlled by State and local governments.

The 2012 NRI report presents national- and State-level estimates for the 48 conterminous States, Hawaii, and the Caribbean Territories for basic NRI data themes, including changes and trends in land cover/use, irrigation, land capability class and subclass, prime farmland, soil erosion, and wetlands.

[31] Data and information on NAHMS are available at https://www.aphis.usda.gov/nahms
[32] More information on the NRI can be found at https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/nri/

APPENDIX B: CONSERVATION TECHNOLOGY INNOVATION CENTER (CTIC) COVER CROP DATA

Starting in 2013, the Sustainable Agriculture Research and Education (SARE) program and CTIC have conducted annual voluntary cover crop user surveys. While the surveys are heavily weighted towards farmers who use reduced tillage and cover crops, they provide a snapshot of changes in cover crop acreage over time (each survey asks farmers for how many acres on which they planted cover crops for the previous 5 years and their projected acreage for cover crops for the next year). As each survey includes a different set of respondents, the data from each survey year are unique and cannot be compared to other survey years. For this report, CTIC provided data on total acreage planted and either total acres planted with cover crops, or percent of acres planted with cover crops by State (CTIC 2013, 2014, 2015, 2016). As the data points were shared using unique ID numbers only, no confidential business information (CBI) or sensitive information was shared.

It is important to note that unlike USDA ARMS data, data from the **CTIC/SARE surveys are not representative of all U.S. farms**. The surveys are conducted voluntarily (unlike USDA ARMS surveys, which are randomized to be statistically representative of all U.S. farms), resulting in a wide variation in respondents geographically and in each survey year. For example, the number of respondents may vary greatly by State and by year, with some States/years having large numbers of respondents with others having few to no respondents. This variation in respondents means that each survey (which asks how many acres of cover crops were planted in each of the previous 5 years and how many acres are expected to be planted the following year) must be viewed as a unique data set and cannot be compared to other survey years. States with fewer than three respondents in a survey year were not included in this report. Additionally, due to the information channels used to market the surveys, the surveys more likely reflect farmers who were already inclined to use cover crops or were already using them. Therefore, the surveys are likely to over-represent farmers who use cover crops and under-represent those who do not, making it difficult to make broader assertions about general use of cover crops by the U.S. farming community from these data (Watts, 2017).

Given the above, data from the 2015- 2016 CTIC/SARE survey are only included in this report as an indication of general trends in the number of acres planted to cover crops (i.e., to indicate whether the number of acres grown using cover crops increases or decreases over the period covered by each survey: the previous 5 years and the upcoming year). They should not be looked at in terms of absolute number of acres planted with cover crops or the average percent of acres planted with cover crops, as these values are likely not representative of U.S. averages or the U.S. farming community in general (Watts, 2017).

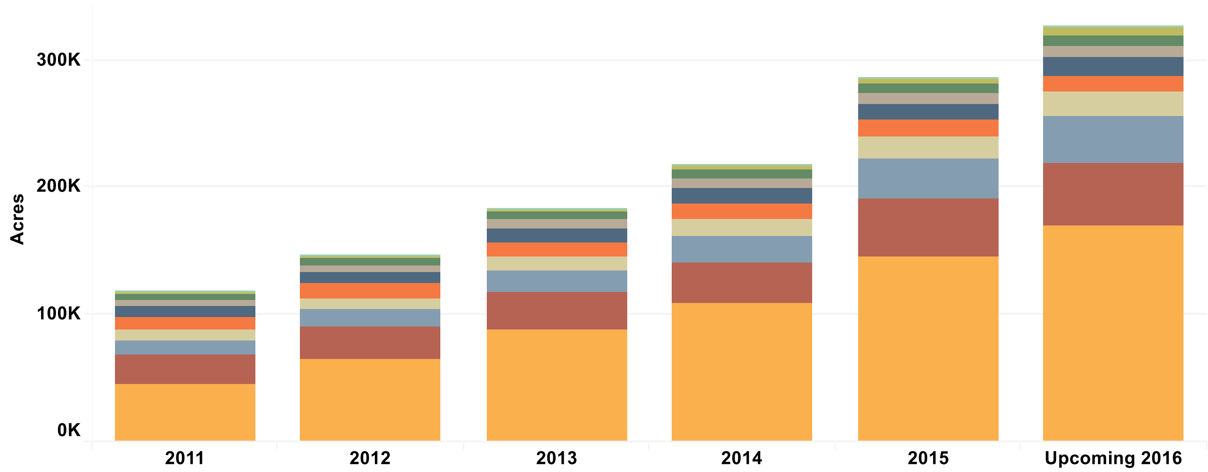
Data are presented in two ways, (1) number of acres where cover crops were grown by USDA region; (2) number of acres where cover crops were grown by farm size. Given that the data are from voluntary (not representative) surveys, there are no statistical analyses on standard error or relative standard error in any of the surveys.

CTIC 2015-2016 Survey

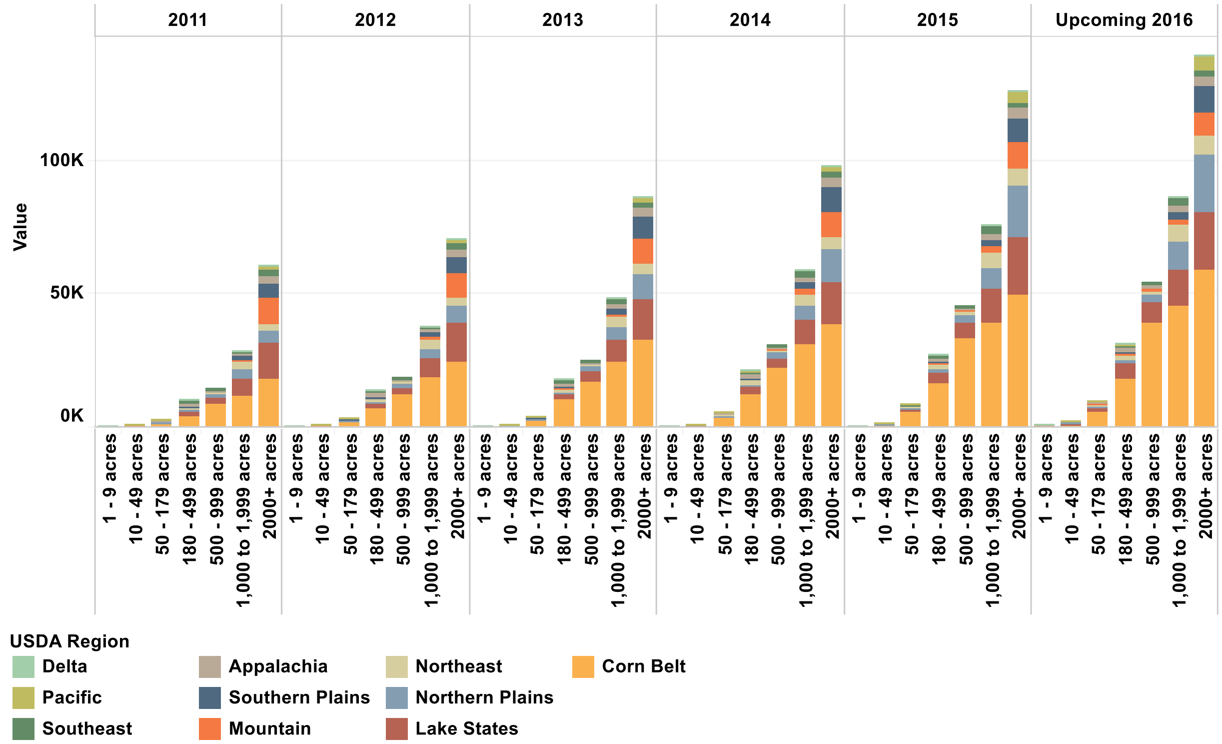
This survey had 990 respondents. The survey clearly shows that the number of acres with cover crops increased from 2011 to 2015 and was projected to increase further in 2016 (surveys were conducted in 2015, so 2016 values were projected numbers of acres where cover crops were planted) (see FIGURE B-1a). Additionally, data from this survey indicated that farm size impacted the number of acres where cover crops were grown (i.e., the larger the farm, the more acres that were planted with cover crops) (see FIGURE B-1b). It is not clear from the data whether this is because larger farms have more acres on which to plant cover crops or because larger farms plant cover crops on a higher percent of total acres than smaller farms. This pattern was consistent for all years covered by the survey. Regional differences (either acres with cover crops or acres with cover crops by farm size) may or may not represent actual regional differences given the voluntary nature of the survey.

FIGURE B-1. Area Planted With Cover Crops, 2015–2016

A. Acres With Cover Crops



B. Acres With Cover Crops by Farm Size



Source: Sustainable Agriculture Research and Education Program (SARE) based on Conservation Technology Information Center data for 2015-2016.

A. Graph of acres planted with cover crops by USDA region and year. Acreage from each region is specified by a different color. K = thousand.

B. Graph of acres planted with cover crops by farm size, USDA region, and year. Acreage from each region is specified by a different color. K = thousand.

TABLE B-1. Area Planted with Cover Crops, 2015–2016 (Acres)

USDA Region	# Surveyed	2011	2012	2013	2014	2015	Upcoming 2016
Delta	5	10	10	141	540	425	951
Pacific	36	2,556	2,679	2,669	3,070	5,213	6,311
Southeast	24	5,713	5,892	6,784	7,488	7,174	8,344
Appalachia	48	4,435	5,311	7,253	8,032	8,760	8,876
Southern Plains	18	7,973	8,418	10,619	11,646	12,163	13,784
Mountain	28	10,845	11,197	11,045	12,509	12,775	12,920
Northeast	107	8,487	9,540	10,984	12,866	17,508	18,828
Northern Plains	95	9,989	12,480	17,254	20,938	32,119	37,128
Lake States	158	23,864	26,062	29,644	32,683	45,109	49,127
Corn Belt	480	45,152	64,976	87,597	108,286	145,364	169,776

Source: Sustainable Agriculture Research and Education Program (SARE) based on Conservation Technology Information Center data for 2015-2016.

Works Cited

CTIC. (2013). *2012-13 Cover Crop Survey.* Conservation Technology Information Center (CTIC), Conservation Technology Information Center. Sustainable Agriculture Research & Education. Retrieved from http://www.ctic.org/media/pdf/Cover%20Crops/SARE-CTIC%20Cover%20Crop%20Survey%202013.pdf

CTIC. (2014). *2013-14 Cover Crop Survey.* Joint publication of the Conservation Technology Information Center and the North Central Region Sustainable Agriculture Research and Education Program. Retrieved from http://www.ctic.org/media/CoverCrops/CTIC_04_Cover_Crops_report.pdf

CTIC. (2015). *2014-15 Cover Crop Survey.* Conservation Technology Information Center. Joint publication of the Conservation Technology Information Center and the North Central Region Sustainable Agriculture Research & Education Program. Retrieved from http://www.ctic.org/media/pdf/20142015CoverCropReport_Draft6.pdf

CTIC. (2016). *2015-16 Cover Crop Survey.* Conservation Technology Information Center. Joint publication of the Conservation Technology Information Center and the North Central Region Sustainable Agriculture Research and Education Program. Retrieved from http://www.ctic.org/media/CoverCrops/2016CoverCropSurvey_Final.pdf

Watts, C. (2017, June 9). (P. communication, Interviewer)

APPENDIX C: DATA TABLES

This appendix presents the data tables that ICF used to produce the graphics.

TABLE C-1. Term Definitions for Data Tables.

Term	Definition	Units
Region	Farm Production Region[33] Appalachia: KY, NC, TN, VA, WV Corn Belt: IA, IL, IN, MO, OH Delta: AR, LA, MS Lake States: MN, WI, MI Mountain: AZ, CO, ID, MT, NM, NV, UT, WY Northeast: CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VT Northern Plains: KS, ND, NE, SD Southeast: AL, FL, GA, SC Southern Plains: OK, TX	States
Planted Acres	Number of acres planted to the target crop	Acre
Percent Applied	Percent of acres that nitrogen fertilizers are applied to for the target crop	%
Average Pounds Per Acre Applied	Total pounds of nitrogen applied divided by total acres applied for target crop	Pounds of nitrogen per bushel
Average Pounds Per Acre (RSE)	Relative standard error of Average Pounds Per Acre Applied	%
Total Acres Applied	Number of acres that nitrogen fertilizers are applied to for the target crop	Acre
Total Acres Applied (RSE)	Relative error of Total Acres Applied	%
Average Pounds Per Bushel	Total pounds of nitrogen applied divided by crop production (measured in bushels) in a region for the target crop	Pounds of nitrogen per bushel
Average Pounds Per Bushel (RSE)	Relative standard error of Average Pounds Per Bushel	%
Fall Application (%)	Percent of nitrogen applied to the target crop's field in the fall	%
Application Before and at Planting (%)	Percent of nitrogen applied to the target crop's field in the spring and/or at planting	%
Application After Planting (%)	Percent of nitrogen applied to the target crop's field after planting	%
Fall Application (Acres)	Number of acres that nitrogen was applied to the target crop's field in the fall	Acres

[33] The ARMS survey does not cover the entire continental United States or each full region, depending on the target crop and year. See for detail: https://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/documentation/

Term	Definition	Units
Application Before and at Planting (Acres)	Number of acres that nitrogen was applied to the target crop's field in the spring and/or at planting	Acres
Application After Planting (Acres)	Number of acres that nitrogen was applied to the target crop's field after planting	Acres
Applied with No Incorporation (%)	Percent of nitrogen applied to the target crop's field without incorporation into the soil	%
Applied with Incorporation (%)	Percent of nitrogen applied to the target crop's field with incorporation into the soil	%
Applied with Incorporation (Acres)	Number of acres that nitrogen was applied to the target crop's field with incorporation into the soil	Acres
Applied with No Incorporation (Acres)	Number of acres that nitrogen was applied to the target crop's field without incorporation into the soil	Acres
Use of X	Percent of acres grown using X practice or technology for the target crop	%
Acres in X	Number of acres treated with X practice or technology for the target crop	Acres
Acres in X (RSE)	Relative standard error of Total Acres with X	%
Total Acres in Field	Total acres planted to any crop	Acres
Total Acres (RSE)	Relative standard error of Total Acres	%
Continuous Conventional-Till	Land treated with a Soil Tillage Intensity Rating (STIR) > 100 for all years in rotation.	
Mulch-Till	Land treated with either continuous mulch tillage (STIR rating between 30 and 100 for all years in a multi-year rotation) or seasonal mulch tillage (multi-year tillage rotation that has at least 1 year of mulch-till [STIR rating between 30 and 100] and other years with conventional till [STIR rating >100]).	
No tillage	Land treated with either continuous no tillage (STIR rating < 30 for all crops in a multi-year rotation) or seasonal no tillage (at least one crop of no tillage [STIR rating< 30] and other crops with mulch tillage [STIR rating <100]).	
Continuous No tillage	Land treated with a STIR < 30 for all years in a multi-year rotation.	
Seasonal No tillage	Land treated with a multi-year tillage rotation that has at least 1 year of no tillage (STIR rating< 30) and other years with mulch tillage (STIR rating between 30 and 100).	
Continuous Mulch Tillage	Land treated a STIR between 30 and 100 for all years in a multi-year rotation.	
Seasonal Mulch Tillage	Land treated with a multi-year tillage rotation that has at least 1 year of mulch tillage (STIR rating between 30 and 100) and other years with conventional tillage (STIR rating >100).	

TABLE C-2. Corn Nitrogen Application Amount (per Acre): Data for FIGURE 9

Nitrogen Applied to Corn Crops in 2005

Region	Planted Acres	Percent of Planted Acres	Average Pounds per Acre Applied	Average Pounds per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Appalachia	2,019,152	98	139	4	1,979,156	1
Corn Belt	37,673,272	97	141	2	36,400,000	2
Lake States	13,496,579	96	99	5	12,900,000	2
Mountain	1,100,000	90	134	17	994,036	6
Northeast	2,340,000	92	76	10	2,161,761	2
Northern Plains	18,191,926	98	118	3	17,800,000	1
Southeast	270,000	98	138	5	264,055	1
Southern Plains	2,070,569	97	150	8	2,006,718	2
National	77,161,498		121	2		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005.

*RSE = Relative Standard Error.

Nitrogen Applied to Corn Crops in 2010

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Acre Applied	Average Pounds Per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Appalachia	2,261,382	95	145	5	2,155,095	3
Corn Belt	38,733,490	97	150	2	37,600,000	1
Lake States	13,961,466	91	103	4	12,700,000	5
Mountain	1,328,611	98	123	14	1,299,590	2
Northeast	2,381,848	91	73	11	2,156,462	3
Northern Plains	20,633,831	99	127	3	20,500,000	0
Southeast	295,944	90	145	6	266,400	7
Southern Plains	2,297,080	99	123	6	2,278,447	1
National	81,893,629		125	2		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010.

*RSE = Relative Standard Error.

Nitrogen Applied to Corn Crops in 2016

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Acre Applied	Average Pounds Per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Appalachia	2,500,037	94	135	5	2,353,332	3
Corn Belt	38,306,292	98	153	1	37,397,510	1
Lake States	14,899,926	96	112	2	14,251,640	1
Mountain	1,340,061	96	141	8	1,292,951	3
Northeast	2,500,002	94	78	3	2,350,935	2
Northern Plains	23,999,979	99	132	1	23,810,400	0
Southeast	409,896	97	165	2	396,065	4
Southern Plains	2,900,052	87	124	4	2,531,102	13
National	86,856,245		128	1		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2016.

*RSE = Relative Standard Error.

TABLE C-3. Corn Nitrogen Application (per Bushel): Data for FIGURE 10

Nitrogen Applied Per Yield of Corn in 2005

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Appalachia	2,019,152	98	1.06	4
Corn Belt	37,673,272	97	0.87	2
Lake States	13,496,579	96	0.72	6
Mountain	1,100,000	90	0.88	17
Northeast	2,340,000	92	0.66	11
Northern Plains	18,191,926	98	0.86	3
Southeast	270,000	98	1.1	7
Southern Plains	2,070,569	97	1.17	5
National	77,161,498		0.84	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005.

*RSE = Relative Standard Error.

Nitrogen Applied to Yield of Corn in 2010

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Appalachia	2,261,382	95	1.09	8
Corn Belt	38,733,490	97	0.87	2
Lake States	13,961,466	91	0.68	4
Mountain	1,328,611	98	0.81	10
Northeast	2,381,848	91	0.65	14
Northern Plains	20,633,831	99	0.85	3
Southeast	295,944	90	1.16	5
Southern Plains	2,297,080	99	1.07	5
National	81,893,629		0.82	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010.

*RSE = Relative Standard Error.

Nitrogen Applied to Yield of Corn in 2016

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Appalachia	2,500,037	94	0.85	6
Corn Belt	38,306,292	98	0.83	2
Lake States	14,899,926	96	0.68	7
Mountain	1,340,061	96	0.83	12
Northeast	2,500,002	94	0.57	7
Northern Plains	23,999,979	99	0.81	3
Southeast	409,896	97	1.20	8
Southern Plains	2,900,052	87	0.92	4
National	86,856,245		0.77	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2016.

*RSE = Relative Standard Error.

TABLE C-4. Soybean Nitrogen Application (per Acre): Data for FIGURE 11

Soybean 2006

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Acre Applied	Average Pounds Per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Appalachia	4,442,186	35	23	14	1,567,622	10
Corn Belt	35,935,999	12	17	5	4,267,083	11
Delta	5,667,189	4	11	10	212,287	34
Lake States	11,100,230	21	14	9	2,289,992	11
Northern Plains	16,132,251	32	14	8	5,203,870	10
National	73,277,855		17	6		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006.

*RSE = Relative Standard Error.

Soybeans 2012

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Acre Applied	Average Pounds Per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Appalachia	4,919,916	42	19	8	2,080,205	9
Corn Belt	33,639,849	19	19	4	6,299,005	2
Delta	6,307,927	9	19	12	575,032	13
Lake States	10,828,795	33	14	5	3,565,424	7
Northern Plains	18,550,469	42	12	5	7,763,195	4
National	74,246,950		17	4		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2012.

*RSE = Relative Standard Error.

TABLEC-5. Soybean Nitrogen Application (per Bushel): Data for FIGURE 12

Soybeans 2006

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Appalachia	4,442,186	35	0.589	16
Corn Belt	35,935,999	12	0.352	5
Delta	5,667,189	4	0.253	13
Lake States	11,100,230	21	0.308	8
Northern Plains	16,132,251	32	0.318	9
National	73,277,855		0.39	6

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006.

*RSE = Relative Standard Error.

Soybeans 2012

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Appalachia	4,919,916	42	0.464	10
Corn Belt	33,639,849	19	0.39	5
Delta	6,307,927	9	0.45	13
Lake States	10,828,795	33	0.32	5
Northern Plains	18,550,469	42	0.296	7
National	74,246,950		0.37	4

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2012.

*RSE = Relative Standard Error.

TABLE C-6. Wheat Nitrogen Application (per Acre): Data for FIGURE 13.

Wheat 2004

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Acre Applied	Average Pounds Per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Corn Belt	2,900,992	100	92	6	2,888,212	0
Lake States	2,367,103	98	92	2	2,319,880	1
Mountain	9,038,580	80	55	6	7,212,409	5
Northern Plains	23,359,997	90	63	4	21,000,000	2
Pacific	3,330,000	98	84	5	3,255,811	2
Southern Plains	12,601,375	79	70	14	9,972,342	6
National	53,598,047		70	3		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004.
*RSE = Relative Standard Error.

Wheat 2009

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Acre Applied	Average Pounds Per Acre (RSE)*	Total Acres N Applied	Total Acres N Applied (RSE)*
Corn Belt	2,629,893	97	94	4	2,539,031	1
Lake States	2,242,639	95	83	5	2,136,806	2
Mountain	9,209,899	83	62	5	7,629,040	3
Northern Plains	22,892,341	94	65	3	21,500,000	1
Pacific	3,178,660	99	86	6	3,146,941	1
Southern Plains	12,052,102	70	55	8	8,419,799	5
National	52,205,526		69	2		

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.
*RSE = Relative Standard Error.

TABLE C-7. Wheat Nitrogen Application (per Bushel): Data for FIGURE 14

Wheat 2004

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Corn Belt	2,900,992	100	1.5	4
Lake States	2,367,103	98	1.45	3
Mountain	9,038,580	80	1.08	7
Northern Plains	23,359,997	90	1.42	5
Pacific	3,330,000	98	1.21	7
Southern Plains	12,601,375	79	1.58	6
National	53,598,047		1.40	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004.

*RSE = Relative Standard Error.

Wheat 2009

Region	Planted Acres	Percent of Planted Acres	Average Pounds Per Bushel	Average Pounds Per Bushel (RSE)*
Corn Belt	2,629,893	97	1.46	3
Lake States	2,242,639	95	1.29	6
Mountain	9,209,899	83	1.24	5
Northern Plains	22,892,341	94	1.33	3
Pacific	3,178,660	99	1.22	5
Southern Plains	12,052,102	70	1.46	7
National	52,205,526		1.34	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.

*RSE = Relative Standard Error.

TABLE C-8. Corn Nitrogen Application by Application Timing: Data for FIGURE 15*

Region	Year	Fall Application (% of Planted Acres)	Application Before and at Planting (% of Planted Acres)	Application After Planting (% of Planted Acres)	Fall Application (Acres)	Application Before and at Planting (Acres)	Application After Planting (Acres)
Corn Belt	2005	24	55	21	8,660,739	20,093,364	7,645,896
	2010	24	55	21	8,943,536	20,858,656	7,797,811
	2016	23	50	26	8,629,790	18,870,211	9,884,656
Northern Plains	2005	11	66	23	1,987,943	11,748,774	4,063,283
	2010	13	61	26	2,719,901	12,452,768	5,301,448
	2016	17	59	23	4,040,982	14,015,635	5,587,963
Lake States	2005	24	57	19	3,076,992	7,355,526	2,467,484
	2010	19	63	18	2,413,215	8,056,635	2,230,150
	2016	19	57	24	2,745,252	8,077,443	3,411,952
Northeast	2005		78	21		1,687,648	461,611
	2010		69	31		1,485,333	669,305
	2016		59	39		1,380,992	922,505
Southern Plains	2005	20	47	33	393,523	943,159	670,036
	2010	21	47	31	488,845	1,082,250	707,352
	2016	18	60	22	454,624	1,524,537	551,940
Appalachia	2005	4	62	34	84,159	1,217,545	677,453
	2010		59	40		1,261,054	871,702
	2016	5	59	36	108,584	1,387,570	857,178
Mountain	2005		55	29		543,630	287,361
	2010		56	39		723,197	505,872
	2016	14	53	32	186,177	687,409	419,365
Southeast	2005	8	25	66	21,740	66,149	175,393
	2010		19	79		51,786	210,183
	2016		36	64		142,560	253,505
National	2005	20	58	22	19,600,000	61,000,000	22,00,000
	2010	19	58	23	20,600,000	61,300,000	24,700,000
	2016	20	54	26	23,200,000	64,400,000	32,000,000

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

*All data presented in this table have a Relative Standard Error of less than 50 percent.

TABLE C-9. Corn Nitrogen Application by Application Method: Data for FIGURE 16*

Region	Year	Applied With No Incorporation (%)	Applied With No Incorporation (Acres)	Applied With Incorporation (%)	Applied With Incorporation (Acres)
Corn Belt	2005	14	5,031,452	86	31,367,620
	2010	15	5,654,453	84	31,716,935
	2016	16	5,821,420	84	31,396,261
Northern Plains	2005	30	5,259,154	70	12,540,846
	2010	29	5,892,290	71	14,561,861
	2016	26	6,277,774	73	17,317,904
Lake States	2005	14	1,779,441	85	10,911,644
	2010	22	2,829,098	78	9,870,902
	2016	29	4,151,920	69	9,787,029
Northeast	2005	32	684,608	68	1,477,153
	2010	52	1,112,435	48	1,038,364
	2016	54	1,260,269	46	1,090,585
Southern Plains	2005	13	259,266	87	1,747,452
	2010	23	519,540	76	1,739,592
	2016	16	399,680	84	2,131,422
Appalachia	2005	42	824,164	56	1,112,426
	2010	31	669,160	69	1,479,101
	2016	54	1,275,925	44	1,038,968
Mountain	2005	25	251,937	74	737,578
	2010			93	1,205,203
	2016				
Southeast	2005	28	72,952	72	189,838
	2010	36	95,868	64	170,532
	2016	57	224,445	43	171,620
National	2005	19	26,100,000	81	66,100,000
	2010	21	29,100,000	79	67,400,000
	2016	23	32,400,000	77	71,200,000

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005, 2010, and 2016.

*All data presented in this table have a Relative Standard Error of less than 50 percent.

TABLE C-10. Corn Acres Grown With Variable Rate Technology (VRT): Data for FIGURE 17.

Corn 2005

Region	Planted Acres	Use of VRT (% of Planted Acres)	Acres in VRT (Acres)	Acres in VRT (RSE)*
Corn Belt	37,673,272	6	2,119,040	22
Lake States	13,496,579	2	325,182	36
Northern Plains	18,191,926	5	938,336	16
National	77,161,498	5	3,590,540	16

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005.

*RSE = Relative Standard Error.

Corn 2010

Region	Planted Acres	Use of VRT (% of Planted Acres)	Acres in VRT (Acres)	Acres in VRT (RSE)*
Corn Belt	38,733,490	8	3,236,975	23
Lake States	13,961,466	11	1,540,610	29
Mountain	1,328,611	16	216,330	40
Northeast	2,381,848	6	137,685	45
Northern Plains	20,633,831	13	2,694,530	18
National	81,893,629	10	8,232,990	14

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010.

*RSE = Relative Standard Error.

Corn 2016

Region	Planted Acres	Use of VRT (% of Planted Acres)	Acres in VRT (Acres)	Acres in VRT (RSE)*
Appalachia	2,500,037	25	608,293	14
Corn Belt	38,306,292	35	13,400,000	4
Lake States	14,899,926	21	3,069,021	7
Mountain	1,340,061	20	214,791	6
Northeast	2,500,002	10	241,465	28
Northern Plains	23,999,979	28	6,369,748	7
Southeast	409,896	8	33,451	18
Southern Plains	2,900,052	6	173,663	29
National	86,856,245	28	24,100,000	3

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2016.

*RSE = Relative Standard Error.

TABLE C-11. Wheat Acres Grown With Variable Rate Technology (VRT): Data for FIGURE 18

Wheat 2004

Region	Planted Acres	Use of VRT (% of Planted Acres)	Acres in VRT (Acres)	Acres in VRT (RSE)*
Corn Belt	2,900,992	3	90,286	37
Lake States	2,367,103	7	157,067	50
Mountain	9,038,580	5	435,199	41
Northern Plains	23,359,997	5	1,218,099	36
Pacific	3,330,000	29	951,904	28
National	53,598,047	7	3,732,297	18

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004.

*RSE = Relative Standard Error.

Wheat 2009

Region	Planted Acres	Use of VRT (% of Planted Acres)	Acres in VRT (Acres)	Acres in VRT (RSE)*
Corn Belt	2,629,893	7	174,116	27
Lake States	2,242,639	9	201,870	30
Mountain	9,209,899	10	953,548	20
Northern Plains	22,892,341	8	1,822,239	18
Pacific	3,178,660	35	1,106,293	12
Southern Plains	12,052,102	10	1,239,060	23
National	52,205,526	11	5,497,126	9

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.

*RSE = Relative Standard Error.

TABLE C-12. Corn Acres Grown With Auto Steer: Data for FIGURE 19

Corn 2005

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Appalachia	2,019,152	10	208,649	31
Corn Belt	37,673,272	13	4,936,033	17
Lake States	13,496,579	9	1,257,778	20
Mountain	1,100,000	24	265,632	23
Northeast	2,340,000	5	113,986	49
Northern Plains	18,191,926	23	4,251,947	17
Southern Plains	2,070,569	27	548,794	25
National	77,161,498	15	11,589,620	10

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005.
*RSE = Relative Standard Error.

Corn 2010

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Appalachia	2,261,382	46	1,043,076	17
Corn Belt	38,733,490	47	18,300,000	5
Lake States	13,961,466	35	4,861,937	13
Mountain	1,328,611	77	1,021,685	11
Northeast	2,381,848	7	177,319	31
Northern Plains	20,633,831	51	10,600,000	7
Southeast	295,944	34	99,819	28
Southern Plains	2,297,080	42	962,564	18
National	81,893,629	45	36,988,190	4

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.
*RSE = Relative Standard Error.

Corn 2016

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Appalachia	2,500,037	49	1,211,381	8
Corn Belt	38,306,292	56	20,900,000	1
Lake States	14,899,926	46	6,681,290	3
Mountain	1,340,061	56	609,584	9
Northeast	2,500,002	23	563,290	14
Northern Plains	23,999,979	67	15,400,000	2
Southeast	409,896	28	114,856	15
Southern Plains	2,900,052	52	1,514,370	9
National	86,856,245	54	47,100,000	1

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2016.

*RSE = Relative Standard Error.

TABLE C-13. Soybean Acres Grown With Auto Steer: Data for FIGURE 20

Soybeans 2006

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Appalachia	4,442,186	12	550,903	21
Corn Belt	35,935,999	18	6,589,840	9
Delta	5,667,189	12	668,745	15
Lake States	11,100,230	17	1,830,463	18
Northern Plains	16,132,251	30	4,864,620	7
National	73,277,855	20	14,504,570	5

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006.

*RSE = Relative Standard Error.

Soybeans 2012

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Appalachia	4,919,916	36	1,754,146	14
Corn Belt	33,639,849	47	15,700,000	4
Delta	6,307,927	33	2,100,428	11
Lake States	10,828,795	44	4,786,238	9
Northern Plains	18,550,469	49	9,166,447	5
National	74,246,950	45	33,464,280	3

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2012.
*RSE = Relative Standard Error.

TABLE C-14. Wheat Acres Grown With Auto Steer: Data for FIGURE 21

Wheat 2004

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Corn Belt	2,900,992	6	166,573	20
Lake States	2,367,103	28	668,334	18
Mountain	9,038,580	17	1,534,919	14
Northern Plains	23,359,997	20	4,689,486	14
Pacific	3,330,000	12	401,801	24
Southern Plains	12,601,375	10	1,250,980	30
National	53,598,047	16	8,712,092	7

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004.
*RSE = Relative Standard Error.

Wheat 2009

Region	Planted Acres	Use of Auto Steer (% of Planted Acres)	Acres in Auto Steer (Acres)	Acres in Auto Steer (RSE)*
Corn Belt	2,629,893	19	503,215	16
Lake States	2,242,639	50	1,129,048	9
Mountain	9,209,899	53	4,879,972	5
Northern Plains	22,892,341	47	10,700,000	8
Pacific	3,178,660	50	1,601,103	7
Southern Plains	12,052,102	27	3,203,579	13
National	52,205,526	42	22,042,540	5

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.
*RSE = Relative Standard Error.

TABLE C-15. Cover Crops on Farmland for Crops and Livestock: Data for FIGURE 22

Region	Year	Use of Cover Crops (% of Total Acres)	Acres in Cover Crops (Acres)	Acres in Cover Crops (RSE)	Total Acres in Field	Total Acres (RSE)*
Northern Plains	2010				89,000,000	19
	2011	1	614,918	49	92,900,000	4
	2012	1	1,210,886	17	95,800,000	3
	2015	2	1,965,824	27	99,300,000	7
Corn Belt	2010	1	518,432	35	91,400,000	1
	2011	1	1,070,281	25	89,700,000	2
	2012	2	2,032,267	10	89,000,000	1
	2015	4	3,783,111	11	87,800,000	2
Mountain	2010	3	1,184,419	29	40,600,000	5
	2011	0	189,518	39	43,800,000	7
	2012	3	1,182,790	37	41,677,174	6
	2015	2	860,103	41	39,500,000	5
Southern Plains	2010				42,500,000	18
	2011	2	758,248	26	40,700,000	6
	2012	4	1,348,013	17	37,800,000	5
	2015	6	2,321,637	38	39,400,000	20
Lake States	2010				36,800,000	9
	2011	1	377,052	34	39,900,000	3
	2012	4	1,637,576	9	39,175,289	2
	2015	4	1,652,234	26	39,700,000	7

Region	Year	Use of Cover Crops (% of Total Acres)	Acres in Cover Crops (Acres)	Acres in Cover Crops (RSE)	Total Acres in Field	Total Acres (RSE)*
Pacific	2010	1	265,295	40	22,714,474	7
	2011	1	306,681	25	20,995,532	9
	2012	5	1,038,398	27	22,887,398	15
	2015	3	668,833	17	20,383,565	6
Appalachia	2010	5	1,140,326	17	23,850,558	4
	2011	5	1,087,339	25	23,105,340	5
	2012	7	1,327,719	13	17,948,988	4
	2015	8	1,608,894	13	19,684,067	4
Delta	2010				17,865,932	4
	2011	3	538,235	44	17,670,815	6
	2012	2	229,534	30	14,842,188	5
	2015				18,503,383	12
Northeast	2010	8	928,197	23	12,048,422	7
	2011	6	701,962	14	12,435,724	7
	2012	12	1,856,444	16	15,186,506	6
	2015	14	1,879,022	15	13,442,617	8
Southeast	2010	3	320,128	34	12,081,051	5
	2011	4	452,658	36	12,483,195	7
	2012	8	906,400	20	11,687,536	5
	2015	10	1,079,686	16	11,359,097	5
National	2010	2	7,701267	9	388,802,400	3
	2011	2	6,096,892	9	393,623,700	2
	2012	3	12,770,030	5	385,904,900	1
	2015	4	16,266,880	10	389,195,300	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010, 2011, 2012, and 2015.

*RSE = Relative Standard Error.

TABLE C-16. Corn Acres Grown With No Tillage: Data for FIGURE 23

Corn 2005

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Appalachia	2,019,152	65	1,307,807	10
Corn Belt	37,673,272	27	10,315,890	10
Lake States	13,496,579	10	1,287,285	17
Mountain	1,100,000	35	390,243	35
Northeast	2,340,000	26	611,893	24
Northern Plains	18,191,926	46	8,300,654	8
Southeast	270,000	39	105,704	23
Southern Plains	2,070,569	16	324,493	20
Total	77,161,498	29	22,643,970	4

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005.

*RSE = Relative Standard Error.

Corn 2010

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Appalachia	2,261,382	67	1,510,943	15
Corn Belt	38,733,490	27	10,277,940	12
Lake States	13,961,466	19	2,599,669	32
Mountain	1,328,611	55	725,536	25
Northeast	2,381,848	48	1,131,891	9
Northern Plains	20,633,831	51	10,435,760	7
Southeast	295,944	41	121,691	32
Southern Plains	2,297,080	11	242,088	39
Total	81,893,629	33	27,045,520	5

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010.

*RSE = Relative Standard Error.

Corn 2016

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Appalachia	2,500,037	68	1,691,430	3
Corn Belt	38,306,292	25	9,545,621	5
Lake States	14,899,926	12	1,799,146	5
Mountain	1,340,061	47	518,646	9
Northeast	2,500,002	46	1,116,119	6
Northern Plains	23,999,979	57	13,100,000	3
Southeast	409,896	35	145,020	7
Southern Plains	2,900,052	11	314,303	33
Total	86,856,245	33	28,300,000	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2016.

*RSE = Relative Standard Error.

TALBE C-17. Corn Acres Grown With Mulch Tillage: Data for FIGURE 24

Corn 2005

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Appalachia	2,019,152	22	447,213	16
Corn Belt	37,673,272	57	21,650,400	6
Lake States	13,496,579	40	5,416,958	7
Mountain	1,100,000	29	320,949	35
Northeast	2,340,000	24	569,584	17
Northern Plains	18,191,926	42	7,550,368	9
Southeast	270,000	40	106,978	17
Southern Plains	2,070,569	26	544,273	23
Total	77,161,498	47	36,606,720	3

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2005.

*RSE = Relative Standard Error.

Corn 2010

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Appalachia	2,261,382	29	655,394	33
Corn Belt	38,733,490	57	21,890,600	7
Lake States	13,961,466	50	7,031,920	10
Northeast	2,381,848	21	496,953	18
Northern Plains	20,633,831	38	7,906,111	8
Southeast	295,944	44	130,693	31
Southern Plains	2,297,080	40	924,067	18
Total	81,893,629	48	39,324,160	4

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2010.
*RSE = Relative Standard Error.

Corn 2016

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Appalachia	2,500,037	27	676,564	7
Corn Belt	38,306,292	61	23,000,000	2
Lake States	14,899,926	51	7,437,043	4
Mountain	1,340,061	40	435,530	13
Northeast	2,500,002	31	764,709	9
Northern Plains	23,999,979	30	6,988,953	4
Southeast	409,896	50	206,225	7
Southern Plains	2,900,052	44	1,267,950	15
Total	86,856,245	47	40,800,000	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2016.
*RSE = Relative Standard Error.

TABLE C-18. Soybean Acres Grown With No Tillage: Data for FIGURE 25

Soybean 2006

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Appalachia	4,442,186	79	3,481,155	4
Corn Belt	35,935,999	56	20,072,330	3
Delta	5,667,189	24	1,365,353	10
Lake States	11,100,230	23	2,549,535	14
Northern Plains	16,132,251	45	7,182,696	6
Total	73,277,855	47	34,651,070	2

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006.

*RSE = Relative Standard Error.

Soybean 2012

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Appalachia	4,919,916	83	4,072,341	4
Corn Belt	33,639,849	50	16,685,840	3
Delta	6,307,927	19	1,195,346	15
Lake States	10,828,795	18	1,895,983	10
Northern Plains	18,550,469	47	8,757,386	5
Total	74,246,950	44	32,606,900	3

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2012.

*RSE = Relative Standard Error.

TABLE C-19. Soybean Acres Grown With Mulch Tillage: Data for FIGURE 26

Soybean 2006

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Appalachia	4,442,186	18	804,651	18
Corn Belt	35,935,999	32	11,252,950	7
Delta	5,667,189	45	2,563,603	14
Lake States	11,100,230	45	4,904,043	7
Northern Plains	16,132,251	38	6,045,020	7
Total	73,277,855	35	25,570,270	4

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2006.

*RSE = Relative Standard Error.

Soybean 2012

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Appalachia	4,919,916	16	767,895	19
Corn Belt	33,639,849	38	12,632,090	5
Delta	6,307,927	44	2,800,135	6
Lake States	10,828,795	47	5,078,380	10
Northern Plains	18,550,469	36	6,673,010	7
Total	74,246,950	38	27,951,510	4

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2012.
*RSE = Relative Standard Error.

TABLE C-20. Wheat Acres Grown With No Tillage: Data for FIGURE 27

Wheat 2004

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Corn Belt	2,900,992	59	1,705,045	7
Lake States	2,367,103	18	418,694	8
Mountain	9,038,580	37	3,378,401	25
Northern Plains	23,359,997	23	5,405,820	10
Pacific	3,330,000	13	430,394	23
Total	53,598,047	22	11,963,650	6

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004.
*RSE = Relative Standard Error.

Wheat 2009

Region	Planted Acres	Use of No Tillage (% of Planted Acres)	Acres in No Tillage (Acres)	Acres in No Tillage (RSE)*
Corn Belt	2,629,893	64	1,686,731	5
Lake States	2,242,639	25	564,273	20
Mountain	9,209,899	53	4,887,961	5
Northern Plains	22,892,341	48	10,903,420	5
Pacific	3,178,660	26	812,954	15
Southern Plains	12,052,102	23	2,769,134	17
Total	52,205,526	41	21,624,470	3

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.
*RSE = Relative Standard Error.

TABLE C-21. Wheat Acres Grown With Mulch Tillage: Data for FIGURE 28

Wheat 2004

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Corn Belt	2,900,992	37	1,059,705	10
Lake States	2,367,103	26	621,127	18
Mountain	9,038,580	25	2,302,299	17
Northern Plains	23,359,997	22	5,195,916	11
Pacific	3,330,000	23	758,832	29
Southern Plains	12,601,375	24	2,992,698	21
Total	53,598,047	24	12,930,580	6

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2004.

*RSE = Relative Standard Error.

Wheat 2009

Region	Planted Acres	Use of Mulch Tillage (% of Planted Acres)	Acres in Mulch Tillage (Acres)	Acres in Mulch Tillage (RSE)*
Corn Belt	2,629,893	29	753,413	10
Lake States	2,242,639	44	996,353	12
Mountain	9,209,899	26	2,398,329	14
Northern Plains	22,892,341	19	4,319,208	13
Pacific	3,178,660	23	736,248	21
Southern Plains	12,052,102	33	3,932,184	14
Total	52,205,526	25	13,135,730	6

Source: USDA Economic Research Service based on Agricultural Resource Management Survey (ARMS) data for 2009.

*RSE = Relative Standard Error.

TABLE C-22. Crop Rotations Split Into Three Tillage Categories: Data for FIGURE 29

Region	Continuous Conventional Tillage (% of Planted Acres)	Mulch Tillage (% of Planted Acres)	No Tillage (% of Planted Acres)
Corn Belt	2.9	43.4	53.7
Northern Plains	8.9	45.8	45.4
Lake States	11.0	66.3	22.7
Southern Plains	51.6	36.9	11.5
Mountain	5.9	44.4	49.6
Appalachia	7.5	30.5	62.0
Delta	15.4	56.4	28.2
Pacific	7.4	51.3	41.3
Northeast	14.1	47.6	38.3
Southeast	12.6	45.5	41.9

Source: USDA Economic Research Service analysis based on Conservation Effects Assessment Project (CEAP) data for 2003, 2004, 2005, and 2006.

TABLE C-23. Crop Rotations Split Into Five Tillage Categories: Data for FIGURE 30

Region	Continuous No Tillage (% of Planted Acres)	Seasonal No Tillage (% of Planted Acres)	Continuous Mulch Tillage (% of Planted Acres)	Seasonal Mulch Tillage (% of Planted Acres)	Continuous Conventional Tillage (% of Planted Acres)
Northern Plains	28.2	17.2	22.0	23.8	8.9
Corn Belt	25.3	28.4	31.8	11.6	2.9
Lake States	10.2	12.5	37.9	28.4	11.0
Southern Plains	5.7	5.7	17.5	19.4	51.6
Mountain	29.6	20.0	12.1	32.4	5.9
Delta	16.1	12.1	37.3	19.1	15.4
Appalachia	48.5	13.5	16.5	14.0	7.5
Southeast	27.0	14.9	21.3	24.2	12.6
Pacific	19.2	22.1	11.0	40.3	7.4
Northeast	23.4	14.9	19.5	28.1	14.1

Source: USDA Economic Research Service analysis based on Conservation Effects Assessment Project (CEAP) data for 2003, 2004, 2005, and 2006.

APPENDIX D: SURVEY QUESTIONS

TABLE D-1. Corn Nitrogen Application Amount (per acre)

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2010 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS CORN PPCR 2016[3]	"How many acres of corn did this operation plant for the 2016 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 3, N, 3
	"How many acres were treated in this application?"	Section C/Question 3, N, 7

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-2. Corn Nitrogen Application (per bushel)

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"What was your yield goal at planting for this field?"	Section C/Question 8
ARMS CORN PPCR 2010[2]	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"What was your yield goal at planting for this field?"	Section C/Question 8
ARMS CORN PPCR 2016[3]	"What quantity was applied per acre?"	Section C/Question 3, N, 3
	"What was your yield goal at planting for this field?"	Section B/Question 8a

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-3. Soybean Nitrogen Application (per acre)

Survey	Question (s)	Section/question #
ARMS SOYBEAN PPCR 2006[1]	"How many acres of soybeans did this operation plant for the 2006 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS SOYBEAN PPCR 2012[2]	"How many acres of soybeans did this operation plant for the 2012 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 3, N, 3
	"How many acres were treated in this application?"	Section C/Question 3, N, 7

[1] (USDA ERS, 2006); [2] (USDA ERS, 2012b). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-4. Soybean Nitrogen Application (per bushel)

Survey	Question (s)	Section/question #
ARMS SOYBEAN PPCR 2006[1]	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"What was your yield goal at planting for this field?"	Section C/Question 8
ARMS SOYBEAN PPCR 2012[2]	"What quantity was applied per acre?"	Section C/Question 3, N, 3
	"What was your yield goal at planting for this field?"	Section B/Question 8b

[1] (USDA ERS, 2006); [2] (USDA ERS, 2012b). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-5. Wheat Nitrogen Application (per acre)

Survey	Question (s)	Section/question #
ARMS WHEAT PPCR 2004[1]	"How many acres of wheat (winter, durum and other spring) did this operation plant for the 2004 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS WHEAT PPCR 2009[2]	"How many acres of wheat (winter, durum and other spring) did this operation plant for the 2009 crop year?"	Section A/Question 1
	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"How many acres were treated in this application?"	Section C/Question 4, N, 7

[1] (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c); [2] (USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-6. Wheat Nitrogen Application (per bushel)

Survey	Question (s)	Section/question #
ARMS WHEAT PPCR 2004[1]	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"What was your yield goal at planting for this field?"	Section C/Question 9
ARMS WHEAT PPCR 2009[2]	"What quantity was applied per acre?"	Section C/Question 4, N, 3
	"What was your yield goal at planting for this field?"	Section C/Question 8

[1] (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c); [2] (USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-7. Corn Nitrogen Application by Application Timing

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"When was this applied?"	Section C/Question 4, N, 5
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2010 crop year?"	Section A/Question 1
	"When was this applied?"	Section C/Question 4, N, 5
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS CORN PPCR 2016[3]	"How many acres of corn did this operation plant for the 2016 crop year?"	Section A/Question 1
	"When was this applied?"	Section C/Question 3, N, 5
	"How many acres were treated in this application?"	Section C/Question 3, N, 7

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-8. Corn Nitrogen Application by Application Method

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"How was this applied?"	Section C/Question 4, N, 6
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2010 crop year?"	Section A/Question 1
	"How was this applied?"	Section C/Question 4, N, 6
	"How many acres were treated in this application?"	Section C/Question 4, N, 7
ARMS CORN PPCR 2016[3]	"How many acres of corn did this operation plant for the 2016 crop year?"	Section A/Question 1
	"How was this applied?"	Section C/Question 3, N, 6
	"How many acres were treated in this application?"	Section C/Question 3, N, 7

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-9. Nitrogen Inhibitor Use in Corn (% of planted acres)

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"Did you use any product to slow the breakdown of nitrogen on this field? *(For example, a nitrification inhibitor such as N-Serve or a urease inhibitor such as Agrotain)*"	Section C/Question 16,
ARMS CORN PPCR 2010[2]	"Which of the following products did you use to slow the breakdown of nitrogen on this field a. How much nitrogen inhibitor did you mix with the nitrogen applied to this field?"	Section C/Question 17, a

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-10. Corn Acres Grown With Variable Rate Technology

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"Was a variable rate applicator (i.e., variable rate technology or VRT; include on-the-go systems such as GreenSeeker) used on this field for--- a. fertilization or liming? (1) nitrogen applications? "	Section F/Question 14, a, 1
	"How many acres of corn did this operation plant in this field for the 2005 crop?"	Section B/Question 1
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2010 crop year?"	Section A/Question 1
	"Was a variable rate applicator used on this field for--- a. fertilization or liming? (1) nitrogen applications? "	Section F/Question 15, a, 1
	"How many acres of corn did this operation plant in this field for the 2010 crop?"	Section B/Question 1
ARMS CORN PPCR 2016[3]	"How many acres of corn did this operation plant for the 2016 crop year?"	Section A/Question 1
	"14. Was any of the following GPS-enabled (Global Positioning System) equipment used to produce crops on this field?" d. Variable rate application for fertilizer/lime?	Section F/Question 14, d
	"How many acres of corn did this operation plant in this field for the 2016 crop?"	Section B/Question 1

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-11. Wheat Acres Grown With Variable Rate Technology

Survey	Question (s)	Section/question #
ARMS WHEAT PPCR 2004[1]	"How many acres of wheat (winter, durum and other spring) did this operation plant for the 2004 crop year?"	Section A/Question 1
	"Was a variable rate applicator (i.e., variable rate technology or VRT) used on this field for--- a. fertilization or liming? a. nitrogen applications? "	Section F/Question 15, a, a
	"How many acres of [X][a] wheat did this operation plant in this field for the 2004 crop?"	Section B/Question 1
ARMS WHEAT PPCR 2009[2]	"How many acres of wheat (winter, durum and other spring) did this operation plant for the 2009 crop year?"	Section A/Question 1
	"Was a variable rate applicator used on this field for--- fertilization or lime application? nitrogen applications? "	Section F/Question 15, a, 1
	"How many acres of [X][a] wheat did this operation plant in this field for the 2009 crop?"	Section B/Question 1

[1] (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c); [2] (USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-12. Corn Acres Grown With Auto Steer

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2005[1]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"Was a guidance or auto steer system (connected to GPS) used with any machine operation on this field (e.g. light bar, assisted steering, automatic steering, etc. – exclude custom operations)?"	Section 5/Question 15
	"How many acres of corn did this operation plant in this field for the 2005 crop?"	Section B/Question 1
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2010 crop year?"	Section A/Question 1
	"Was a guidance or auto steer system (connected to GPS) used with any machine operation on this field (e.g., light bar)?"	Section F/Question 16
	"How many acres of corn did this operation plant in this field for the 2010 crop?"	Section B/Question 1
ARMS CORN PPCR 2016[3]	"How many acres of corn did this operation plant for the 2016 crop year?"	Section A/Question 1
	"Was any of the following GPS-enabled (Global Positioning System) equipment used to produce crops on this field? Guidance auto steer (excluding Light Bar)? Light Bar?"	Section F/Question 14, a and b
	"How many acres of corn did this operation plant in this field for the 2016 crop?"	Section B/Question 1

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a).

[a] Depending on survey, [x] = winter, spring or durum wheat

TABLE D-13. Soybean Acres Grown With Auto Steer

Survey	Question (s)	Section/question #
ARMS SOYBEAN PPCR 2006[1]	"How many acres of soybeans did this operation plant for the 2006 crop year?"	Section A/Question 1
	"Was a guidance or auto steer system (connected to GPS) used with any machine operation on this field (e.g., light bar, assisted steering, automatic steering, etc. – excluding custom operations)?"	Section F/Question 14
	"How many acres of soybeans did this operation plant in this field for the 2006 crop?"	Section B/Question 1
ARMS SOYBEAN PPCR 2012[2]	"How many acres of soybeans did this operation plant for the 2012 crop year?"	Section A/Question 1
	"Was a guidance or parallel swathing system (connected to GPS) used with any machine operation on this field (e.g., light bar)?"	Section F/Question 14
	"How many acres of soybeans did this operation plant in this field for the 2012 crop?"	Section B/Question 1

[1] (USDA ERS, 2006); [2] (USDA ERS, 2012b). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-14. Wheat Acres Grown With Auto Steer

Survey	Question (s)	Section/question #
ARMS WHEAT PPCR 2004[1]	"How many acres of wheat (winter, durum and other spring) did this operation plant for the 2004 crop year?"	Section A/Question 1
	"Was a guidance or parallel swathing system (connected to GPS) used with any machine operation on this field (e.g., light bar)?"	Section F/Question 16
	"How many acres of [X][a] wheat did this operation plant in this field for the 2004 crop?"	Section B/Question 1
ARMS WHEAT PPCR 2009[2]	"How many acres of wheat (winter, durum and other spring) did this operation plant for the 2009 crop year?"	Section A/Question 1
	"Was a guidance or parallel swathing system (connected to GPS) used with any machine operation on this field (e.g., light bar)?"	Section F/Question 16
	"How many acres of [X][a] wheat did this operation plant in this field for the 2009 crop?"	Section B/Question 1

[1] (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c); [2] (USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

[a] Depending on survey, [x] = winter, spring or durum wheat

TABLE D-15. Cover Crops on Farmland for Crops and Livestock

Survey	Question (s)	Section/question #
ARMS CRR 2010[1]	"How many acres of cropland were (1) planted to a cover crop after the 2009 crop was harvested and (2) Subsequently planted to an annual crop (e.g., corn, wheat) for 2010?"	Section B/Question 5, 1 and 2
ARMS CRR 2011[2]	"How many acres of cropland were (1) planted to a cover crop after the 2010 crop was harvested and (2) Subsequently planted to an annual crop (e.g., corn, wheat) for 2011?"	Section B/Question 5, 1 and 2
ARMS CRR 2012[3]	"During 2012, considering the total acres on this operation, (g) how many cropland acres were planted to a cover crop?"	Section 34/Question 1, g
ARMS CRR 2015[4]	"On how many cropland acres in 2015 did you: Plant a cover crop?"	Section A/Question 14, b

[1] (USDA ERS, 2010a); [2] (USDA ERS, 2011); [3] (USDA ERS, 2012a); [4] (USDA ERS, 2015). ARMS CRR = Agricultural Resource Management Survey Costs and Returns Report.

TABLE D-16. Corn Acres Grown With No tillage and Corn Acres Grown With Mulch Tillage

Survey	Question (s)	Section/question #
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"What operation or equipment was used?"	Section F/Question 1, 3
	"How many acres were covered?"	Section F/Question 1, 8
ARMS CORN PPCR 2010[2]	"How many acres of corn did this operation plant for the 2010 crop year?"	Section A/Question 1
	"What operation or equipment was used?"	Section F/Question 3, 3
	"How many acres were covered?"	Section F/Question 3, 9
ARMS CORN PPCR 2016[3]	"How many acres of corn did this operation plant for the 2005 crop year?"	Section A/Question 1
	"What operation or equipment was used?"	Section F/Question 1, 3
	"How many acres were covered?"	Section F/Question 1, 8

[1] (USDA ERS, 2005); [2] (USDA ERS, 2010b); [3] (USDA ERS, 2016a). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-17. Soybean Acres Grown With No Tillage and Soybean Acres Grown With Mulch Tillage

Survey	Question (s)	Section/question #
ARMS SOYBEAN PPCR 2006[1]	"How many acres of soybeans did this operation plant for the 2006 crop year?"	Section A/Question 1
	"What operation or equipment was used?"	Section F/Question 1, 3
	"How many acres were covered?"	Section F/Question 1, 8
ARMS SOYBEAN PPCR 2012[2]	"How many acres of soybeans did this operation plant for the 2012 crop year?"	Section A/Question 1
	"What operation or equipment was used?"	Section F/Question 1, 3
	"How many acres were covered?"	Section F/Question 1, 8

[1] (USDA ERS, 2006); [2] (USDA ERS, 2012b). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

TABLE D-18. Wheat Acres Grown With No Tillage and Wheat Acres Grown With Mulch Tillage

Survey	Question (s)	Section/question #
ARMS WHEAT PPCR 2004[1]	"How many acres of [X][a] wheat did this operation plant in this field for the 2004 crop?"	Section B/Question 1
	"What operation or equipment was used?"	Section F/Question 3, 3
	"How many acres were covered?"	Section F/Question 3, 9
ARMS WHEAT PPCR 2009[2]	"How many acres of [X][a] wheat did this operation plant in this field for the 2009 crop?"	Section B/Question 1
	"What operation or equipment was used?"	Section F/Question 3, 3
	"How many acres were covered?"	Section F/Question 3, 9

[1] (USDA ERS, 2004a; USDA ERS, 2004b; USDA ERS, 2004c); [2] (USDA ERS, 2009a; USDA ERS, 2009b; USDA ERS, 2009c). ARMS PPCR = Agricultural Resource Management Survey Production Practices and Costs Report.

[a] Depending on survey, [x] = winter, spring or durum wheat

TABLE D-19. Crop Rotations Split Into Three Tillage Categories

Survey	Question (s)	Section/question #
CEAP 2003[1]	"In 2003, how many acres in the field were Cropped? Idle cropland or summer fallow"	Question 7, a or c
	"What operation or equipment was used on this field in 2003, 2002 and 2001?"	Section H/Question 1, 3
CEAP 2004[2]	"In 2004, how many acres in the conservation tract containing the sample point were planted or cropped (including hay acres harvested)? c. idle cropland, summer fallow, or rotational pasture?"	Section A/Question 1, a or c
	"What operation or equipment was used on this field in 2004, 2003, 2002?"	Section I/Question 3, 4
CEAP 2005[3]	"In 2005, how many acres in the conservation area containing the sample point were planted or cropped *(including hay acres harvested) (selected field)*? c. idle cropland, summer fallow, or rotational pasture? *(selected field)*?	Section A/Question 1, a or c
	"What operation or equipment was used on this field in 2005, 2004, 2003?"	Section I/Question 1, a, 4
CEAP 2006[4]	"In 2006, how many acres in the conservation area containing the sample point were planted or cropped *(including hay acres harvested) (selected field)*? c. idle cropland, summer fallow, or pasture in rotation with crops? *(selected field)*?	Section A/Question 1, a or c
	"What operation or equipment was used on this field in 2006, 2005, 2004?"	Section I/Question 1, a, 4

[1] (USDA NRCS, 2003); [2] (USDA NRCS, 2004); [3] (USDA NRCS, 2005); [4] (USDA NRCS, 2006). CEAP = Conservation Effects Assessment Project.