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Tillage Intensity and Conservation Cropping in the United States

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Abstract

Reducing tillage and increasing soil cover can enhance soil health. Conservation tillage, particularly no-till or strip-till, used in conjunction with soil cover practices (like conservation crop rotations and cover crops) can lead to a range of soil health benefits: improved agricultural productivity, greater drought resilience, and better environmental outcomes. This report uses field-level data to estimate tillage practice adoption based on soil disturbance as measured by absence of tillage operations (for no-till) and the Soil Tillage Intensity Rating (STIR, for mulch till). To gauge the intensity of tillage over time, we estimate the number of years no-till or strip-till are used over a 4-year period. Rates of adoption for practices that affect soil cover—including conservation crop rotations, cover crops, double cropping, fallowing, and residue harvest or grazing—are also estimated. The rates at which these practices are adopted in conjunction with no-till/strip-till are also estimated to illustrate interactions between tillage and practices that affect soil cover.

Keywords: tillage, no-till, mulch-till, conservation tillage, conservation crop rotation, cover crop, double cropping

Acknowledgments

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Contents

Errata

On October 12, 2018, the report *Tillage Intensity and Conservation Cropping in the United States* was reposted to correct for coding errors that resulted in the miscalculation of some estimates for conservation cropping, cover crops, and other practices that affect crop residue. Specifically, Figure 3, Figure 4, Table 1a, and Table 1b have been replaced. Conforming changes have been made in the text on pages 6, 9, 10, 11, 12, and 18. The largest changes are an increase in cover crop acreage for corn (2016) and cotton (2015) and an increase in conservation cropping for wheat (2017). Acreages for tillage types in Tables 1a and 1b are lower because observations with less than 4 years of crop and tillage data were inadvertently included (but have now been excluded). All changes are restricted to figures, tables, and text that rely on ARMS cropping and tillage history data.

United States Department of Agriculture

A report summary from the Economic Research Service September 2018

Tillage Intensity and Conservation Cropping in the United States

Roger Claassen, Maria Bowman, Jonathan McFadden,
David Smith, and Steven Wallander

What Is the Issue?

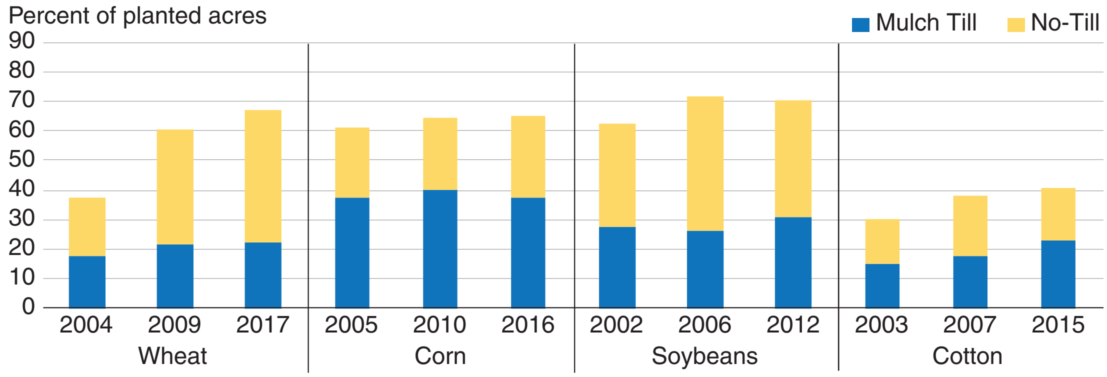
Tillage is used to control weeds, incorporate crop residue, and prepare land for planting, but minimizing soil disturbance and maintaining soil cover are critical to improving soil health. Crop choice is typically driven by crop prices, soils, and climate, but crop rotations can also break weed and pest cycles, improve crop yields, and reduce soil erosion. USDA conservation programs are increasingly focused on reducing tillage and promoting cropping practices (like cover crops and crop rotations) that could improve soil health. Progress toward improving soil health and soil erosion control can be monitored, at least in part, by tracking trends in the use of practices that reduce or minimize soil disturbance and increase soil cover.

What Did the Study Find?

Conservation tillage practices—including no-till, strip-till, and mulch-till—vary widely across crops and regions:

- Conservation tillage was used on roughly 70 percent of soybean (2012), 65 percent of corn (2016), 67 percent of wheat (2017), and 40 percent of cotton (2015) acres.
- The share of total conservation tillage that is no-till also varied from 67 percent (45 percent of total acreage) in wheat (2017) and 56 percent (40 percent of total acreage) in soybeans (2012) to 44 percent (18 percent of total acreage) in cotton (2015) and 42 percent (27 percent of total acreage) in corn (2016).
- Despite initial increases in no-till wheat (2004-09) and soybeans (2002-06), more recent data show less rapid gains for wheat (2009-17) and an apparent decline in no-till adoption on soybeans (2006-12).
- For individual crops, the rate of no-till varies by region. The likelihood of no-till corn, for example, is relatively high in the Northern Great Plains (50 percent of conservation tillage in corn, 34 percent of total corn acreage), Prairie Gateway (69 percent of conservation tillage, 49 percent of corn), and the South (the Eastern Uplands, Southern Seaboard, and Mississippi Portal combined) (67 percent of conservation tillage, 53 percent of corn).
- Almost 50 percent of corn, soybean, wheat, and cotton acreage was in no-till or strip-till at some time over a 4-year period (including the survey and 3 previous years), but only about 20 percent of these acres were in no-till or strip-till all 4 years.

Trends in conservation tillage adoption



Note: Mulch till is land with tillage and a Soil Tillage Intensity Rating less than 80.

Source: USDA Economic Research Service, based on USDA Agricultural Resource Management Survey (ARMS) data for 2002-2017.

Residue and cover practices can also affect soil health by determining—in conjunction with tillage practices—the extent to which soil remains covered throughout the year. Adoption of these practices varies across crops and, to some extent, across tillage practices:

- Conservation crop rotations (rotations that include high-residue crops that require relatively little nitrogen) are more frequently identified on land in the survey of corn producers (2016) than in the soybean, wheat, or cotton surveys.
- Double cropping and cover crops—which increase crop residue—were used on 12 percent or less of all surveyed fields.
- Fallowing—which typically reduces crop residue—was used on 13 percent of wheat acreage and less than 5 percent of other crops.
- Corn stover (residue) removal through grazing or harvest—which reduces residue—occurred on about 16 percent of corn acres.
- Evidence suggests that farms using no-till or strip-till practices, at least in some years, are more likely to also adopt residue- and cover-increasing practices.

How Was the Study Conducted?

All data are from the Agricultural Resource Management Survey (ARMS), a national-level survey of farming operations conducted by USDA's National Agricultural Statistics Service (NASS) and ERS. Data are based on the three most recent field-level, crop-specific production practice surveys of the four most widely grown U.S. crops: corn (2005, 2010, and 2016); soybeans (2002, 2006, and 2012); cotton (2003, 2007, and 2015); and wheat (2004, 2009, and 2017). Data on tillage operations, supplied by survey respondents, are used to identify fields in no-till (absence of tillage operations) and mulch till (tillage operations with a Soil Tillage Intensity Rating (STIR) less than 80). Using the STIR—rather than methods based on soil residue cover (previously used by ERS to estimate conservation tillage adoption)—focuses our estimates on soil disturbance, rather than a combination of soil disturbance and residue from the previous crop. To capture the interaction of tillage and practices that increase soil cover, we estimate the extent to which conservation crop rotations, cover crops, double cropping, and fallow are used in conjunction with no-till. ARMS data provide a 4-year history of crops grown (including cover crops) and an indicator of no-till or strip-till for each crop in the history, as identified by the survey respondent.

Tillage Intensity and Conservation Cropping in the United States

Introduction

Farmers till for many reasons. Tillage is used to prepare the soil for planting, control weeds, incorporate manure or fertilizer spread on the soil surface, and mix crop residue into the soil. Soils exposed by tillage typically absorb more heat and warm up more quickly, allowing earlier planting for some crops (particularly corn) in regions where spring weather is often cool and wet.

Conservation tillage—the use of tillage methods that disturb the soil less than "conventional" tillage—was originally promoted as a soil and water conservation technology. In the aftermath of the Dust Bowl, early conservation tillage implements—such as the Hoeme, Noble, and stubble-mulch plows—were developed to keep crop residue on the soil surface, reducing soil erosion and conserving soil moisture (Allen and Fenster, 1986; Russel, 1976; Unger and Baumhardt, 2001). Because soil and water conservation were the primary purposes and residue cover is effective for both, conservation tillage was initially defined as any system that retained at least 30 percent residue cover at planting (Conservation Tillage Information Center, 2018).

In recent decades, farmers have increasingly adopted conservation tillage methods for a broader set of reasons. In addition to reducing erosion and preserving soil moisture, conservation tillage can reduce crop production costs by reducing the use of fuel, labor, and tillage machinery. Herbicide-tolerant crops have increased the availability of pesticides for post-emergent weed control and further reduced reliance on tillage (Givens et al., 2009; Perry et al., 2016). Increasingly sophisticated planters equipped to cut through or clear crop residue from the row have made it easier to plant directly into untilled, residue-covered soil.

More recently, USDA's Natural Resources Conservation Service (NRCS) has identified soil health as a key focus for soil management (USDA-NRCS, 2018a). Soil health refers to the "continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (USDA-NRCS, 2018a). Healthier soils[1] can reduce environmental damage and benefit farmers. For example, the adoption of soil health practices can improve rainfall infiltration rates and soil water-holding capacity, reducing environmental damage due to sediment, nutrient, and pesticide runoff while reducing the risk of low crop yields by increasing drought resilience (Karlen et al., 1994; Moebius-Clune et al., 2008; Rawls et al., 2003).

[1]Although there are many physical, chemical, and biological indicators of soil health, soil scientists have developed several indicators that reflect underlying processes and help us assess the health of soils. These include soil organic carbon, soil aggregation, readily available carbon and nitrogen pools, and measures of the activity and diversity of the soil microbial community (USDA-NRCS, 2018b).

USDA's NRCS outlines four basic principles to help farmers manage for soil health by protecting and "feeding" the soil[2] (USDA-NRCS, 2017; Moore-Kucera, 2018):

- Keep the soil covered (protect),
- Reduce soil disturbance (protect),
- Keep living roots in the soil (feed), and
- Diversify using rotations and cover crops (feed).

Conservation tillage, which protects the soil by reducing soil disturbance and keeping the soil covered, is considered to be a key component of a soil health management system (USDA-NRCS, 2017). Other management practices that increase soil cover, crop residue, or crop diversity may also contribute to building soil health. Conservation crop rotations and cover crops, for example, increase the amount of residue available for soil cover, the diversity of plants grown, and the proportion of the year when living roots are in the soil.

Given increasing focus on soil health, our characterization of tillage practices focuses on (1) the intensity of soil disturbance, (2) consistency in use of minimum-disturbance tillage practices over time in individual fields, and (3) the relationship of tillage intensity to practices that increase residue, crop diversity, and crop cover. To focus on soil disturbance, the absence of tillage is used to define no-till systems and the Soil Tillage Intensity Rating (STIR) is used to define how much tillage is allowed in any conservation tillage system. The term "conservation tillage" generally encompasses no-till and mulch-till (any tillage practice that is not no-till and has a STIR rating of less than 80). Strip-till is a mulch-till method used in row crops to minimize soil disturbance by tilling only in narrow strips over the rows. Uptake of tillage practices is estimated using USDA's Agricultural Resource Management Survey (ARMS) data for corn (2005, 2010, 2016), cotton (2003, 2007, 2015), soybeans (2002, 2006, 2012), and wheat (2004, 2009, 2017) (see box, "USDA's Agricultural Resource Management Survey").

[2]Feeding the soil means providing an environment where a diverse set of soil microbes can thrive. These microbes provide nutrients (and other compounds) to the plant at the root-soil interface where the plants can take them up. Microbial food is exuded by plant roots. Sugars from living plant roots, recently dead plant roots, crop residues, and soil organic matter all feed the many and varied members of the soil food web. A diverse set of soil microbes requires planting a diverse set of crops.

USDA's Agricultural Resource Management Survey

USDA collects information on farm costs and returns, farm financial conditions, farm structure, and crop/livestock production practices using the Agricultural Resource Management Survey. Data underlying this study are from the field-level (phase II) survey. The questionnaire collects information on crop production inputs, management practices, and costs (fertilizer, pesticide, labor, tillage, seed, etc.) for target commodities, including corn, soybeans, wheat, cotton, sorghum, barley, oats, rice, and peanuts. ARMS data include extensive field-level information on cropping patterns, including double cropping and cover crops (some surveys), field operations (used to estimate tillage practices), residue management, nutrient applications (including manure), and many other practices. Data are collected on a rotating basis for each crop; the interval between surveys depends on the importance of the crop (as measured by acreage or production value) and the rate at which crop-specific production technologies are changing. These rotations do not have a fixed length and can change in response to a number of concerns. For example, data on corn production were collected in 2005, 2010, and 2016. Wheat data were collected in 2004, 2009, and 2017. For more information on how ARMS data are collected, please see USDA, ERS, 2018.

Glossary

Conservation tillage—Tillage management practices that result in a STIR (see below) of less than or equal to 80, and do not use a moldboard plow. Conservation tillage practices can include mulch-till, no-till, or strip-till.

Conservation crop rotation—A sequence of crops on the same field for the purpose of supporting soil health, conserving natural resources, and improving environmental outcomes from farming (USDA-NRCS, 2014a). Specifically, we define a conservation rotation to include at least one high-residue crop (e.g., corn), at least one low-nitrogen crop (e.g., grass or legume), and as attaining a threshold level of average annual residue. A corn-soybean (only) rotation is not considered a conservation crop rotation.

Conventional tillage—A combination of tillage management practices that result in a STIR of greater than 80.

Cover cropping—Planting a crop for seasonal cover, as when annual ryegrass is planted during the winter months between cash crops.

Crop residue—Plant material from a crop, such as cornstalks or soybean stubble, that remains after harvest. Residue can be left on the field, grazed, or harvested.

Double cropping—Harvesting two commodity crops from the same field in a given year (e.g., winter wheat and soybeans).

Fallowing—Leaving land idle for a year, often to accumulate moisture in semi-arid regions. Fallowing is most often used in wheat production.

Mulch-till—A type of conservation tillage where soil is tilled (for example with a chisel or disk) but soil disturbance is low (STIR less than 80).

No-till—The practice of refraining from tilling the soil from harvest of the previous crop to harvest of the current crop.

Residue grazing—The practice of letting livestock graze crop residue after a crop has been harvested.

Residue harvest—The practice of harvesting the residue of a cash crop for a secondary use, such as harvesting corn residue for animal feed or bedding material.

Soil Tillage Intensity Rating (STIR)—A numerical index that represents the type and severity of disturbance caused by tillage operations. The STIR value incorporates the type, speed, depth, and degree of disturbance caused by tillage management decisions. The STIR is the sum of STIR values of individual field operations.

Strip-till—A tillage system used to minimize soil disturbance in row crops by tilling only in narrow strips where seeds are planted. In fields where tillage is limited to narrow strips, the STIR is typically well under 80.

Tillage Practices

While conventional tillage, conservation tillage, and no-till are often presented as a simple choice, the choice of tillage practice actually consists of a wide set of choices. Many different types of tillage equipment—plows, discs, etc.—can be used for tillage operations. Prior to planting, farmers may make zero, one, or multiple passes with the tillage equipment. Tillage practices are much researched because they affect both crop residue and soil disturbance. Other field operations during crop production (e.g., planting and fertilizer application) also impact residue and soil disturbance.

We define no-till as the absence of tillage operations from harvest of the previous crop to harvest of the current crop. Mulch till involves limited tillage operations. National practice standards for mulch (reduced) tillage,[3] established by USDA's Natural Resources Conservation Service (NRCS), set a maximum STIR of 80 for "Residue and Tillage Management, Reduced Till" (USDA-NRCS, 2016).

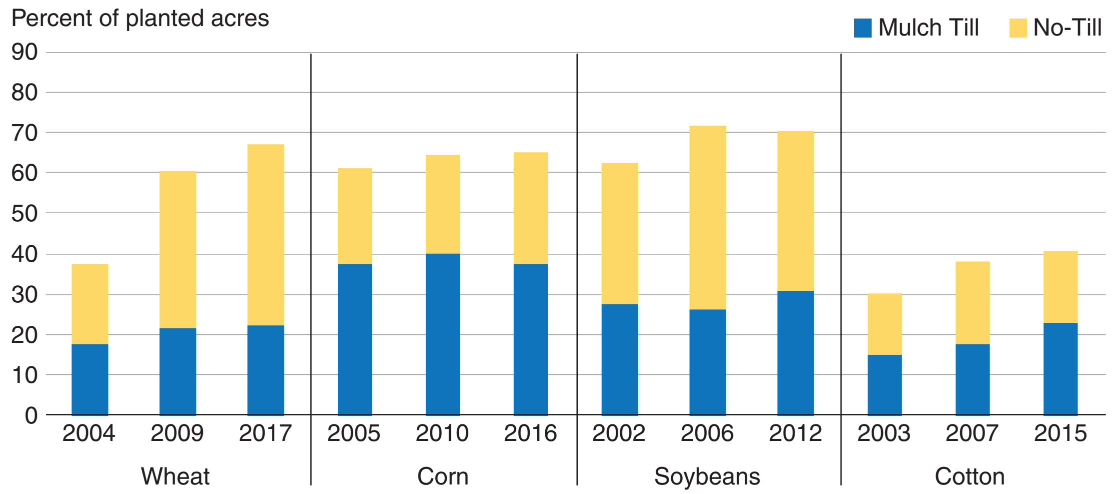
Conservation tillage was used on a majority of wheat (67 percent in 2017), corn (65 percent, 2016), and soybeans (70 percent, 2012) in the most recent surveys (fig. 1a). Conservation tillage was used on just 40 percent of cotton acres (2015). No-till accounted for more than 50 percent of conservation tillage acres on 2017 wheat (67 percent of conservation tillage; 45 percent overall) and 2012 soybeans (56 percent; 40 percent overall). Smaller proportions of conservation tillage were no-till on 2016 corn (42 percent; 27 percent overall) and 2015 cotton (44 percent; 18 percent overall).

In general, no-till adoption increased from 2000 to 2007 (Horowitz et al., 2010). Our data (2002-17; fig. 1b) include periods of increasing no-till adoption, particularly for wheat (2004-2009) and soybeans (2002-2006), and periods when no-till adoption leveled off and may have actually declined, particularly for soybeans (2006-2012) and cotton (2007-2015). Changes in no-till are far less dramatic for corn, where the data indicate only modest gains for 2005-10 and 2010-16.

The Soil Tillage Intensity Rating (STIR) is a measure of soil disturbance developed by NRCS to reflect all field operations. A STIR value is assigned to each field operation. The type of tillage equipment, tillage depth, speed, and percent of soil surface disturbed (width) are all factors that help determine operation-specific STIR values (USDA-NRCS, 2008). The STIR for the field is the simple sum of STIR values for all field operations from the harvest of the previous crop through the harvest of the current crop. The STIR is an index (without units) that typically falls in the range of 0-200, with high values associated with higher tillage intensity.

[3]What we define as "mulch tillage" is similar to "reduced tillage" in the most recent NRCS practice standards (USDA-NRCS, 2016). We continue to use the term "mulch tillage" to differentiate this practice from "reduced till," previously defined by the Conservation Tillage Information Center (CTIC) as land where residue cover is 15-30 percent after planting and is not considered to be conservation tillage.

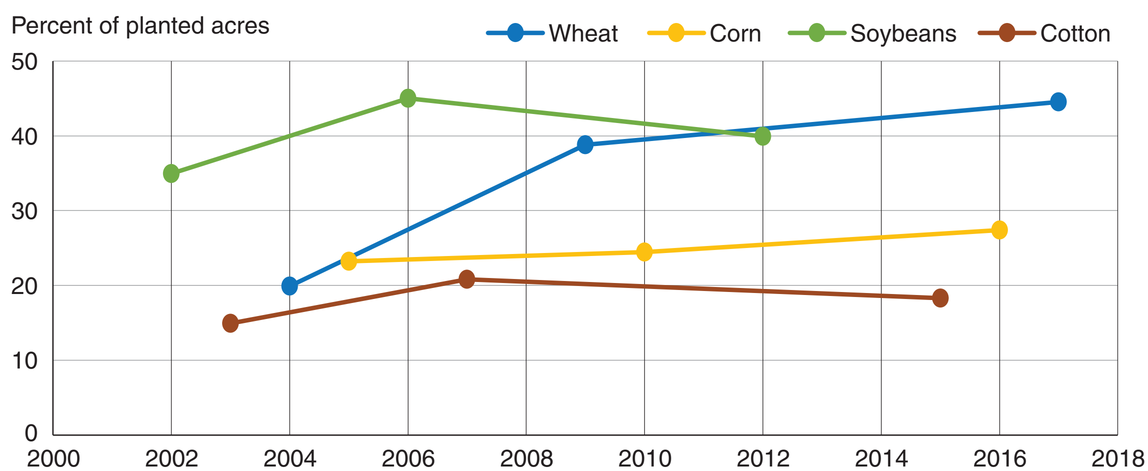
Figure 1a
Conservation tillage, 2002-2017



Note: No-till is based on the absence of tillage operations reported in the Agricultural Resource Management Survey (ARMS). Mulch till is indicated when the Soil Tillage Intensity Rating (STIR) is less than or equal to 80 (for the entire season) with some tillage operations.

Source: USDA Agricultural Resource Management Survey data for 2002-2017.

Figure 1b
No-till adoption, 2002-2017



Note: No-till is based on the absence of tillage operations reported in the Agricultural Resource Management Survey (ARMS).

Source: USDA Agricultural Resource Management Survey data for 2002-2017.

Conservation tillage adoption also varies across regions (fig. 2). These variations may reflect a range of concerns, including soil moisture conservation, timely planting (tilled soils tend to warm more quickly than untilled soils), and the risk of soil erosion. In corn, no-till adoption is greater in drier regions (Northern Great Plains, Prairie Gateway) and warmer regions (Prairie Gateway, the South). Higher adoption in dryer regions may reflect the importance of conserving soil moisture in areas where rainfall is limited (Davey and Furtan, 2008; Ding et al., 2009). Higher adoption in warmer regions may mean that tillage is not needed to facilitate soil warming and ensure timely planting. No-till soybeans are most likely in warm regions (Prairie Gateway, the South) and seem to be more likely in portions of the north with higher rainfall (e.g., no-till is more likely in the Heartland and the Northern Crescent than in the Northern Great Plains). A higher rate of no-till adoption in regions with greater rainfall has been observed previously (Pautsch et al., 2001) and may reflect concern about soil erosion. Conservation tillage (including no-till) in wheat is most common in the Basin and Range, Northern Great Plains, Northern Crescent, and Heartland regions, exceeding 50 percent of 2017 acreage in each of these regions.

Tillage over time. Soil health benefits of conservation tillage may be fully realized only when practices minimize soil disturbance (e.g., no-till, strip-till) consistently over time (USDA-NRCS, 2014b). Nonetheless, many producers alternate no-till or strip-till with tillage practices that disturb the entire soil surface (conventional or mulch-till). The prevalence of no-till/strip-till in any given field may depend on the likelihood of these practices on the crops grown in rotation in the region where the field is located. Topography and soil conditions are also likely determinants. Previous research shows that "highly erodible" land and well-drained land (land that dries out quickly enough to avoid crop damage due to wet conditions) are more likely than other land to be continuously in no-till over time (Wade and Claassen, 2017).

In the ARMS data, tillage practice estimates are derived from two sources. For survey years (e.g., 2005, 2010, and 2016 for corn), tillage practices are estimated from detailed data on field operations. For the 3 years prior to the survey year (e.g., 2013, 2014, and 2015 for the 2016 corn survey), ARMS respondents are asked to list up to two crops for each year (one fall-planted and one spring-planted crop) and whether no-till or strip-till[4] was used to grow each listed crop.[5] Using these data, each surveyed field was placed in one of three tillage categories: continuous no-till/strip-till (no full-width tillage during the 4-year period), alternating no-till/strip-till (full-width tillage in 1-3 years), and continuous tillage (full-width tillage in all 4 years).

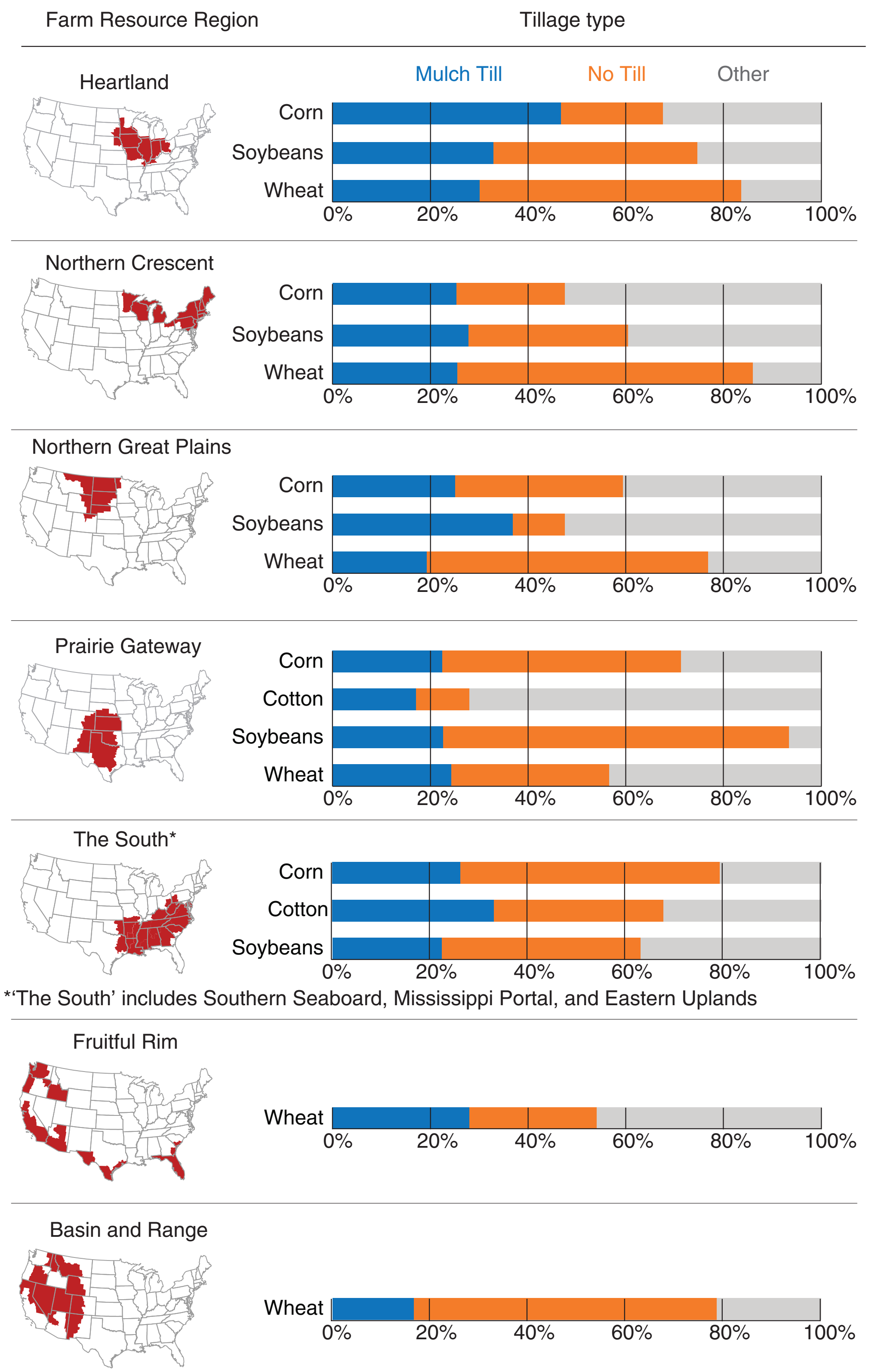
Using these data, an estimated 21 percent of the combined acreage in the four surveys (corn, 2016; cotton, 2015; soybeans, 2012; and wheat, 2017) were continuously in no-till or strip-till in all 4 years (fig. 3). Continuous no-till/strip-till was most common in those fields where the surveyed crop was wheat. Continuous no-till/strip-till was least common where the surveyed crop was cotton.

On an estimated 30 percent of land in the four crop surveys combined, producers used some combination of no-till or strip-till and full-width tillage (alternating no-till/strip-till). An estimated 49 percent of land across all four crops was continuous tillage (that disturbs the entire soil surface) in all 4 years. Continuous tillage was most common in the corn and cotton surveys.

[4]The 2012 soybean survey asks only about no-till. The 2015 cotton and 2016 corn surveys ask whether no-till or strip-till was used. Strip-till is not used in wheat.

[5]In the survey, no-till is defined as leaving soil and previous crop residue undisturbed from harvest to planting. Strip-till is defined as tilling a narrow strip over the row, leaving soil and previous crop residue between the rows undisturbed.

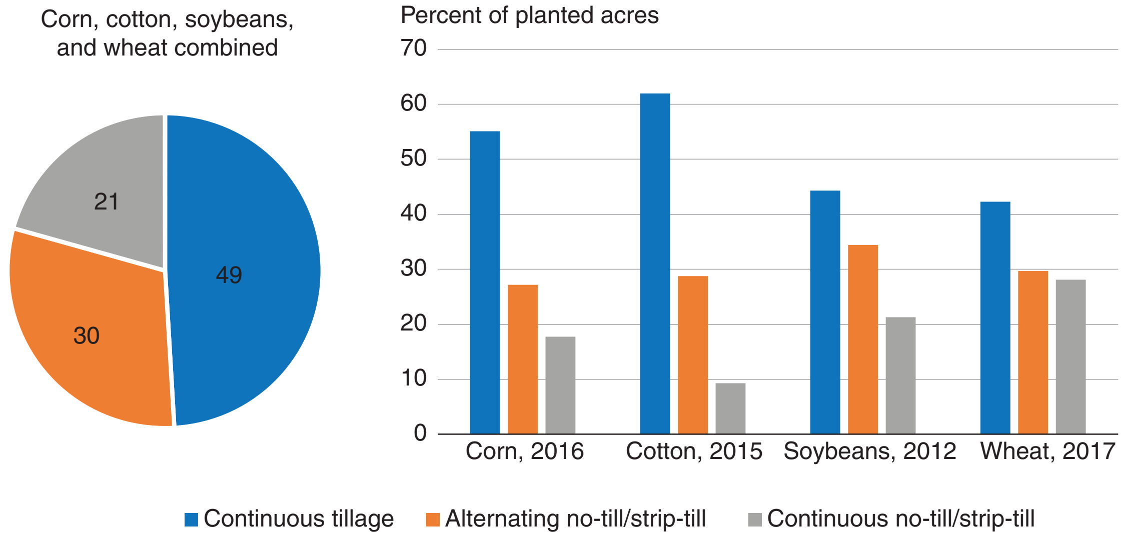
Figure 2
No-till and mulch-till adoption by crop and ERS farm resource region



Notes: No-till is based on the absence of tillage operations reported in the Agricultural Resource Management Survey (ARMS). Mulch till is indicated when the Soil Tillage Intensity Rating (STIR) is less than 80 (for the entire season).

Source: USDA Agricultural Resource Management data for wheat (2017), corn (2016), soybeans (2012), and cotton (2015).

Figure 3
Tillage over time, by surveyed crop and for all crops combined



Notes: Continuous tillage is continuous full-width tillage for 4 years. Surveyed fields grew wheat in 2017, soybeans in 2012, cotton in 2015, or corn in 2016, but could have been planted to other crops during any of the 3 years preceding the survey year.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, field-level data from the Agricultural Resource Management Survey, 2012, 2015, 2016, and 2017.

Cropping Practices That Improve Soil Health

Tillage decisions and their impacts on crop production cannot be fully understood in isolation. Many farmers make concurrent decisions about tillage, crops, residue-related practices, and other practices related to tillage (e.g., use of herbicide-tolerant seeds). These choices interact to determine an operation's profitability because the production practices are often complementary. In other words, the incremental benefit from increased adoption of no-till or other conservation tillage practices depends on the crop or cropping practice. For example, no-till adoption is higher in some crops (wheat and soybeans) than others (corn and cotton). Field-level and farm-level evidence suggests that some farmers rotate tillage practices along with crops (Wade et al., 2015).

Conservation Crop Rotations. Crop rotations are common in U.S. agriculture. Conservation crop rotation refers to a sequence of crops on the same field for the purpose of supporting soil health, conserving natural resources, and improving environmental outcomes from farming (USDA-NRCS, 2014a). There is no single definition of a conservation crop rotation. The crops grown vary based on crop prices, climate, growing conditions, resource concerns, and conservation/commodity policies. For example, rotating shallow-rooted with deep-rooted crops can help crops use more of the water available throughout various layers of soils. Including crops that provide food and habitat for beneficial insects (e.g., buckwheat or clover) or trap crops (that provide an alternate source of food) can reduce pest pressure. Excess nutrients applied to some crops can be partly taken up by a subsequent crop that roots quickly and at an appropriate depth (USDA-NRCS, 2014a). Our emphasis is on rotations with high-residue crops that can improve soil health when used in conjunction with conservation tillage, particularly no-till or strip-till. For this report, a conservation crop rotation[6] must have:

1. An average annual residue rating greater than 1.5 (see below),

2. At least one high-residue crop (annual residue rating of at least 2),

3. More than one crop in the rotation (including cover crops), and

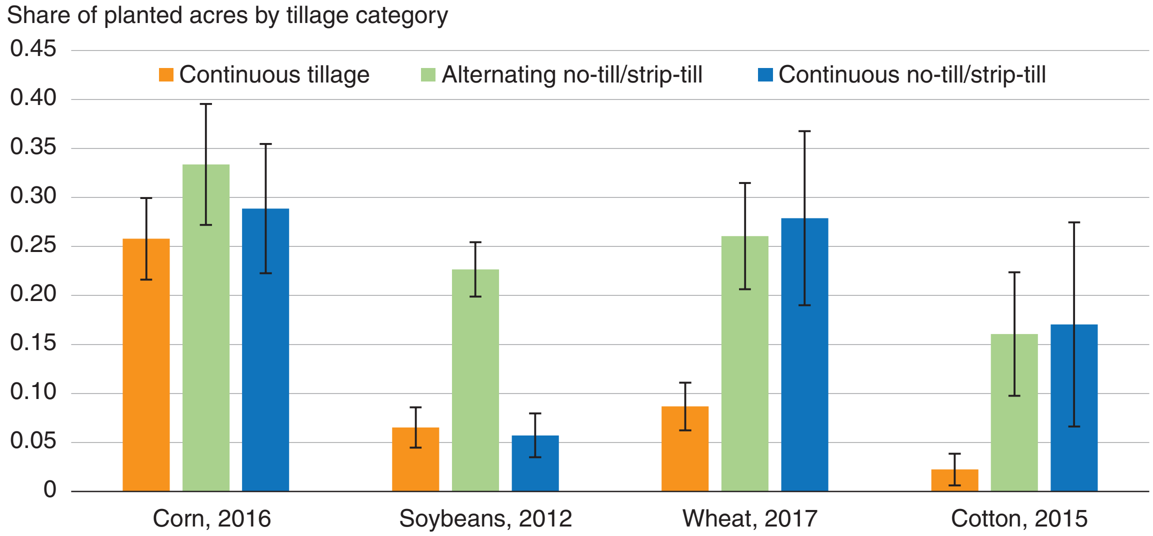
4. At least one low-nitrogen crop (e.g., a grass or legume).

We assign annual residue ratings (obtained from USDA's Natural Resources Conservation Service), which range from 0.25 to 4.0, for each crop. Very-high-residue perennial crops (e.g., alfalfa and other grasses) have a residue rating of 4. High-residue annual crops (e.g., corn, wheat, sorghum, and barley) have a residue rating of 2. Low-residue annual crops (e.g., soybeans and cotton) have a residue rating of 1. Based on this definition, a simple corn-soybean rotation is not considered a conservation crop rotation because its average annual residue rating is exactly 1.5. However, a soybean-winter wheat-corn rotation is considered a conservation crop rotation since it satisfies criteria (2) through (4) and has an average annual residue rating of 1.67 over the 3-year rotation.

Roughly 28 percent of 2016 corn acreage was planted as part of a conservation crop rotation, a larger share than for cotton (8 percent), soybeans (12 percent), and wheat (19 percent) in recent years (table 1a). The predominance of conservation cropping varies by crop and tillage practice (fig. 4).

[6]This is designed to be consistent with characterizations of conservation crop rotations used in the Conservation Effects Assessment Project carried out by USDA\NRCS (Norfleet, 2018).

Figure 4
Share of planted acres adopting conservation crop rotation by crop and tillage practice



Note: Continuous tillage refers to continuous (4 years) full-width tillage. Error bars show 95 percent confidence interval for each estimate.

Source: USDA, Economic Research Service based on Agricultural Resource Management Phase II data for 2012, 2015, 2016, and 2017.

Multi-Cropping and Fallowing. The relative benefits of conservation crop rotations—and crop rotations more generally—can depend directly on the intensity of cropping. Rotations that involve more intensive use of cropland, including double cropping and cover cropping, increase residue production. In contrast, idled cropland—including fallowed fields—reduces residue production but is often used to accumulate moisture needed for crop production in drier climates.

Double cropping is the practice of harvesting two crops in 1 year. Cover cropping often involves planting two crops in 1 year but harvesting only one crop, although cover crops may be grazed or harvested for silage but not grain or seed (USDA-NRCS, 2014c).[7] Both practices are uncommon (table 1a). Between 3 and 6 percent of corn, cotton, soybean, and wheat acres were double cropped in recent years. Similarly, 5 percent of 2016 corn acreage, 12 percent of 2015 cotton acreage, and 2 percent of 2017 wheat acreage was cover cropped. Some highly productive cropland does not have sufficiently long growing seasons to accommodate two crops in the same year without reducing the economic returns to one or both crops (Borchers et al., 2014). Double cropping is highest in Southern States with longer growing seasons (Wade et al., 2015). Corn and soybeans are the most common spring-planted crops in these rotations, while winter wheat and rye are the most common fall-planted crops (Borchers et al., 2014).

Differences in management of the fall-planted crop create differences in soil health benefits from cover cropping relative to double cropping (Bergtold et al., 2017). Although harvested crops leave residue on the field, unharvested cover crops can leave behind more. In cotton (2015) and corn (2016), cover crops are more likely to be grown in fields where no-till or strip-till is used continuously or at least in some years during the 4-year crop history, although these practices are applied jointly on only a small number of acres. Legume cover crops like hairy vetch, sunn hemp, and

[7]ARMS respondents self-identify cover crops in the crop history table.

winter peas can provide supplemental nitrogen to cash crops for the following season (Bergtold et al., 2017). Both double cropping and cover cropping increase crop residue available for cover, reducing soil erosion and the potential for leaching or runoff of agricultural chemicals.

Fallowing is the practice of leaving a field unplanted for one or more seasons following crop harvest. This most commonly occurs as cultivated summer fallow—cropland left unplanted in dry environments to accumulate moisture before planting, typically to small grains. In 2017, 13 percent of wheat acreage was fallowed (table 1b). Fallowed cropland has been declining in recent decades (USDA-ERS, 2017) as acreages under intensified cropping practices have increased. Cropping patterns that simultaneously reduce fallowing and tillage intensity can increase soil organic matter, water content, and soil microbial activity and can improve overall soil structure (Nielsen and Calderón, 2011).

Other Cropping Practices That Influence Soil Health. Applying manure to cropland and harvesting or grazing of crop residues also influence soil structure and soil organic matter. In particular, the harvesting of residue reduces cover, increasing the potential for soil erosion, reducing organic matter formation, and (possibly) increasing nutrient requirements for the next crop (Karlen et al., 2014). In contrast, manure applications can significantly increase organic matter (Haynes and Naidu, 1998).

Residue was grazed on 12 percent and harvested on 4 percent of 2016 corn acres (table 1b).[8] In the western Corn Belt, corn stover has long been grazed or harvested for cattle feed. More recently, corn stover has been harvested for energy feedstock used in cellulosic biofuels plants in the central Corn Belt (Rosburg et al., 2017). Wheat has been grazed for cattle feed in seasons when early crop growth is sufficient to withstand temporary grazing without damaging grain yields. In 2017, 19 percent of wheat acreage was grazed. Wheat straw, which is often used as livestock bedding, was harvested from about 5 percent of wheat acres. Soybeans and cotton are low-residue field crops not typically used for grazing or residue harvest, so ARMS Phase II questionnaires do not elicit such information from soybean and cotton farmers.

Manure directly increases soil organic matter since it is organic matter in the form of liquid, semi-dry, or solid waste. Manure's contribution to soil organic matter varies directly with its carbon-nitrogen ratio, which is affected by animal source and diet, as well as the duration and type of storage. All of these factors are highly variable, though recurring manure applications over many years clearly increase organic carbon, soil microbial activity, and porosity (Haynes and Naidu, 1998).[9] However, manure use varies significantly by crop. Nearly 16 percent of 2016 corn acreage received manure (table 1b) while only 4 percent of cotton (2105), 3 percent of soybeans (2012), and 2 percent of wheat (2017) received manure.

Linking Tillage, Cropping, and Residue Practices. There is some evidence to suggest that residue-increasing practices are more common on land in continuous no-till/strip-till or alternating no-till/strip-till, particularly for soybeans, wheat, and cotton (table 1a). Overall adoption of conservation rotations are higher for corn, but adoption rates for land in no-till/strip till (alternating or continuous) are not significantly different from the rate on continuously tilled corn acres. Between 5 and 13 percent of cotton, soybean, and wheat acres in alternating no-till/strip-till were double

[8]Across multiple ARMS survey years and target crops, farmers' primary reason for not harvesting residue was either the desire to leave it for organic matter or because there was no market or other use.

[9]It is difficult to precisely apply nutrients in manure, possibly leading to water quality issues.

cropped. In contrast, only 2 to 4 percent of cotton, soybean, and wheat acres in continuous tillage were double cropped. This trend holds for cover crops, which are less common on cotton and corn acreage under continuous tillage.

The link between tillage and manure applications varies by crop. Just over 18 percent of continuously tilled corn acres received manure, while only 10 percent of continuously no-tilled/strip-tilled corn acres received manure (table 1a). Because corn is the primary feed grain grown in the United States, it is likely to be grown near large concentrations of livestock. (For cotton, manure applications may be more common on fields under no-till/strip-till practices. However, relatively wide confidence intervals around these estimates make it difficult to establish clear trends in manure use for cotton, soybeans, and wheat under various tillage systems.)

For cropping practices that reduce residue, there is less variability in acreage shares by tillage practices for each crop (table 1b). For example, the share of continuously tilled corn acres with residue harvested (4 percent) does not significantly differ from the share of corn acres in alternating no-till/strip-till (4 percent) or continuous no-till/strip-till (2 percent). There are no clear relationships between tillage and fallowing for any of the major field crops.

Table 1a

Conservation cropping and practices that increase residue by crop and continous tillage, alternating no-till/strip-till, and continuous no-till/strip-till

Crop	Tillage	Acres	Share of acres by crop	Conserva-tion cropping	Double cropping	Cover crop	Manure application
				Share of planted acres by tillage category (95% confidence interval)			
Corn, 2016	Cont. till	44,058	0.55	0.26	0.02	0.03	0.18
	95% CI	±2,388		±0.042	±0.005	±0.009	±0.026
	Alt. no/strip-till	21,747	0.27	0.33	0.05	0.05	0.14
	95% CI	±2,596		±0.062	±0.016	±0.016	±0.050
	Cont. no/strip-till	14,203	0.18	0.29	0.01	0.08	0.10
	95% CI	±1,734		±0.066	±0.006	±0.027	±0.051
	All tillage[1]	81,903		0.28	0.03	0.05	0.16
	95% CI	±1,077		±0.031	±0.006	±0.010	±0.019
Cotton, 2015	Cont. till	4,543	0.62	0.02	0.03	0.06	0.03
	95% CI	±386		±0.016	±0.017	±0.018	±0.014
	Alt. no/strip-till	2,109	0.29	0.16	0.12	0.22	0.06
	95% CI	±440		±0.063	±0.047	±0.077	±0.030
	Cont. no/strip-till	679	0.09	0.17	0.02	0.27	0.06
	95% CI	±227		±0.104	±0.013	±0.084	±0.053
	All tillage	7,472		0.08	0.06	0.12	0.04
	95% CI	±294		±0.023	±0.013	±0.030	±0.011
Soybeans, 2012	Cont. till	30,420	0.44	0.07	0.03	NA	0.04
	95% CI	±1,605		±0.021	±0.007		±0.011
	Alt. no/strip-till	23,634	0.34	0.23	0.13	NA	0.04
	95% CI	±1,959		±0.028	±0.022		±0.019
	Cont. no/strip-till	14,638	0.21	0.06	0.02	NA	0.01
	95% CI	±1,544		±0.022	±0.012		±0.011
	All tillage	69,246		0.12	0.06	NA	0.03
	95% CI	±949		±0.016	±0.009		±0.009
Wheat, 2017	Cont. till	15,443	0.42	0.09	0.04	0.01	0.02
	95% CI	±2,206		±0.024	±0.023	±0.005	±0.016
	Alt. no/strip-till	10,839	0.30	0.26	0.07	0.01	0.02
	95% CI	±1,981		±0.054	±0.028	±0.005	±0.017
	Cont. no/strip-till	10,259	0.28	0.28	0.04	0.04	0.01
	95% CI	±1,031		±0.089	±0.031	±0.025	±0.009
	All tillage	36,993		0.19	0.05	0.02	0.02
	95% CI	±1,018		±0.028	±0.013	±0.007	±0.009

[1]Observations with partial crop histories are excluded, so acreage estimate for "All tillage" is less than for all ARMS observations. However, "All tillage" includes some observations for which tillage history could not be established, so it is greater than the sum of continuous tillage, alternating no-till/strip-till and continuous no-till/strip-till.
NA = data not available for these surveys. CI = confidence interval.

Source: USDA, Agricultural Resources Management Survey data for 2012, 2015, 2016, and 2017.

Table 1b

Conservation cropping and practices the reduce residue by crop and continous tillage, alternating no-till/strip-till, and continuous no-till/strip-till

Crop	Tillage	Acres	Share of acres by crop	Fallow	Residue harvested	Grazing[2]
			Share of planted acres by tillage practice (95% confidence interval)			
Corn, 2016	Cont. till	44,058	0.55	0.00	0.04	0.06
	95% CI	±2,388		±0.002	±0.011	±0.019
	Alt. no/strip-till	21,747	0.27	0.02	0.04	0.16
	95% CI	±2,596		±0.010	±0.020	±0.034
	Cont. no/strip-till	14,203	0.18	0.01	0.02	0.23
	95% CI	±1,734		±0.007	±0.014	±0.059
	All tillage[1]	81,903		0.01	0.04	0.12
	95% CI	±1,077		±0.003	±0.007	±0.019
Cotton, 2015	Cont. till	4,543	0.62	0.02	NA	NA
	95% CI	±386		±0.013		
	Alt. no/strip-till	2,109	0.29	0.01	NA	NA
	95% CI	±440		±0.016		
	Cont. no/strip-till	679	0.09	0.07	NA	NA
	95% CI	±227		±0.099		
	All tillage	7,472		0.02	NA	NA
	95% CI	±294		±0.012		
Soybeans, 2012	Cont. till	30,420	0.44	0.01	NA	NA
	95% CI	±1,605		±0.003		
	Alt. no/strip-till	23,634	0.34	0.01	NA	NA
	95% CI	±1,959		±0.004		
	Cont. no/strip-till	14,638	0.21	0.01	NA	NA
	95% CI	±1,544		±0.015		
	All tillage	69,246		0.01	NA	NA
	95% CI	±949		±0.003		
Wheat, 2017	Cont. till	15,443	0.42	0.13	0.05	0.25
	95% CI	±2,206		±0.032	±0.015	±0.064
	Alt. no/strip-till	10,839	0.30	0.11	0.07	0.19
	95% CI	±1,981		±0.030	±0.024	±0.069
	Cont. no/strip-till	10,259	0.28	0.16	0.03	0.11
	95% CI	±1,031		±0.040	±0.011	±0.039
	All tillage	36,993		0.13	0.05	0.19
	95% CI	±1,018		±0.015	±0.009	±0.032

[1]Observations with partial crop histories are excluded, so acreage estimate for "All tillage" is less than for all ARMS observations. However, "All tillage" includes some observations for which tillage history could not be established, so it is greater than the sum of continuous tillage, alternating no-till/strip-till and continuous no-till/strip-till.

[2]On corn, residue is commonly grazed; Wheat grazing usually occurs when wheat is growing in early spring.

NA = data not available for these surveys. CI = confidence interval.

Source: USDA, Agricultural Resources Management Survey data for 2012, 2015, 2016, and 2017.

How Tillage Estimates Differ Using STIR and Residue Methods

In the past, ERS classified tillage practices using an estimate of soil residue cover remaining at planting time, which focused on the "keep it covered" approach to reducing soil erosion. However, because a number of other practices influence residue cover estimates, the STIR is more likely to accurately characterize soil disturbance due to tillage. Nonetheless, a key question is how these methods actually differ in classifying the tillage systems. Our method of determining no-till does not change (i.e., the absence of tillage operations), so no-till estimates are unchanged.

Residue Cover Method. Data on the previous crop and pre-planting tillage operations, obtained from the ARMS survey, have been used to estimate the extent of conservation tillage since 1988 (USDA-ERS, 1993; Bull, 1993). This method for characterizing tillage systems uses percent residue cover on the field at planting.[10] Fields that have more than 30 percent cover on the field and have a tillage operation are categorized as mulch tillage. Fields that do not have any tillage operations are categorized as no-till. These two categories together constitute conservation tillage. To estimate percent residue cover that remains at planting, we start with an estimate of residue cover from the previous crop and then estimate the reduction in residue for each tillage pass. Residue from hay, including alfalfa, leaves the soil almost entirely (90-95 percent) covered (table 2). Corn, sorghum, and wheat residues also leave the soil mostly covered (85 percent). Soybeans leave a moderate amount of residue (60 percent). Corn and sorghum silage (10 percent) and cotton (35 percent) leave relatively little residue.

Each tillage pass reduces residue coverage. The percentage reduction depends on the tillage implement and whether residue from the previous crop is "fragile." One pass with a moldboard plow, for example, reduces residue coverage by 95 percent. In contrast, a stubble mulch plow—a conservation tillage implement—reduces nonfragile residue coverage by only 15 percent. Fragile residue (e.g., soybeans) decomposes more easily and has higher residue reduction rates with each tillage pass. For example, one pass with a stubble mulch plow reduces fragile residue by 45 percent, compared to 15 percent for non-fragile residue. Due to differences in the previous planted crop, two fields that are tilled the same way can be categorized into different tillage systems.

Table 2
Surface residue coverage and fragility for common field crops

	Surface residue coverage		
Fragility	Low (<40%)	Medium (40-70%)	High (>70%)
Low	Cotton, corn silage, sorghum silage	Rice, canola	Hay, corn, wheat, small grains, sorghum
High	Sugarbeets, beans, peas, peanuts	Soybeans	

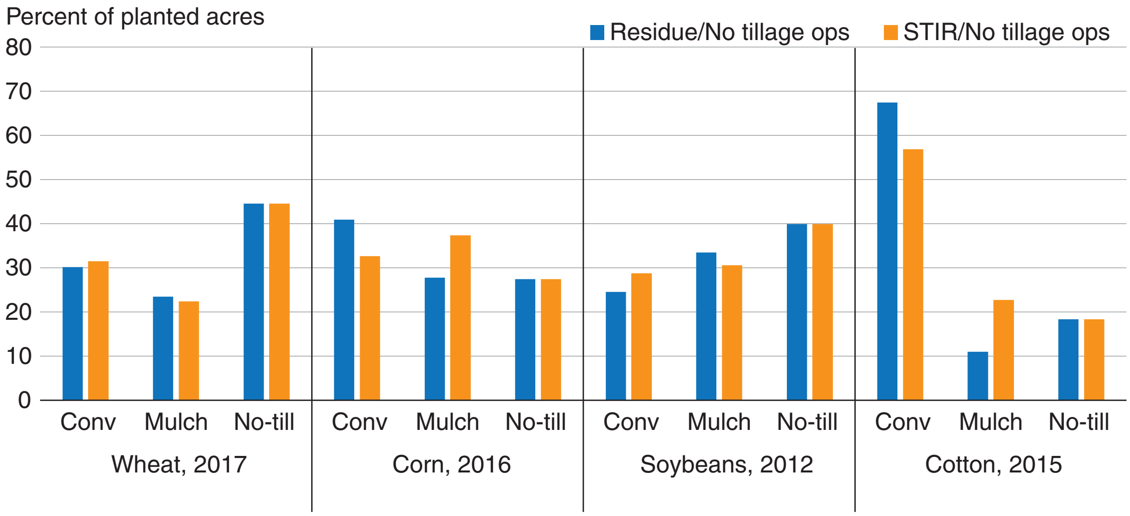
[10]This method has no relation to the method used to determine a conservation crop rotation. Conservation rotation is broader than just the amount of residue produced in a single year.

Because the residue method relies on the previous crop, and different crops are grown in rotations together, the impacts of switching tillage methods will vary from crop to crop. In addition, certain types of tillage equipment, with differing impacts on surface residue and soil disturbance, may be used on one crop more than another. Finally, because the residue method relies on tillage *up to planting* and the STIR method relies on tillage and other field operations *for the entire season*, post-planting operations (e.g., row cultivation for weed control) could affect differences in categorization.

Results. In wheat (2017) and soybeans (2012), the STIR method categorizes more fields as conventionally tilled than does the residue-based method (fig. 5). In corn (2016) and cotton (2015), the STIR method categorizes more fields as mulch tilled than the residue-based method.

Figure 5

Tillage practice estimates using STIR and estimated residue at planting, as a share of planted acres



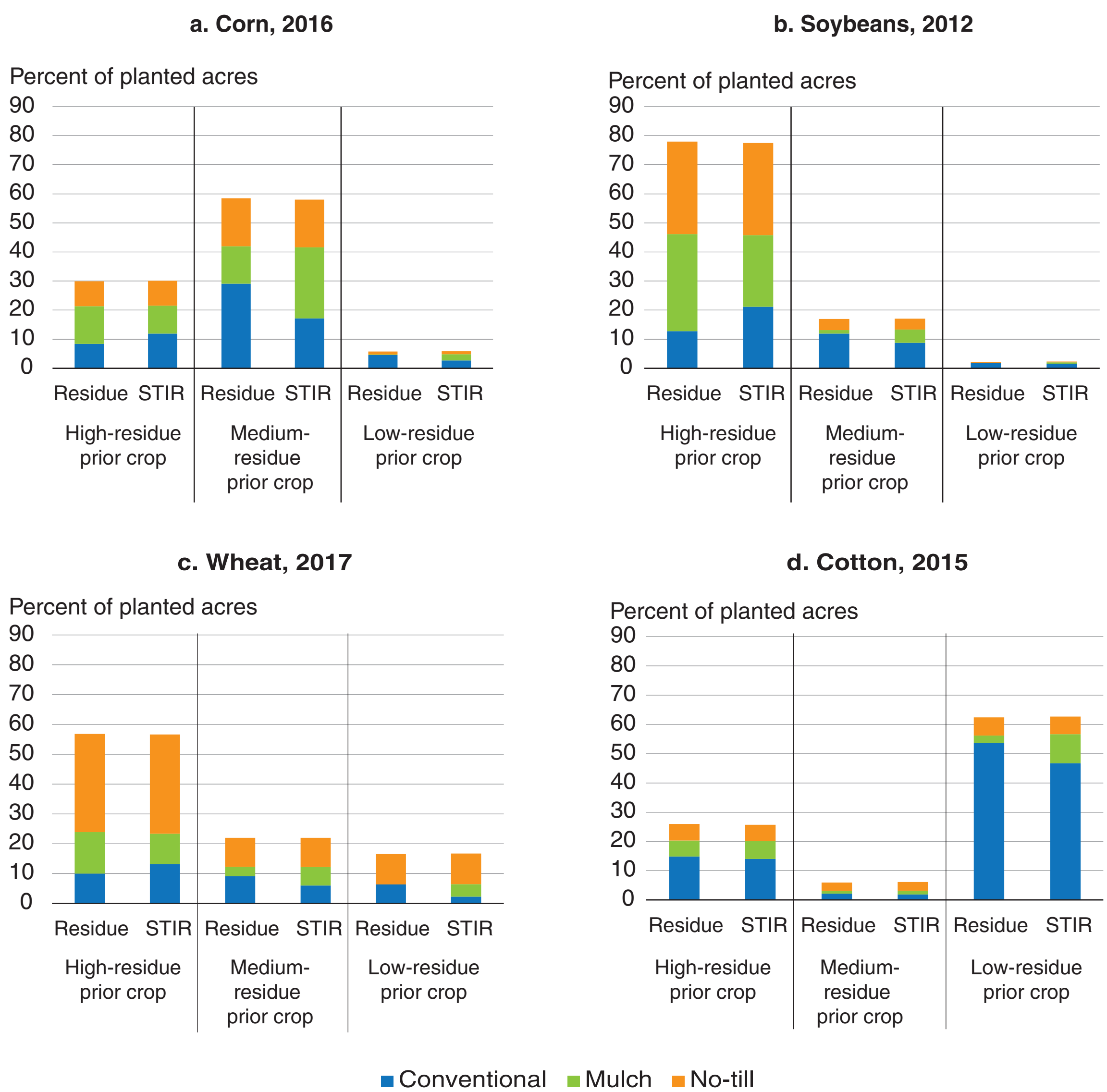
Note: No-till is based on the absence of tillage operations reported in ARMS. Mulch till with the residue method is indicated when at least 30 percent of the soil surface is estimated to be covered with residue just prior to planting with some tillage operations. Mulch till with the Soil Tillage Intensity Rating (STIR) method is indicated when the STIR measure is less than 80 (for the entire season) with some tillage operations.

Source: USDA, Agricultural Resources Management Survey data for 2012, 2015, 2016, and 2017..

Classification of tillage using the residue method depends on the amount of residue produced by the previous crop and whether the residue is “fragile,” meaning it breaks down easily with tillage. Where a crop that produces a high level of non-fragile residue, such as corn for grain or wheat, was planted in the previous year, a conservation tillage classification is more likely using the residue method than the STIR method. Where a medium- or low-residue crop or a crop with fragile residue—such as soybeans, cotton, or silage—was planted in the previous year, a conventional tillage classification is more likely using the residue method than the STIR method. The majority of corn fields follow a medium-residue crop, most commonly soybeans. These fields are more than twice as likely to be categorized as conventional till using the residue method when compared to the STIR method (fig. 6a). Soybean fields leave relatively little residue cover on the field (65 percent), and soybean residue is relatively fragile. Soybeans often follow corn, a high-residue crop. Because of high starting residue cover on these fields, the residue method is more likely to categorize the tillage system as mulch till than is the STIR method (fig. 6b). On soybean fields that follow a medium-residue crop, the residue method is more likely to categorize the tillage system as conventional. The story for wheat is similar to that for soybeans. Wheat often follows a high-residue crop (fig. 6c), so the residue method is less likely to categorize the tillage system as conventional. Finally, cotton fields (fig. 6d) commonly follow a low-residue crop, making a conventional tillage categorization more likely when using a residue-based method.

Figure 6

Residue from prior crop and residue-based tillage versus STIR-based classifications



Notes: Primary high-residue crops include hay, corn, wheat, sorghum, and barley. The primary medium-residue crop is soybeans. Primary low-residue crops are cotton and any other crop harvested for silage. STIR = Soil Tillage Intensity Rating.

Source: USDA, Agricultural Resources Management Survey data for 2012, 2015, 2016, and 2017.

Conclusions

Conservation tillage is widely used in the production of major field crops, but adoption of conservation tillage—including no-till and strip-till—varies across crops and regions. Conservation tillage in general and no-till in particular increased significantly in wheat across the 2004 and 2009 surveys, but growth slowed over 2009-17. Growth in conservation tillage and no-till were both quite modest in corn and cotton. In soybeans, 2002-06 growth in overall conservation tillage and no-till was followed by an apparent decline in no-till from 2006 to 2012.

Within crops, there is also significant regional variation in conservation tillage and no-till adoption. Temporally, no-till/strip-till was used at least once on nearly 50 percent of land in the most recent surveys for the four major commodity crops. In contrast, continuous no-till was applied to only about 20 percent of acreage is these same surveys. In general, variation in tillage intensity may reflect crop choice, climate, soil productivity, soil erodibility, drainage, and soil topography (Ogle et al., 2012; Toliver et al., 2012; Wade et al., 2015; Wade and Claassen, 2017).

There is some evidence to suggest that farmers who use no-till are also more likely to use conservation crop rotations and cover crops. These practices may be viewed, at least by some farmers, as complementary because of their combined effect on soil health and productivity. The relatively high rate of conservation crop rotations by corn producers may be largely due to the fact that corn is a high-residue crop and (unlike wheat, the other common high-residue crop) is often grown in rotation with a legume (soybeans), although a simple corn-soybean rotation would not meet all of the criteria for a conservation rotation. Practices that could lead to higher residue, including cover crops and double cropping, are less widely adopted on all crops (except for cover crops on cotton farms). Some practices that reduce residue production or remove it from the field after harvest are adopted more often, including fallowing in wheat (13 percent of acres), residue grazing in corn (12 percent), and residue harvest in corn (4 percent) and wheat (5 percent). At present, there is little evidence to indicate whether farmers consider conservation tillage and residue practices to be complementary in production. That is particularly true for cover crop practices where adoption, although increasing, is still very low.

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