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Economic Outcomes of Soil Health and Conservation Practices on U.S. Cropland

Maria Bowman, Paul J. Ferraro, Kate Binzen Fuller, Benjamin Gramig, Roberto Mosheim, Eric Njuki, Bryan Pratt, Roderick Rejesus, and Andrew Rosenberg

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Abstract

The use of soil health and conservation practices has the potential to benefit society and agricultural producers through improvement in soil health, water quality, agricultural productivity, and other ecosystem services. However, there are costs associated with implementing such practices, and the net benefit to the producer and to society depends on how the practice is implemented, the production system, weather, climate, soils, and other variables. In addition, the factors affecting a producer's decision to implement soil health and conservation practices are complex. These factors include expectations about short- and long-run profitability, the risk and uncertainty associated with the practices, and behavioral factors such as producer willingness to take on risk, peer effects, and stewardship identity. This report provides conceptual framing and background on soil health management, producer decision making, and economic outcomes of soil health and conservation practices; documents trends in the adoption of key soil health and conservation practices on cropland; reviews key findings on the economic effects of soil health and conservation practices; and provides new results on the relationship between selected practices and the yields and costs at the field level and farm-level productivity and technical efficiency.

Keywords: soil health, conservation practices, economics, agriculture, productivity

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A report summary from the Economic Research Service *June 2025*

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What Is the Issue?

Soil health and conservation practices, such as conservation tillage, cover cropping, and nutrient management, have the potential to provide ecosystem services for society and improve the profitability of crop and livestock production for producers. However, the economic incentives that shape a producer's decision to use these practices are complex, and the public and private costs and benefits (and net benefit) of implementing these practices—alone or in combination—are not always known to producers, researchers, or society. Net benefits also vary by region, cropping system, soil type, climate, and other factors. This report describes the complexity of producer decision making with respect to soil health and conservation practices and provides new insights into the current rates of adoption and profitability of key practices in U.S. crop agriculture.

What Did the Study Find?

A review of the literature revealed that:

- Reducing tillage intensity can reduce input costs, but net profitability varies. The short-term return to adopting cover crops was often negative without cost-share or financial assistance.
- The economic outcomes of soil health practices are dynamic (change over time) and may vary with the amount of time a producer has been using the practice.
- Risk and uncertainty affect producer adoption of new soil health practices, such as cover cropping, as do other behavioral factors, such as time and risk preferences, and peer effects and social norms.
- The profitability of individual practices depends on the suite of conservation and other management practices employed in the management system (e.g., rotations, no-till, cover cropping, nutrient management).

An analysis of Census of Agriculture and Agricultural Resource Management Survey (ARMS) data showed that adoption rates of key soil health and conservation practices on cropland (conservation tillage, cover cropping, and nutrient management) varied by practice, region, and over time:

- Adoption of conservation tillage (no-till and reduced tillage combined) continues to increase, but the adoption of no-till alone has slowed for some crops.
- Cover crop adoption rates have been relatively low but increasing in many regions. Still, analysis of Census of Agriculture data suggests that more than half of operations stopped cover cropping from 1 census year to the next. Forty-eight percent of producers with cover crop acres in 2012 reported cover cropped acres in 2017, and 46 percent of operations with reported cover crop acres in 2017 reported cover cropped acres in 2022.
- For most commodity crops, fields with no-till and reduced tillage were more likely to be planted with cover crops relative to conventionally tilled fields.
- Corn and cotton fields that were also planted with cover crops had a larger share of nitrogen applied at or after planting relative to fields without cover crops.
- Nitrogen application has remained relatively constant across crops over time, but the timing of nitrogen applications has changed for some crops. More nitrogen is being applied at or after planting on wheat fields, and there was a recent increase in fall application for corn fields.

Analysis of data from ARMS suggests the following about the relationships between soil health practices, field-level yield and costs of production, and farm-level productivity and technical efficiency (which refers to how efficient users of the practice/technology are in combining available inputs to maximize production compared with nonusers):

- Conservation tillage was associated with higher corn but not soybean yields and with lower total operating costs for both corn and soybeans.
- Farms that used no-till/strip-till in corn, soybean, and cotton production had higher aggregate output, but cover crops were not found to be associated with farm-level productivity.
- Operations that adopted no-till/strip-till (but not cover crops) were slightly less technically efficient (i.e., less successful at using inputs to their fullest potential to maximize production) than those operations that did not.
- Operations that adopted both no-till/strip-till and cover crops were more technically efficient (i.e., had greater success at maximizing crop production through the combination of various inputs) relative to operations that had not adopted both practices.

How Was the Study Conducted?

To provide background on the economic effects of soil health practices on cropland and how producers make decisions regarding practice adoption (including the behavioral economic issues unique to soil health management systems), the report authors conducted a literature review. To estimate the persistence of cover cropping and joint adoption of cover crops and conservation tillage at the farm operation level, the authors used microdata (operation-level data) from the 2012, 2017, and 2022 Censuses of Agriculture. They also used data from Phase 2 (field-level data) and Phase 3 (operation-level data) of ARMS over the last two decades to estimate the rates of soil health and conservation practice adoption by crop, the effects of conservation tillage on input costs and yields for corn and soybeans, and the effects of conservation tillage and cover crops on production efficiency at the operation level and for individual crops. ARMS is a national survey of farming operations and production practices conducted by USDA's National Agricultural Statistics Service and Economic Research Service.

Economic Outcomes of Soil Health and Conservation Practices on U.S. Cropland

Background

Soil health and conservation practices[1] can benefit agricultural producers and society (see box, "Examples of Soil Health Practices on Cropland"). To improve soil health and function, soil health practices and management systems (i.e., multiple practices adopted together or practices combined with other management actions or inputs) follow four principles: maximize the presence of living roots, minimize disturbance, maximize soil cover, and maximize biodiversity (USDA, Natural Resources Conservation Service (NRCS), n.d.-a). The benefits these practices provide can be directly related to changes in the health or structure of the soil, such as reduced soil erosion, or can be derived from other pathways, such as weed control or nutrient uptake benefits of cover crops. Despite the potential to generate these benefits, soil health practices and management systems, as with many production practices, can be costly to implement. The benefits of the practices can also be related to how often and for how long the practice is used (Wood & Bowman, 2021; Krupek et al., 2022).

Economics suggest that a producer will adopt a soil health practice or management system if the expected net present value of doing so is positive or, more generally, if the expected benefits to the producer outweigh the costs. Some of the potential costs and benefits of soil health management practices that can influence adoption decisions include both private (accrue to producers) and public (accrue primarily to society beyond the farm) costs and benefits (table 1). Broadly, potential benefits of soil health practices can include improved soil health, soil carbon sequestration and other greenhouse gas (GHG) benefits, decreased soil erosion, improved water quality, improved yield, and decreased input costs, among others.[2] Conversely, costs associated with adoption (primarily private costs) can include increased input

Examples of Soil Health Practices on Cropland

No-till: Growing crops without tilling or plowing the soil.

Strip tillage: Tilling the soil using equipment that tills only a narrow strip where the crop will be planted, leaving the area between the rows undisturbed.

Reduced tillage: Tilling the soil in ways that minimize disturbance to the soil or maintain more residue cover than conventional tillage.

Mulching: Adding plant residue (or other materials) to the surface of the soil.

Cover cropping: Growing a crop primarily for conservation purposes, often over the winter. A cover crop is typically left in place as residue or harvested for forage or other on-farm use.

Conservation crop rotation: Choosing crop rotations to maximize crop diversity, build organic matter, and improve soil biodiversity.

Nutrient management: Adjusting the type, location, rate, and timing of fertilizer or other nutrients to meet plant needs and minimize environmental effects.

For additional information, see USDA's Farmers.gov Soil Health landing page and USDA's Natural Resources Conservation Service Soil Health landing page.

[1] The authors use "soil health and conservation practices" in this report to refer to land management practices that hold the potential to improve environmental outcomes that include—but are not limited to—soil health. The practices highlighted in this report are a subset of all soil health and conservation practices.

[2] For additional information on soil health indicators, see Bagnall et al. (2023) and USDA, Natural Resources Conservation Service (2023).

costs (including additional field operations), decreased yield, and opportunity costs (e.g., in the case where a cash crop could be grown instead of a cover crop) (Bergtold et al., 2019; Blanco-Canqui et al., 2015; Bowman, 2018; Claassen et al., 2018a; Plastina et al., 2020; Rejesus et al., 2021; Schipanski et al., 2014; Stevens, 2018; Wallander et al., 2021) (table 1). These costs and benefits also vary regionally, with climate, soils, crop types and rotations, production systems, and other factors, which might make it difficult for producers to estimate the profitability of these practices and systems or the expected profitability on their farms.

Soil health management practices chosen to address a specific need or resource concern could also have tradeoffs with respect to other outcomes. For example, cover crops might be effective at reducing nitrogen leaching and reducing nitrate concentrations in waterways but have uncertain or variable effects on phosphorus loss (Liu et al., 2019). Although nutrient management in the form of improving nutrient use efficiency or reducing the amount of nitrogen applied to a crop reduces nitrous oxide emissions, the effects of cover crops and tillage on nitrous oxide emissions are not always straightforward and depend on climate, timing, amount of residue, and soils (Basche et al., 2014; Deng et al., 2016; Grados et al., 2022). When cover crop biomass is removed via grazing or harvesting for forage rather than left unharvested, the producer obtains a private return. However, some studies have found there may be an effect on selected soil health and/or environmental outcomes, such as soil compaction (Dhakal et al., 2022; Schomberg et al., 2021). Additional research on the effects of different types of management practices on both economic and environmental outcomes will help inform when and where the net benefits of practice implementation are positive.

Table 1
Examples of private and public costs and benefits of soil health management practice decisions

	Potential benefits (Revenue increasing or cost decreasing)	**Potential costs** (Revenue decreasing or cost increasing)
Private (e.g., farm operation)	▪ Increased average yield or decreased yield variability (e.g., more resilient to drought and/or moisture during the growing season) ▪ Decreased input costs (e.g., less fertilizer with legume cover crop or fuel with conservation tillage) ▪ Grazing or harvested forage benefits from cover crops ▪ Reduced soil erosion/decreased soil compaction ▪ Improved nutrient use efficiency and/or reduced nutrient loss	▪ Decreased average yield or increased yield variability from cover crops (e.g., competition for moisture or nutrients with cash crop) ▪ Fixed costs (e.g., equipment purchases or capital investments to implement new practices or systems) ▪ Increased input costs (e.g., cover crop seed, herbicide costs for no-till, or cover crop termination) ▪ Opportunity costs (e.g., planting a cover crop instead of a cash crop where double cropping is feasible) ▪ Cover crop may attract unwanted wildlife or pests ▪ Adding field operations (e.g., planting, spraying) may affect field work scheduling and increase labor costs

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	Potential benefits (Revenue increasing or cost decreasing)	Potential costs (Revenue decreasing or cost increasing)
Public (e.g., external to farm operation)	▪ Reduced pest and disease outbreak incidence (e.g., due to beneficial insects or reduction in herbicide-resistant weeds) ▪ Reduced soil erosion improves air and water quality ▪ Carbon sequestration ▪ Reduced nutrient loss or improved pesticide management improves water quality ▪ Increased soil infiltration or water holding capacity could mitigate effects of extreme precipitation events ▪ Increased biodiversity	▪ Decreased yield or increased yield variability could have public costs in terms of federal program expenditures or land use change tradeoffs ▪ Increased pest or disease incidence for neighbors due to cover crops being a possible host ▪ Practices and management systems must be evaluated for environmental tradeoffs

Source: USDA, Economic Research Service compilation using Bowman (2018) and Rejesus et al. (2021).

The literature on soil health practice adoption emphasizes the private costs and benefits and the public benefits to society of adopting soil health practices when assessing the net benefit to the producer of adopting soil health and conservation practices and the economics of programs that provide financial assistance for these practices (table 1). However, lessons from behavioral economics and other social sciences suggest that there are additional factors other than just the magnitude of the private and public costs and benefits that affect producer adoption decisions (table 2). For example, soil health practices often require producers to incur short-term costs to generate long-term benefits. More generally, how a producer weighs forgoing something of value now (e.g., money, time) for something of value later (e.g., improved soil health, less variable yields) is represented in economics by the term "discount rate." In many cases, how producers discount future benefits is just as important as how large the future benefits are expected to be. Moreover, future benefits and costs of soil health practices are often uncertain, and thus attitudes toward uncertainty will also be just as important as the expected size of the future benefits and costs. Together with the factors in table 1, the factors in table 2 shape the incentives for producers to use soil health practices and management systems, including barriers to adoption.

Table 2
Summary of key behavioral factors that may affect adoption of soil health practices

Behavioral factor	Summary	Potential effects on adoption decision
Time preferences	How a producer weighs forgoing something of value now (e.g., money, time) for something of value later (e.g., improved soil health, less variable yields). Represented in economics by the intertemporal discount rate.	If a producer has a high discount rate, they may value large future benefits significantly less than the smaller short-term costs of adopting a soil health practice or management system.

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Behavioral factor	Summary	Potential effects on adoption decision
Risk preferences	Producers may consider the risks and uncertainty of outcomes in a range of ways, which may include reacting differently to expected gains and losses based on the context.	Soil health practices can increase or decrease risk, depending on the situation and context. More risk-averse producers would be less likely to adopt practices or systems that increase uncertainty and more likely to adopt practices that reduce uncertainty. The perception of practices as generating a risk of loss may also decrease the likelihood of adoption.
Peer effects and social norms	Producer decisions are affected by the choices of their neighbors and their peers, as well as social norms that shape the decision-making environment.	Adoption of a new practice may lag if it challenges social norms (e.g., clean/neat fields), and/or the practice is seen as unpopular by the producer's peers. Conversely, adoption may spread if peers and neighbors successfully implement new practices/management systems and share that news within their networks.
Stewardship identity	A producer's social identity with respect to conservation and environmental stewardship.	Producers who see themselves as stewards or conservationists may be more likely to implement soil health practices and management systems. Programs that recognize this identity (e.g., through awards, farm signs, or other public recognition) may have an impact on adoption.
Choice complexity	The number of steps required or the number of potential options from which a producer can choose can affect adoption.	Producers may be less likely to participate in programs that offer many options for participation or require multiple steps for signing up. They may be less likely to adopt complex practices that require making a set of interrelated decisions (e.g., cover cropping).
Anchoring and defaults	In contexts that are unfamiliar, producer decisions may be influenced by aspects that economics predicts would be irrelevant, such as default choices or starting values.	When applying to a conservation program with multiple options, the option presented as the "default" may be chosen more frequently than expected. Thus, if the default is to not select a conservation practice, then it can be less likely that this practice will be chosen.
Learning by doing or observing	When experience using or observing a practice impacts long-term use.	Producers may need to stick with a practice to see evidence of the benefits first-hand or to learn how to reduce the costs associated with the practice.

Source: USDA, Economic Research Service drawing on common themes in the behavioral economics literature.

Producer decision making is shaped by behavioral factors (table 2), as well as by the costs and benefits of soil health and conservation practices (table 1). However, the producer adoption decision is also affected by policies and programs that directly and indirectly incentivize adoption of soil health practices by offering producers financial and/or technical assistance. These resources include Federal and State programs, as well as regional and local initiatives. Technical assistance may incentivize adoption when a practice is profitable to the producer once implemented, but the producer lacks the skills, knowledge, or experience to install or implement the practice. Short-term financial assistance (e.g., 1–3 years) might be more likely to incentivize adoption when a practice is profitable in the long run after covering upfront investments and costs or after learning about or trialing the practice. Long-term financial assistance (e.g., 5–10 years) may be most useful when the private benefit is negative (the practice is not profitable for the producer), but the public benefit (to society) is positive.

At the Federal level, programs that provide financial assistance for soil health and conservation practices on working lands include the USDA, Natural Resources Conservation Service's (NRCS) Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP). These programs provide direct financial assistance to producers who implement practices or enhancements according to NRCS practice standards. USDA, NRCS also offers complimentary technical assistance to producers through the Conservation Technical Assistance (CTA) program as well as in support of financial assistance programs (Rosenberg & Wallander, 2022; USDA, Natural Resources Conservation Service (NRCS), n.d.-b). In 2021 and 2022, USDA, Risk Management Agency (RMA) implemented the Pandemic Cover Crop Program that offered a $5 per acre crop insurance premium support to producers who planted cover crops and reported them to RMA as part of the USDA's Pandemic Assistance for Producers initiative. This program was similar to State-level initiatives in Iowa, Illinois, and Indiana that offered (and in some cases continue to offer) a similar crop insurance premium discount for fields planted with cover crops (Illinois Department of Agriculture, 2022; Indiana State Department of Agriculture, 2022; Iowa Department of Agriculture and Land Stewardship, 2022).[3] Other researchers have provided more information about trends in spending on programs that support the adoption of conservation and soil health practices in the United States (Bowman et al., 2016; Claassen et al., 2018a; Wallander et al., 2021).

Current Adoption of Soil Health Practices on U.S. Cropland

This section reports current levels of adoption and recent trends in the adoption of several soil health and conservation practices, including conservation tillage (no-till and reduced tillage), cover cropping, conservation crop rotations, and nutrient management, as well as the joint adoption of some combinations of practices. This report does not specifically address the characteristics of operations using these practices or look at differential adoption of practices across different farm operation variables. However, there is a rich literature that looks at how the adoption of conservation practices varies with operator and operation characteristics, including land ownership and tenure, farm size, land quality/erodibility, operator age, and education and many others (Lee & McCann, 2019; Prokopy et al., 2019; Rahm & Huffman, 1984; Burnett et al., 2024). Also, in addition to their role in crop production systems, soil health practices and management systems are also implemented in livestock systems. This topic is beyond the scope of this report. Interested readers are referred to other recent USDA, ERS research that focuses on soil health practices and livestock production systems (Whitt & Wallander, 2022; Bowman et al., 2024).

To estimate these levels and trends, data from the U.S. Census of Agriculture (2012, 2017, and 2022)[4] and the USDA's Agricultural Resource Management Survey (ARMS) Phase 2 field-level surveys were used. In contrast to the census data, which provide high-level information on conservation practice adoption for a few practices for all U.S. farms every 5 years, data from ARMS Phase 2 provide more details on conservation practice adoption for a sample of fields producing specific commodities in specific years.[5]

Using data from the most recent ARMS Phase 2 survey year, table 3 summarizes adoption rates for tillage practices, cover crops, and conservation crop rotations by crop. No-till adoption rates ranged from 19–59 percent of acreage, depending on the crop, with total acreage in conservation tillage (no-till plus reduced tillage) ranging from 43–81 percent. The cover crop adoption rate was highest on cotton acreage, at 19 percent of acreage, and lowest on wheat and sorghum acreage. Oat acreage in 2023 and barley acreage in

[3] A number of States also offer cover crop programs or cost-share programs that pay for cover crops and other soil health practices (AGree, 2019; Bowman & Lynch, 2019; Wallander et al., 2021).

[4] Statistics from the Census of Agriculture were derived using data collected in the 2012, 2017, and 2022 Censuses of Agriculture by the USDA, National Agricultural Statistics Service (NASS). Any interpretations and conclusions derived from the data represent author viewpoints and are not necessarily those of USDA, NASS.

[5] ARMS Financial and Crop Production Practices documentation on the USDA, ERS website provides more information about what geographies and crops were sampled as part of the ARMS Phase 2 surveys.

2019 were most likely to meet the criteria for a conservation crop rotation, which reflects the crops typically grown in rotation with those surveyed crops (including cover crops), and the amount of residue associated with each crop in the rotation. Claassen et al. (2018a) have a detailed description of conservation crop rotations.[6] This report finds that acres that were in no-till or reduced till were more likely to have cover crops (table 3). This finding could indicate the benefits of jointly adopting both practices, such as greater improvements in soil physical properties like water infiltration (Blanco-Canqui et al., 2011). This pattern was consistent with findings in Wallander et al. (2021) and Claassen et al. (2018a), both of which have discussed rates of joint adoption of cover crops and tillage practices. In general, the adoption of conservation and soil health practices varied regionally, which is partially reflected in the adoption rates presented by crop in table 3.[7]

Table 3

Summary of adoption rates for key soil health practices by crop (percent of acreage), 2019–23

							Wheat (2022)	
	Barley (2019)	**Corn** (2021)	**Cotton** (2019)	**Oats** (2023)	**Sorghum** (2019)	**Soybeans** (2023)	**Durum and other spring wheat**	**Winter wheat**
	Percent							
Conventional tillage	20.9	24.5	57.1	23.7	24.4	19.3	20.8	34.4
Reduced tillage	35.0	39.9	23.5	39.8	16.8	35.9	21.7	25.6
No-till	44.1	35.6	19.4	36.5	58.9	44.8	57.5	40.1
Cover crops	2.1	8.4	18.8	3.4	1.1	11.1	0.8	0.0
Conservation crop rotation	27.3	23.9	9.7	34.3	14.0	22.2	18.5	25.8
Conventionally tilled acres with cover crops	1.6	4.3	5.4	5.5	0.0	4.7	0.0	0.0
Reduced tillage acres with cover crops	3.6	3.7	43.1	3.2	0.0	6.9	*	0.0
No-till acres with cover crops	1.3	14.3	29.0	2.4	2.0	17.0	*	0.0

Note: * denotes an estimate that was suppressed due to small sample size for that category. Tillage categories are determined based on reported field operations performed from the harvest of the previous crop through the harvest of the current crop. A field is considered to be no-till if the producer reported 0 tillage operations on the field during that period, and fields are considered to be reduced tillage if the Soil Tillage Intensity Rating (STIR) calculated for the field from information about tillage operations is less than 80. STIR values range from 0 to 200. Conventional tillage reflects a STIR value greater than 80. Cover crops are those adopted in the fall prior to the surveyed cash crop. Reduced- and no-till acres with cover crops are not reported for durum and other spring wheat due to small sample sizes. A conservation crop rotation is defined using 4 years of crop history data to evaluate whether crop rotations meet the following criteria: (1) an annual Natural Resources Conservation Service (NRCS) crop residue rating was greater than 1.5 averaged across 4 years of crop history data reported in the Agricultural Resource Management Survey (ARMS); (2) more than 1 crop was in rotation across 4 years of data; (3) rotation included a low-nitrogen-demanding crop such as soybeans or clover; and (4) included at least 1 crop with a residue rating greater than or equal to 2.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service ARMS Phase 2 (field-level) data.

[6] A conservation crop rotation is defined based on four criteria: (1) an annual residue rating greater than 1.5 averaged across 4 years of crop history data reported in ARMS, where residue ratings are assigned to each crop by NRCS; (2) inclusion of more than one crop in the rotation across 4 years of data; (3) the rotation includes a low-nitrogen-demand crop such as soybeans or clover; and (4) includes at least one crop with residue rating greater than or equal to 2.

[7] For example, cotton is primarily grown in Texas and the Southeast, where conventional tillage is more common independent of the crop being grown.

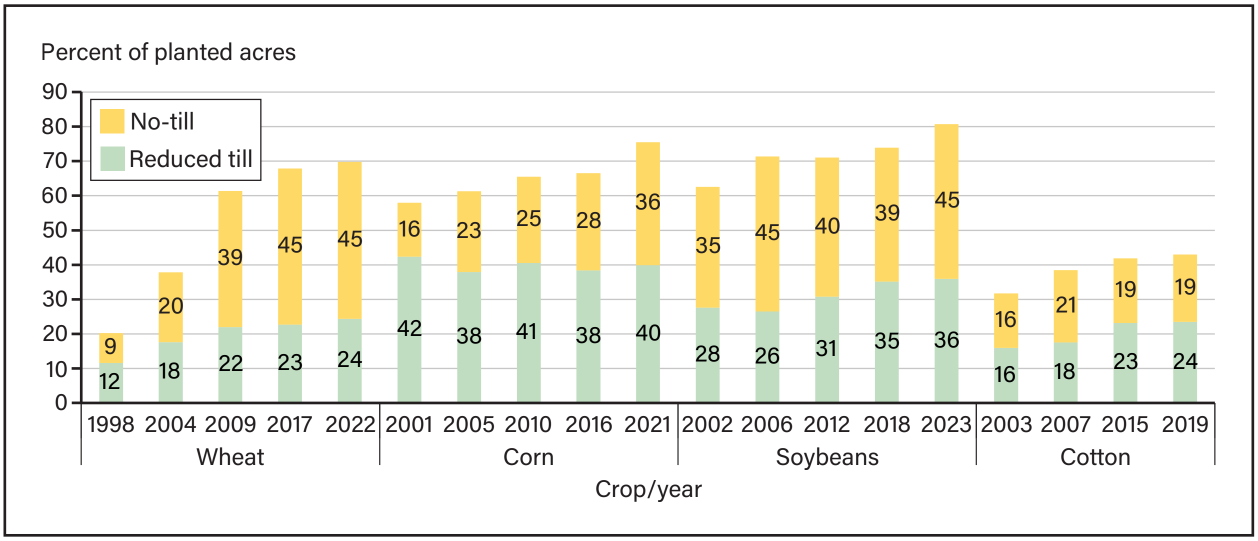
Conservation Tillage

The Census of Agriculture started collecting information on tillage practices in 2012. From 2012 to 2022 on all acres where tillage practices were reported, no-till use increased from 35 to 38 percent of acres, and reduced tillage use increased from 28 to 35 percent of acres.[8]

ARMS data highlighted that rates and growth of adoption in no-till and reduced tillage varied by crop (table 3, figure 1) and also varied regionally due to differences in cropping systems, weed pressure, soil types, precipitation, and other variables (Claassen et al., 2018a; Wade et al., 2015). Over time, the estimated share of wheat, corn, soybean, and cotton acres under no-till and reduced tillage changed (figure 1). While these data give a sense of conservation tillage adoption rates in the survey years, previous research has shown that tillage practices are dynamic and influenced by many factors (e.g., crop rotations). This means that neither census data nor figure 1 represents acres under continuous no-till or any other continuous tillage practice (Claassen et al., 2018a).[9]

Several trends emerge from figure 1. First, the share of total conservation tillage (no-till plus reduced till) has increased over time for all four crops. For winter, durum, and other spring wheat combined, the share of acreage under conservation tillage increased from 21 percent in 1998 to 69 percent in 2022. Second, the share of acreage under no-till increased over time for corn and wheat but leveled off for cotton and has been variable in soybeans. Although the introduction of glyphosate-tolerant soybeans initially contributed to the adoption of conservation tillage and no-tillage in soybeans (Perry et al., 2016), the increased prevalence of herbicide-resistant weeds, such as water hemp, giant ragweed, and palmer amaranth, has been one factor contributing to tillage decisions for soybeans (Van Deynze et al., 2022).

Figure 1
No-till and reduced till adoption over time on wheat, corn, soybean, and cotton fields, 1998–2023



Note: A field is considered to be no-till if the producer reported no tillage operations on the field, and fields are considered to be reduced tillage if the Soil Tillage Intensity Rating (STIR) calculated for the field based on tillage operations is less than 80. STIR values range from 0 to 200. Wheat includes winter, spring, and durum wheat combined.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service Agricultural Resource Management Survey data.

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[8] For reference, the NRCS Conservation Effects Assessment Project 2016 Cropland Report estimated that 67 percent of cropland acreage was in conservation tillage in 2016, and 47 percent of those acres were in seasonal and continuous no-till.

[9] Although the ARMS Phase 2 surveys ask if a field was no-tilled or strip-tilled over a several year period, "no-tilled or strip-tilled" is not a category of tillage the authors estimate adoption of elsewhere in this report and is not readily comparable to Census of Agriculture or Conservation Effects Assessment Project (CEAP) estimates.

For acreage in the conventional tillage and reduced tillage categories, the intensity of each tillage pass (different tillage operations have different levels of disturbance) and the total number of tillage passes are reflected in the Soil Tillage Intensity Rating (STIR). A low STIR value implies less overall soil disturbance. For fields in conventional tillage, the average STIR value ranged from 114 in soybeans to 159 in cotton. For fields in reduced tillage, the average values fell within a narrower range—from 45 in corn to 50 in wheat (table 4). Conventional tillage typically has two to four tillage passes, whereas reduced tillage typically has one to two tillage passes. Examples of tillage equipment used most frequently in conventional tillage systems included chisel plows, field cultivators, heavy disks, and tandem disks; reduced tillage systems more typically reported use of a field cultivator and/or tandem disk. Note that no-till fields typically had more chemical applications than other categories, which is consistent with more herbicide passes in no-till systems, where chemical weed control often substitutes for mechanical weed control.

Tillage practices combine with soil type and agricultural land management over time to determine soil carbon dynamics. Over time, these practices contribute to agriculture's role as both a source and sink for atmospheric carbon (Lewandrowski et al., 2004). Fewer tillage operations require less fossil fuel and can contribute further to reductions in carbon emissions from agricultural production (USDA, NRCS, 2022). For these reasons, no-till and minimal disturbance tillage (e.g., strip-till) continue to be part of market-based attempts to commoditize soil carbon sequestration in agriculture. Existing State and regional policies have capped greenhouse gas emissions in California and within a cooperative of eastern States (Regional Greenhouse Gas Initiative, RGGI). This market is changing rapidly with multiple different voluntary carbon registries and exchanges operating today (Plastina et al., 2024). Tillage, together with other practices such as cover crops, nutrient management, and livestock methane management, can potentially contribute to carbon markets or meeting regulatory requirements.

Table 4

Characterization of soil disturbance and intensity of field operations associated with different tillage practices for corn, wheat, and cotton acreage in Agricultural Resource Management Survey Phase 2 surveys, 2019–23

		Corn (2021)	Cotton (2019)	Soybeans (2023)	Wheat (2022)
Proportion of crop acres in each tillage category	Conventional tillage	0.24 (0.43)	0.57 (0.50)	0.19 (0.39)	0.30 (0.46)
	Reduced tillage	0.40 (0.49)	0.24 (0.42)	0.36 (0.48)	0.24 (0.43)
	No-till	0.36 (0.48)	0.19 (0.40)	0.45 (0.50)	0.45 (0.50)
Average Soil Tillage Intensity Rating (STIR index)	Conventional tillage	116.21 (27.21)	159.10 (108.10)	113.72 (37.12)	136.54 (74.67)
	Reduced tillage	44.58 (12.57)	48.39 (32.03)	41.93 (20.15)	49.80 (22.47)
	No-till	7.12 (4.01)	8.32 (20.48)	4.43 (5.89)	7.44 (9.83)
Average number of field operations	Conventional tillage	10.05 (2.11)	13.99 (7.15)	9.86 (2.28)	8.82 (3.45)
	Reduced tillage	8.57 (1.45)	11.81 (7.96)	8.09 (1.85)	7.52 (3.61)
	No-till	7.27 (1.36)	10.92 (8.71)	6.50 (1.62)	6.96 (3.39)

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		Corn (2021)	Cotton (2019)	Soybeans (2023)	Wheat (2022)
Average number of tillage operations	Conventional tillage	2.24 (0.86)	3.84 (2.91)	2.70 (1.32)	3.18 (1.58)
	Reduced tillage	1.02 (0.43)	1.25 (1.66)	1.20 (0.73)	1.43 (1.07)
	No-till	0.00	0.00	0.00	0.00
Average number of fertilizer applications	Conventional tillage	1.71 (0.71)	1.19 (1.51)	0.44 (0.61)	0.98 (0.90)
	Reduced tillage	1.51 (0.59)	1.37 (1.49)	0.38 (0.48)	0.90 (1.06)
	No-till	1.53 (0.67)	1.55 (2.94)	0.54 (0.58)	1.10 (1.10)
Average number of chemical applications	Conventional tillage	1.60 (0.71)	3.90 (5.04)	2.12 (1.15)	0.98 (1.01)
	Reduced tillage	1.61 (0.56)	4.81 (5.49)	2.08 (0.87)	1.39 (1.76)
	No-till	1.75 (0.62)	4.97 (5.88)	2.11 (0.92)	1.86 (1.64)

Note: Standard deviations are in parentheses. A field's acreage is considered to be no-till if the producer reported no tillage operations on the field, and field acreage is considered to be reduced tillage if the Soil Tillage Intensity Rating (STIR) calculated for the field is less than 80. Conventional tillage has a STIR greater than 80. Chemical applications include applications of herbicides, insecticides, fungicides, or other biocontrols or pesticides. Wheat includes winter, spring, and durum wheat combined.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service Agricultural Resource Management Survey data.

Cover Crops

Between the 2012 and 2017 Censuses of Agriculture, cover crop adoption[10] grew by 50 percent, from approximately 3.4 to 5.1 percent of harvested cropland acreage (Wallander et al., 2021). Although the rate of adoption slowed between the 2017 and 2022 Censuses, overall adoption on cropland still grew by 17 percent (Bowman & Morales, 2024). Like the adoption of tillage practices, the adoption of cover crops varied regionally with soils, climate, cropping systems, State regulations and incentive programs, and other variables. Data from the ARMS Phase 2 survey not only suggest that cover crop adoption has increased over time but also that cover crop adoption varies widely by cash crop (figure 2). Specifically, figure 2 shows crop-specific trends in fall cover crop adoption using ARMS data collected from 2010 to 2021 on fields that were planted to the surveyed crop. In the fall preceding the survey year,

[10] Cover crop adoption in this report is measured using self-reported data from producer respondents to two different USDA surveys; thus, there is no single definition of what is included or excluded from being reported as a cover crop in the data reported.

Cover Crop Adoption is Increasing, but Many Producers Do Not Continue Cover Cropping

Between the 2012 and 2017 Censuses of Agriculture, cropland acres with cover crops grew by 50 percent, and acres increased by 17 percent between 2017 and 2022 (Wallander et al., 2021; Bowman & Morales, 2024). However, many operations cover cropped in some census years but not others.

From those farming operations that responded to the Census of Agriculture in all 3 census years (2012, 2017, and 2022), the authors identified whether the operators had cover cropped acres in 2012, 2017, and/or 2022. Forty-eight percent of producers with cover crop acres in 2012 reported cover cropped acres in 2017, and 46 percent of operations with cover crop acres in 2017 reported cover cropped acres in

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producers adopted cover crops on 8 percent of corn-for-grain (2021), 11 percent of soybean (2023), 19 percent of cotton (2019), and 20 percent of corn-for-silage (2021) acreage. Adoption may be highest for corn grown for silage if, for example, producers are using cover crops to address soil health and erosion concerns on fields in continuous corn silage or if producers are grazing or harvesting cover crops for forage on livestock operations (e.g., dairies).[11] Corn grown for silage is also harvested earlier than corn grown for grain, which can provide a longer window for cover crop planting and establishment (Bowman et al., 2022). Cover crop adoption was also relatively high on cotton fields, where cover crops can provide erosion prevention, increase moisture retention, and increase soil organic matter (DeLaune et al., 2019; Lewis et al., 2018).[12]

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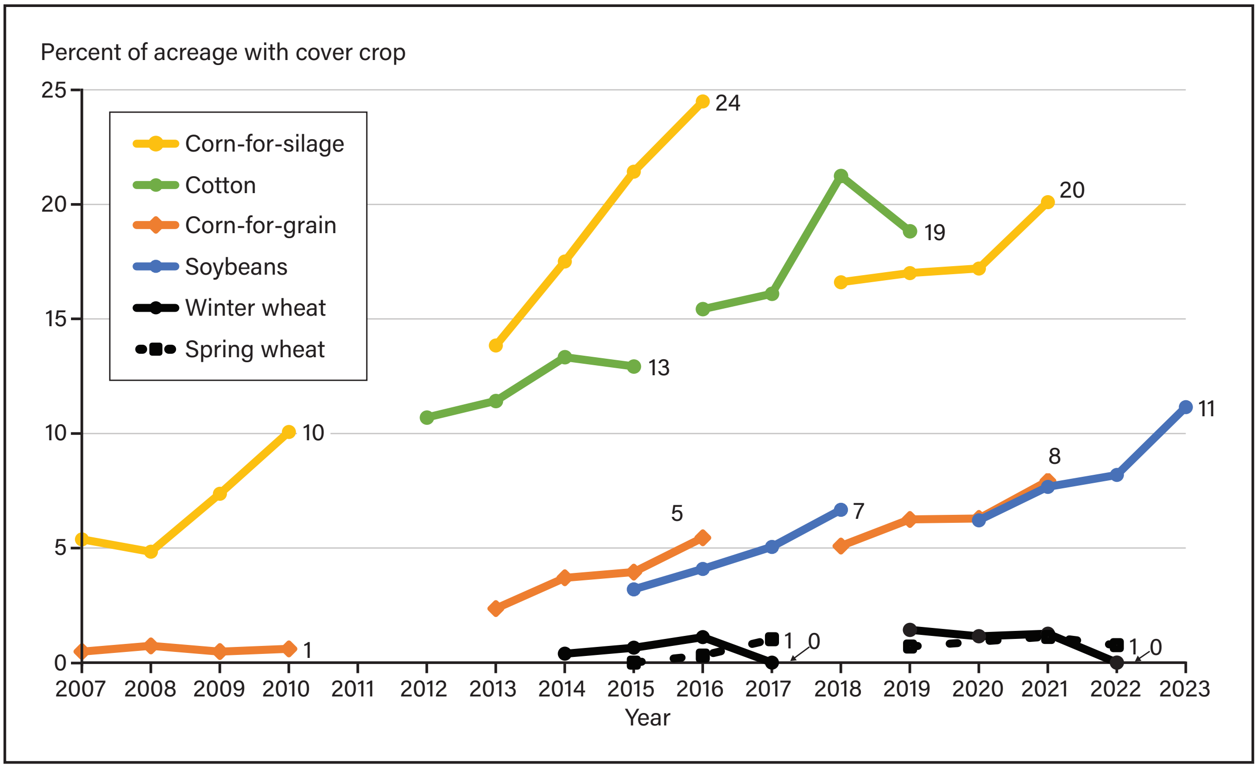
2022, suggesting that more than half of operations stopped cover cropping from 1 census year to the next. In each census year, more than a third of cover croppers were observed cover cropping in only that census year.

These findings suggest that, although cover crop acreage and the proportion of operations with cover crops are increasing nationally, adoption of cover crops is dynamic (figure 4).

Figure 2
Rates of fall cover crop adoption by surveyed cash crop, 2007–23



Note: For each crop, the sampled fields are planted with the designated crop in the survey year and a mix of other crops in earlier years. For example, an estimated 8 percent of acreage planted to corn for grain in 2021 had cover crops in the preceding fall, and that same acreage had a mix of cash crops (and lower cover crop adoption rates) in the 3 prior years. The samples used to calculate these adoption percentages are restricted to observations that had a complete record of all crops planted on the field in the 4.5 years prior to the survey year. The adoption rate in the survey year (2022) was lowest for winter wheat acreage. This pattern reflects that producers typically plant cover crops around the same time as winter wheat in the fall, which makes it difficult to grow both winter wheat and a fall-planted cover crop on the same field in the same crop year.

[11] In some regions, cover crops may also help ensure compliance with State or regional nutrient management or manure application requirements (Hively et al., 2015).

[12] Wallander et al. (2021) provides an indepth look at cover crop adoption in the United States, as well as the Federal and State programs that support cover crop adoption through financial and technical assistance. Bowman et al. (2024) provides information about the adoption of cover crops in livestock systems and associated economic issues.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service Agricultural Resource Management Survey for corn (2010, 2016, 2021), cotton (2015, 2019), wheat (2017, 2022), and soybeans (2018, 2023).

To assess whether farm operations continue to use cover crops over time, operation-level data from the 2012, 2017, and 2022 Censuses of Agriculture were analyzed (see box, "Cover Crop Adoption is Increasing, but Many Producers Do Not Continue Cover Cropping").[13] Considering the population of 496,800 (weighted) operations that responded to all three censuses,[14] results showed that 25.3 percent of operations with cropland reported cover crops in at least 1 of the 3 census years. Approximately 3.4 percent of operations (13.3 percent of operations that ever reported cover cropping) reported cover cropping in all 3 census years. And, in each census year, around 5 percent of operations (approximately 20 percent of operations that ever reported cover cropping and over a third of operations cover cropping in each census year) were observed using cover crops in only that census year (figure 4). Of the operations that reported using cover crops in 2012 and 2017, 48 percent and 46 percent, respectively, also reported using cover crops in the subsequent census year. This implies that more than half of operations using cover crops in either 2012 and 2017 were not using them in the next survey year—1.3 percent of operations reported cover crops in 2012 and 2022 but not in 2017. At the same time, an estimated 57 percent of those reporting cover crops in 2017 and 41 percent of those reporting cover crops in 2022 were likely new adopters (i.e., had not been observed reporting cover crops in a previous census year).

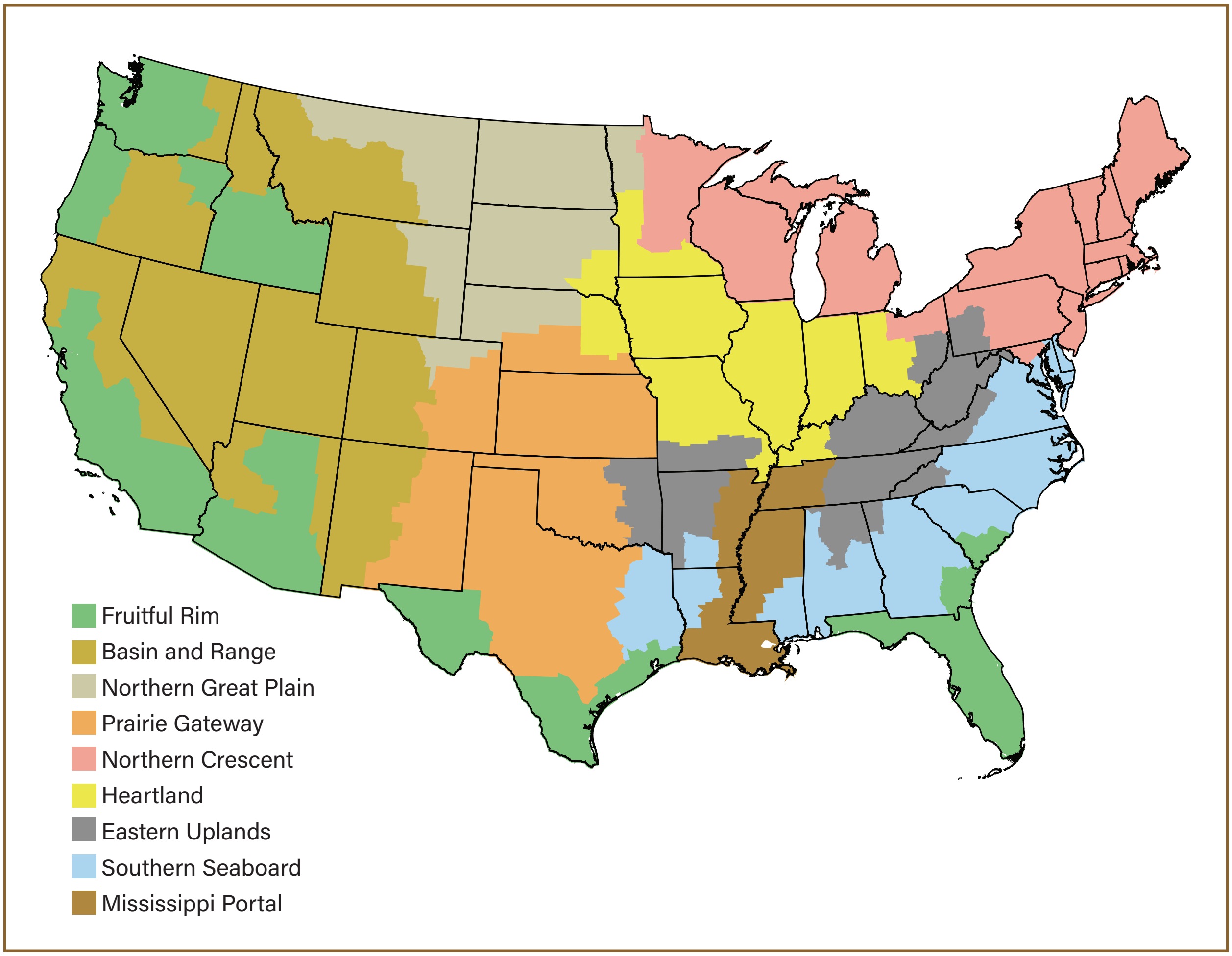
Looking at regional differences (figure 3 and figures A.1–A.9), results showed that the Northern Crescent region had the highest proportion of operations reporting cover cropping in all 3 census years (7.1 percent of operations) and a stable proportion of operations using cover crops over time. The Eastern Uplands region showed declining adoption among operations reporting to all three censuses (from 10 percent of operations in 2012 to around 8 percent of operations in 2022) and also declining persistence across the three censuses. The Heartland Region showed increasing adoption and increasing persistence over time. Note that while these findings suggest that many producers tried but did not continue cover cropping, it was not directly observed in census data why this might be the case.[15] Operations that reported cover crops only in 2012 or 2017 may have stopped cover cropping for a variety of reasons, including changes in cropping systems or management practices, or they may have transitioned out of Federal or State programs that pay for cover crops (Chami et al., 2023; Dunn et al., 2016; Irvine et al., 2025).

[13] Sawadgo and Plastina (2022) report on cover crop acreage decreases at the county and regional level, providing preliminary evidence that disadoption occurred at an aggregated level between the 2012 and 2017 Censuses of Agriculture.

[14] Note that operations that appear in all 3 census years may not be representative of the population of all census respondents in a given year and do not represent the full population of farm operations using cover crops.

[15] Although it is possible that reporting cover crop acres in 1 census year but not the next could be a result of crop rotations on the operation, this would only be a major factor if an operation had all of its acres in a single crop or in the same crop rotation since these statistics are calculated at the farm operation level rather than at the field level.

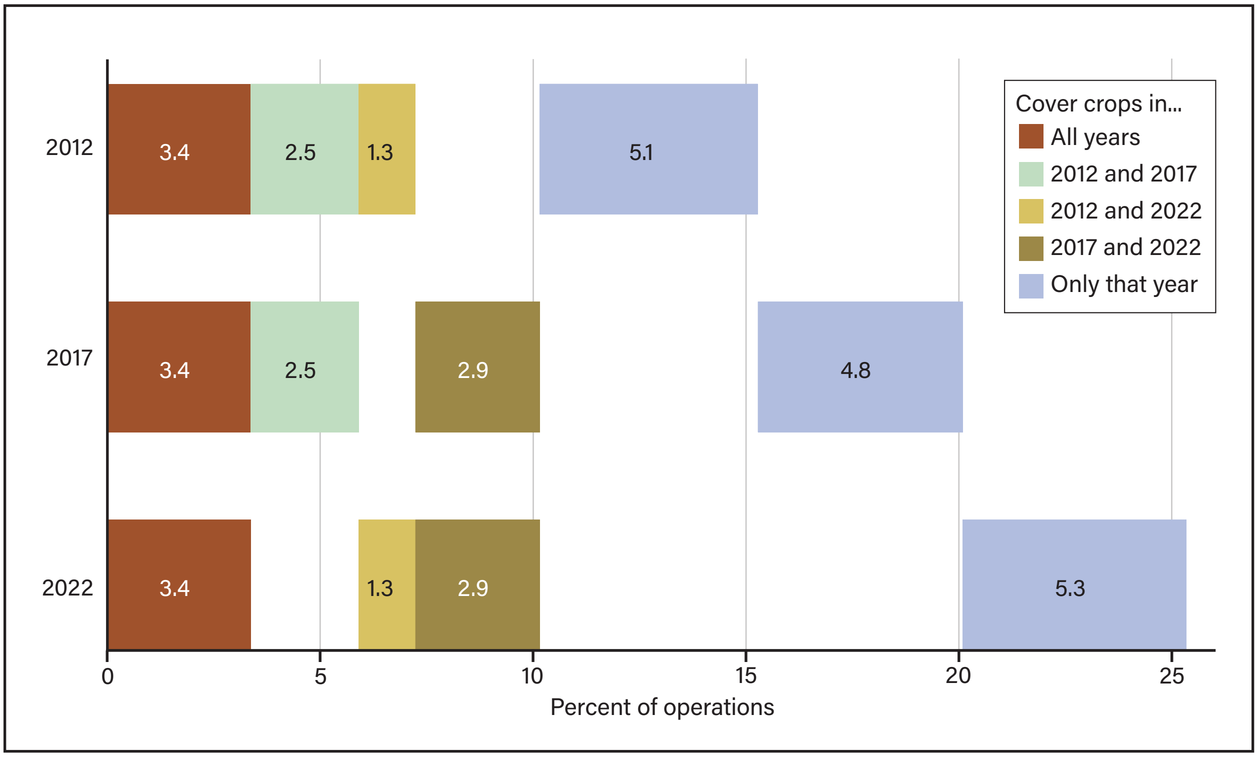
Figure 3
USDA, Economic Research Service Farm Resource Regions



Note: USDA, Economic Research Service (ERS) Farm Resource Regions depict geographic specialization in production of U.S. farm commodities. They identify where areas with similar types of farms intersect with similar physiographic, soil, and climatic traits. The Farm Resource Regions do not include Alaska and Hawaii.

Source: USDA, ERS Farm Resource Regions developed and characterized by USDA, ERS Agricultural Information Bulletin No. 760 (Heimlich, 2000).

Figure 4
Share of operations with cropland that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture



Note: This figure shows the share of operations in the United States with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover-cropped acreage) in 1 or more census years. The population is the 496,800 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

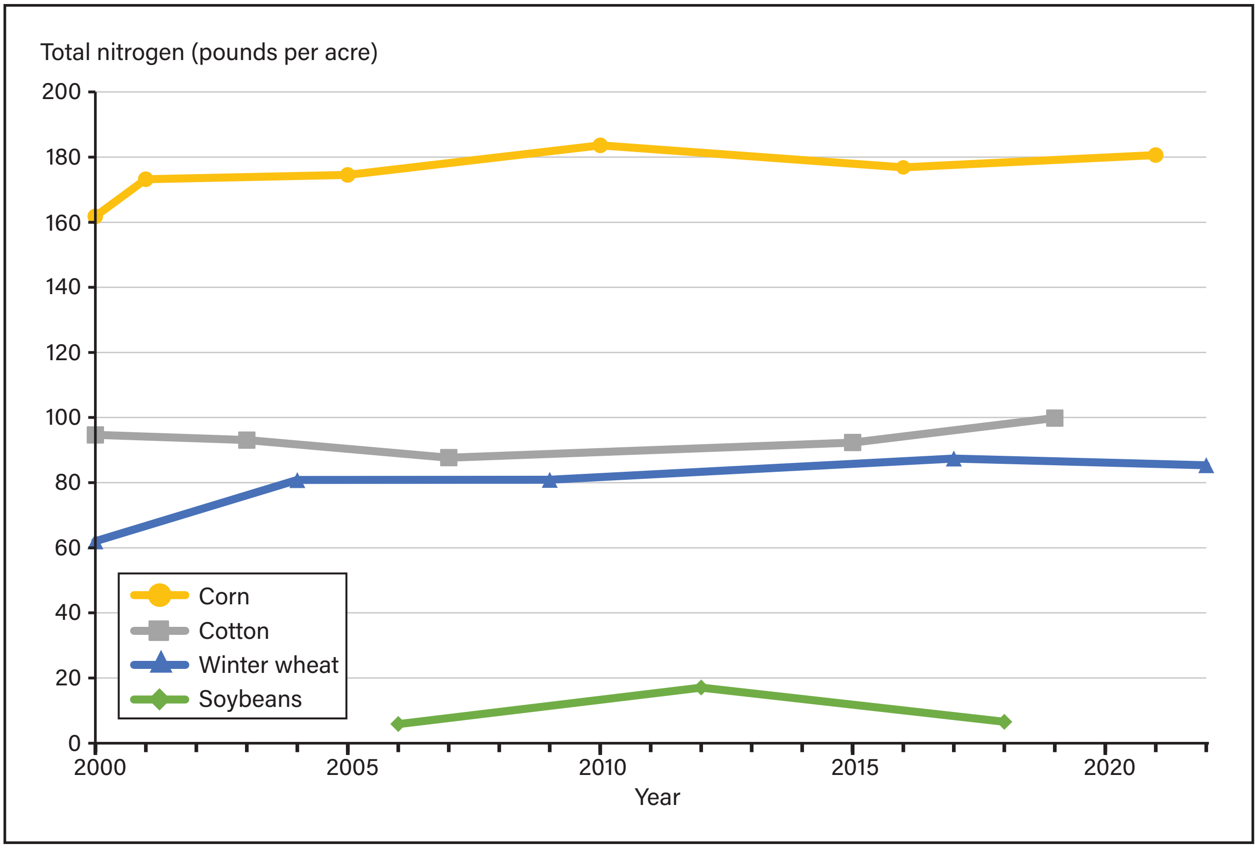
Nutrient Management

How producers apply nutrients and manage nutrient applications is critical to crop growth and productivity. However, nutrients not used by crops are also vulnerable to loss to the environment, and nutrient application affects outcomes such as greenhouse gas (GHG) emissions, air quality, and water quality. Synthetic fertilizer production is also resource-intensive and has a large GHG footprint. Nutrient management practices are, therefore, also important conservation methods. These practices include reducing or eliminating the fall application of fertilizer or manure (nutrients are most vulnerable to loss to the environment during the winter months if there is no crop growing on the field); aligning the rate of nutrients applied with the crop needs or profit-maximizing application rate (not overapplying); incorporating fertilizer or manure into the soil to reduce nutrient loss; or using soil test or plant tissue test results to help determine appropriate fertilizer application rates (Wade et al., 2015). Nutrient management can also be important to successfully implementing other conservation practices, such as cover crops and reduced tillage, where the timing and amounts of nitrogen needed by the crop can change with practice implementation. One framework for conceptualizing and implementing good nutrient management used broadly in industry settings is the “4R” concept, which involves implementing best management practices that emphasize using the (first R) right fertilizer source at the (second R) right rate, at the (third R) right time, and in the (fourth R) right place (Fixen, 2020).

There have been changes in some aspects of nutrient management over time that likely improve conservation outcomes. To provide some information on nutrient management by crop, two findings from ARMS about nitrogen application rates and the timing of nitrogen applications are included in this report. Figure 5 shows the average total nitrogen per acre applied to corn, cotton, soybean, and wheat acres over time for the corresponding ARMS Phase 2 survey years. Although there were no clear trends in nitrogen application rates, the fact that nitrogen application rates remained relatively stable even as, for example, corn yields increased implies that there was likely improved nitrogen use efficiency over time.[16] To the extent that more nitrogen is being used by crops, less nitrogen is vulnerable to runoff, which can contribute to improvements in water quality. Table 5 also provides information about the proportion of nitrogen applied by crop and by season; these data address the question of application timing. Looking at trends in season of application over time, there is evidence that wheat fields were shifting toward applying more nitrogen at or after planting. However, there was also an increase between 2016 and 2021 in the percent of nitrogen applied in the fall on corn acreage. Applying nitrogen at or after planting ensures that the timing of application aligns with the period when the crop most needs the additional nutrients, thereby improving nutrient use efficiency and reducing the potential for loss of nitrogen to the environment. Statistics on the timing of nitrogen application by USDA, ERS Farm Resource Region are also presented for these three crops for the most recent survey year in appendix B. Precision agricultural technologies can also improve nutrient use efficiency and reduce the amount of nutrients lost to the environment. McFadden et al. (2023) found that the use of variable rate fertilizer/lime technologies in ARMS ranged from approximately 8 percent of planted acres in sorghum (2019); to 14–15 percent of planted acres in cotton (2019), winter wheat (2017), and soybeans (2018); and to about 28 percent of planted acres in corn (2016).

Figure 5

Average total nitrogen applied to corn, cotton, soybean, and wheat acres over time (including synthetic fertilizer and manure), 2000–22



Note: Different crops have different numbers of data points due to differences in when the crop is surveyed over time as part of the Agricultural Resource Management Survey (ARMS) Phase 2 sample.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service ARMS Phase 2 surveys for corn, cotton, wheat, and soybeans.

[16] For soybeans, nitrogen fertilizer is most commonly only applied as part of a starter fertilizer around planting because all or most of the crop demand for nitrogen is satisfied by nitrogen fixation and available soil nitrogen. Only in extremely high-yield environments do soybeans typically have any additional demand for nitrogen.

Table 5

Percent of nitrogen applied by season for corn, cotton, winter wheat, and durum and other spring wheat acreage over time for acreage with no manure application, 2005–21

		Percent of nitrogen applied			
Crop	Year	In the fall	In the spring	At planting	After planting
Corn	2005	20.6 (1.7)	49.1 (2.2)	8.9 (0.5)	21.5 (1.3)
	2010	20.0 (1.7)	49.7 (2.4)	8.2 (1.0)	22.0 (1.6)
	2016	19.9 (1.5)	46.2 (1.4)	8.0 (0.6)	25.6 (1.3)
	2021	25.6 (2.4)	40.8 (3.5)	8.3 (0.9)	25.3 (2.6)
Cotton	2003	12.1 (3.0)	29.0 (1.9)	5.1 (0.6)	53.8 (1.7)
	2007	6.7 (1.2)	28.1 (1.6)	6.1 (0.7)	58.9 (1.9)
	2015	7.7 (1.7)	35.1 (2.6)	9.9 (2.4)	47.0 (2.9)
	2019	6.9 (2.2)	31.9 (3.3)	8.2 (1.3)	52.4 (3.2)
Winter wheat	2004	50.4 (2.8)	5.3 (0.9)	7.1 (1.1)	37.2 (2.5)
	2009	35.5 (1.9)	5.3 (0.8)	14.2 (1.2)	45.0 (2.0)
	2017	31.2 (3.0)	3.6 (0.7)	21.1 (3.4)	43.9 (3.0)
	2022	28.8 (3.9)	9.3 (2.3)	16.2 (2.2)	45.2 (3.1)
Durum and other spring wheat	2004	26.9 (4.9)	44.7 (4.5)	25.4 (2.0)	3.0 (0.6)
	2009	19.8 (3.2)	40.6 (2.8)	34.1 (3.3)	5.5 (0.9)
	2017	19.7 (2.5)	34.4 (3.9)	36.2 (3.7)	9.7 (1.1)
	2022	16.0 (2.6)	38.1 (3.3)	37.0 (4.1)	8.7 (1.2)

Note: Standard errors are in parentheses. Totals across columns may not sum to 100 due to rounding. "At planting" and "after planting" may refer to nitrogen application in different seasons for different crops. For example, winter wheat is typically planted in the fall, which means that both the fall application and the application at planting would occur in the fall. Similarly, nitrogen applied in the spring can likely be interpreted as being applied before planting for corn but after planting for winter wheat. The seasonality of the percent of nitrogen applied after planting is ambiguous for winter wheat.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service ARMS Phase 2 surveys for corn, cotton, wheat, and soybeans.

Management Systems: Practices Adopted in Combination

Crop production requires a host of management decisions that comprise a management system. In the case of soil health management systems, decisions about crop rotations, tillage, cover crops, grazing, and nutrient management—among others—interact to affect crop and livestock production, nutrient and water cycling, soil health and structure, and environmental outcomes.

Claassen et al. (2018a) looked at joint adoption of tillage practices and other conservation and soil health practices in ARMS data. They found that adoption of conservation rotations was higher for corn but did not vary by tillage practice. Double cropping was more common for cotton, soybean, and wheat acres in alternating no-till/strip-till, and cover crops were less common for cotton and corn acreage under continuous tillage (fields where tillage was reported every year for a series of years). Similarly, Wallander et al. (2021) looked at joint adoption of cover crops, no-till, conservation crop rotations, and soil nutrient and organic matter testing. They found that fields with cover crops were more likely to be in no-till than those not using cover crops, more likely to meet the criteria for a conservation crop rotation, and more likely to be soil tested than fields without a cover crop.

For the most recent corn and soybean ARMS surveys, no-till acres were substantially more likely to be cover cropped—but this was not true for cotton (table 3). For reduced tillage cotton acres, 43 percent of acres had cover crops versus 29 percent of no-till cotton acres. The proportion of farm operations that reported acreage with conservation tillage, as well as cover cropped acreage, increased between 2012 and 2017 for all U.S. regions as well as nationally. Between 2017 and 2022, the proportion of farm operations reporting acreage with conservation tillage, as well as cover cropped acreage, increased nationally and for all regions except the Eastern Uplands and Southern Seaboard (table 6).[17]

Nutrient management is also an important component of a soil health management system and related to cropping, tillage, and cover crop decisions. For example, in no-till systems, fertilizer is not incorporated into the soil via fall or spring tillage, and cover crops can often affect the timing and rate of nutrient needs of the subsequent cash crop. Figure 6 suggests that fields with more soil health management practices may be managing the timing of their nitrogen applications differently. Fields with cover crops applied a larger share of nitrogen at or after planting compared with fields without cover crops, which suggests that producers may be making changes to nutrient management as they adopt cover crops, that fields where cover crops are adopted have unique nutrient management timing needs, or that producers adopting cover crops may be more likely to adopt more management-intensive nutrient management systems.

Table 6

Share of farms reporting both cover crops and conservation tillage in the 2012, 2017, and 2022 Censuses of Agriculture (for operations reporting tillage practices)

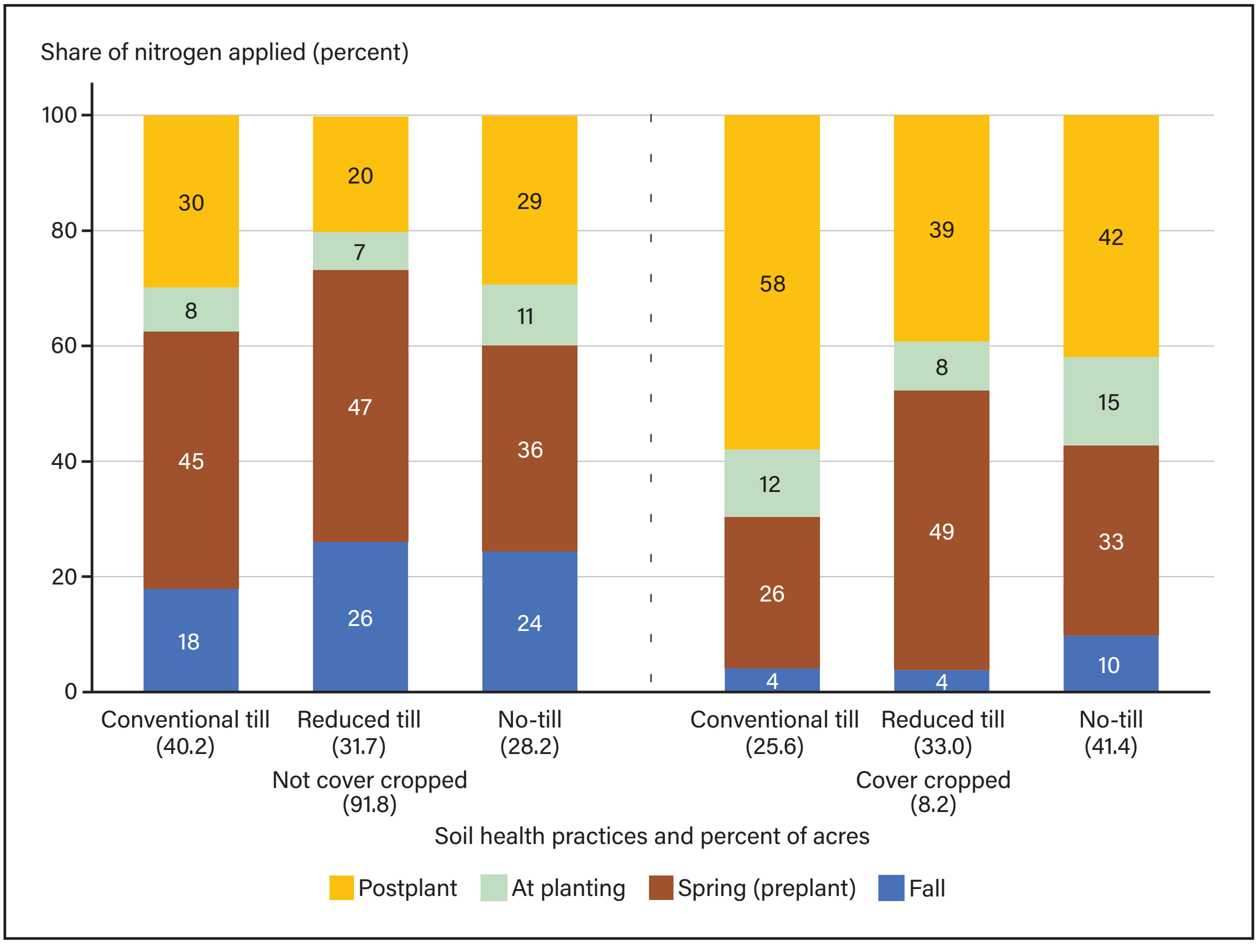
USDA, Economic Research Service Farm Resource Region	2012 (percent)	2017 (percent)	2022 (percent)
U.S. overall	9.2	13.7	14.1
Basin and Range	4.5	8.2	9.4
Eastern Uplands	13.9	17.1	15.6
Fruitful Rim	4.4	8.6	9.2
Heartland	8.2	13.1	13.6
Mississippi Portal	5.8	10.3	12.1
Northern Crescent	14.3	18.5	19.6
Northern Great Plains	5.5	10.5	11.4
Prairie Gateway	5.2	8.7	9.9
Southern Seaboard	14.5	20.0	18.7

Note: Conservation tillage includes no-till and reduced tillage acres. Because only a subset of operations responding to the Census of Agriculture reported acreage in 1 or more tillage categories, the adoption rates for cover crops and conservation tillage reported here may be larger than the estimated number of operations adopting cover crops alone when not considering tillage practices.

Source: USDA, Economic Research Service using data from the USDA, National Agricultural Statistics Service, 2012, 2017, and 2022 Censuses of Agriculture.

[17] Note that the Census of Agriculture does not ask whether these practices were adopted simultaneously on the same fields, only the total acreage on the operation in different tillage categories and the total cover cropped acreage. So, this report's authors observed the joint adoption of the practice at the operation level but not necessarily on the same fields at the same time.

Figure 6
Timing of nitrogen application on corn and cotton fields for combinations of soil health practices, 2015–21



Note: The figure shows how all nitrogen applications were applied across different seasons for different combinations of tillage and cover crop practices. The sample includes fields that did not apply noncommercial manure. In the parentheses of category labels for cover cropped and not cover cropped categories are the percentages of acreage in each cover crop category. In the parentheses of category labels for tillage category labels are percentages of acres with the given cover crop category in each tillage category. For example, nearly 92 percent of fields were not cover cropped, and of these fields, 40 percent were in conventional tillage in the survey year. For the over 8 percent of fields that were cover cropped, 41 percent were no-tilled in the survey year. Values within bars represent percentages of total nitrogen applied during that time of the year, conditional on the combination of cover crop and tillage type. Totals in stacked bars and across tillage categories may not sum to 100 due to rounding.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service Agricultural Resource Management Survey for corn (2016 and 2021) and cotton (2015 and 2019).

Profitability of Soil Health Practices: Background and Evidence

Key Themes in the Literature

This report provides a review of the literature on the profitability of soil health and conservation practices, with a focus on no- and reduced-tillage and cover crops, and identifies five key themes (table 7). The description of the literature and the background and evidence contained therein is not intended to be comprehensive—instead, the focus is on presenting selected papers where the profitability impact of key soil health practices, such as tillage and cover crops, were explicitly examined and quantified for the four main commodity crops in the United States (corn, soybeans, wheat, and cotton). In addition to the two themes that focus on individual practices, a discussion in this report centers on three themes that link concepts in behavioral and resource economics to the discussion of profitability and adoption of soil health practices.

In spite of a number of knowledge gaps, this rich literature provides several insights into the economic impacts of soil health and conservation practice adoption. Because no-till and reduced tillage have been widely adopted in the United States across a broad geography, there is evidence in the literature that reducing tillage intensity can reduce input costs, although net profitability outcomes are varied. In contrast, the long-term economic outcomes associated with cover crops are more uncertain and dynamic. The short-term return to adopting cover crops as a standalone practice is often negative due to the costs associated with planting and managing a cover crop. For new practices like cover crops, risk and uncertainty about practice outcomes in the short-, medium-, and long-run also impact the producer adoption decision. Finally, although research about soil health and conservation practices has often been conducted so as to intentionally isolate the outcomes associated with individual practices, the literature suggests that the profitability of individual practices depends on the suite of practices employed in the management system (e.g., rotations, no-till, cover cropping, nutrient management). This means that research on economic outcomes that address individual practices may be missing relationships between and among practices and the associated effects on costs, profitability, and risk/uncertainty.

Table 7
Key themes surrounding the profitability of soil health practices

Theme	Key studies	Major ideas within key themes
Reducing tillage intensity can reduce input costs, but net profitability varies.	Al-Kaisi et al., 2016; Cusser et al., 2020; Liu and Duffy, 1996; Singh et al., 2021; Trlica et al., 2017	▪ Lower tillage intensity can lead to reduced input costs in labor, machinery, and fuel. ▪ Estimated yield effects of no-till and reduced-tillage are variable.
The short-term return to adopting cover crops is often negative.	Bowman et al., 2022; Deines et al., 2022; Myers et al. 2019; Plastina et al., 2018b; Wallander et al., 2021	▪ Cover cropping increases input costs, specifically for seed, planting, and terminating the crop. ▪ Cover crops may lead to yield losses in the short-run. ▪ Profit effects are more likely to be positive if cover crops are used for grazing livestock or forage or for addressing in-field resource concerns, such as soil compaction.
The economic outcomes of soil health practices are dynamic.	Bergtold et al., 2019; Boyer et al., 2018; Myers et al., 2019; Snapp et al., 2005; Wood and Bowman, 2021	▪ Profitability of practices such as cover crops may increase over time. ▪ The literature is mixed about the long-term profitability of cover cropping. ▪ Long-term profits depend largely on assumptions about the discounting of future benefits. Estimates of producer discounting range widely.
Risk and uncertainty impact producer adoption of new soil health practices like cover crops.	Arbuckle and Roesch-McNally, 2015; Bowman et al., 2022; Connor et al., 2021; Plastina et al., 2020; Stanger et al., 2008; Thompson et al., 2021	▪ Producers are typically risk and ambiguity averse; they avoid practices when they lead to more variability in yields or in the absence of information about outcomes. ▪ More research on the effects of cover crops on yields and yield risk is needed to improve decision making for producers.
The profitability of individual practices is impacted by the management system as a whole.	Canales et al., 2020; Gong et al., 2021	▪ Use of other practices might make a certain practice more profitable if adopted. Several studies have found complementarities between no-till, cover crops, and other practices.

Source: USDA, Economic Research Service using the published literature listed in the Key studies column.

Reducing Tillage Intensity Can Reduce Input Costs, but Net Profitability Varies

A number of studies have researched the profitability of no-till or other conservation tillage practices relative to conventional tillage. Such studies typically quantify differences in yields and input costs, where they exist, between the two systems. No-till systems are expected to lead to savings in labor, machinery, and energy due to a reduction in the number of field equipment passes (Weersink et al., 1992). Residue cover, however, can have varied impacts on pests and diseases (which can affect input costs) and influence soil temperatures, which can have tradeoffs at different times in the year (Blanco-Canqui & Ruis, 2018; Fuglie, 1999). No-till and conservation tillage systems can also increase yields over time by improving soil structure (Blanco-Canqui & Ruis, 2018; Deines et al., 2019; Gál et al., 2007). However, there are also several studies that have shown potential yield decreases with no-till systems (Vyn & Raimbult, 1993; West et al., 1996). Where no-till and other conservation tillage systems have been found to be more profitable than conventional tillage, this was primarily due to input cost savings (rather than yield increases).[18]

In general, long-term studies have found that profits from no-till systems are not uniformly higher or lower than conventional tillage (Al-Kaisi et al., 2016; Al-Kaisi & Yin, 2004; Cusser et al., 2020; Doster et al., 1983; Fan et al., 2020a; Karlen et al., 2013; Singh et al., 2021; Trlica et al., 2017)[19] (appendix table C.1). However, in a survey of Iowa producers, Liu and Duffy (1996) reported that most conservation tillage systems, such as no-till, had higher profits than conventional tillage due mainly to lower production costs. A recent study by Cheet al. (2023) found that the long-term yield effects of no-till were not generally statistically significant in a long-term field experiment, but operation costs were estimated to be lower, which suggests higher net returns per acre. These themes extended to irrigated systems, where no-till may not lead to higher yields but can result in lower irrigation costs (Archer et al., 2008; Fan et al., 2020a). Where the profitability of no-till systems is lower than conventional systems, this can be due to no-till having higher chemical costs for weed and pest control that offset savings in labor and machinery (Marra & Kaval, 2000; Williams et al., 2000). Using a choice experiment designed to estimate willingness to accept (WTA) payments, Gramig and Widmar (2018) found that Indiana producers who had never adopted reduced tillage practices required an estimated $40 per acre increase in net revenue to switch from conventional tillage to no-till, which (among other explanations) could mean that producers perceive reduced tillage as less profitable or that there are fixed costs of switching tillage systems. The geography of where fields are located has previously been found to influence the profitability of no-till, with climate and soils being important, as well as crop type in determining the impact of no-till on yield (Toliver et al., 2012). For example, Toliver et al. (2012) found that no-till tended to produce similar or greater mean yields than tillage for crops grown on loamy soils in the Southern Seaboard and Mississippi Portal regions of the United States.

The literature comparing the profitability of reduced tillage practices (e.g., ridge-till, reduced-till, strip-till, mulch-till) to conventional tillage suggests that the profitability can increase or decrease with reduced tillage and that the difference in profit is often smaller and less variable than the difference in profit between no-till and conventional tillage (appendix table C.2). Some studies have shown consistently positive effects (Karlen et al., 2013; Liu & Duffy, 1996), while others have shown a mixture of negative and positive effects (Al-Kaisi et al., 2016; Al-Kaisi & Yin, 2004; Doster et al., 1983). Reduced till practices may have less of a yield penalty than is sometimes observed with no-till in the initial years of use but also have lower reductions in input costs relative to no-till. Therefore, the net returns to reduced tillage practices tend to be much closer to conventional tillage practices.

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[18] No-till systems have changed over time as the adoption of genetically engineered crop varieties that are herbicide-tolerant (HT) has allowed for the application of herbicides such as glyphosate at any time during the year. This has reduced the need to use tillage for weed control in systems where HT varieties are planted and has fundamentally changed the economics of reducing or eliminating tillage. Based on USDA, NASS survey data, more than 90 percent of soybean, cotton, and corn acres are planted to HT varieties, with the greatest increase in adoption occurring in the early 2000s; see the USDA, ERS web page, "Recent Trends in GE Adoption," for more information.

[19] The studies reviewed in this report do not include cost-share or conservation program payments in calculations of net profit associated with tillage or cover crop practices unless otherwise noted.

The Short-Term Return to Adopting Cover Crops Is Often Negative

In contrast to conservation tillage, which in many cases has been shown to decrease input costs, growing a cover crop typically involves increased input costs, at least in the short term. These costs include cover crop seed and the expense of planting and terminating the cover crop (Bowman et al., 2022; Plastina et al., 2018b; Wallander et al., 2021). Although cover crops can also provide valuable benefits, these may only show up over time (as in the case of soil health improvements), and they often vary by region, crop/livestock system, soil type, or resource concerns. To determine the net change in profits when cover crops are used, Plastina and coauthors used a partial budget analysis to calculate the difference in mean annual net returns for producers in Illinois, Iowa, and Minnesota who used cover crops compared with those who did not (table C.3). The authors found that short-term annual profits were typically lower for producers who used cover crops compared with those who did not, although cover crops improved profitability in soybeans and had the opposite result for corn when terminated with herbicides (Plastina et al., 2018a, 2018b, 2020). Results from Myers et al. (2019) also indicated that the change in annual net returns for producers who decided to use cover crops was usually negative based on a partial budget analysis of a voluntary, national survey of cover crop adopters. This was especially true for those producers who had only adopted the practice for 1 or 2 years. A recent study estimating the impact of cover crops on corn and soybean yields in the Midwest in 2019 and 2020 found that 3 or more years of cover cropping was associated with a 5.5-percent and 3.5-percent average yield loss for corn and soybeans, respectively (Deines et al., 2022).

To estimate the short-term profitability of cover cropping, a number of studies have used data from field experiments (often not on working farms), usually at the plot level for a particular year. For example, Mahama et al. (2016), Reddy (2003), and Roberts et al. (1998) used field experiment data to evaluate economic returns to cover cropping (and other conservation practices) in Kansas, Mississippi, and Tennessee, respectively. Findings from these types of experimental studies are mixed with respect to whether cover crops are expected to increase or decrease profit, depending upon the cover crop management practices being compared and associated costs/revenue (Boquet et al., 2004; Cai et al., 2019; Dunn et al., 2016; Fan et al., 2020a, 2020b; Foote et al., 2014; Hughes & Langemeier, 2020; Larson et al., 2001; Miguez & Bollero, 2005; Snapp et al., 2005; Varco et al., 1999; Zhou et al., 2017).

In some situations, cover crops can be profitable. Both Plastina et al. (2018b) and Myers et al. (2019) found that the profitability of cover crops improved if they were used for grazing livestock or forage or that profitability was dependent on whether the operation received cost-share incentive payments from government programs.[20] Myers et al. (2019) also noted several other situations when cover crops could improve profitability, such as when herbicide resistant weeds are a problem, when cover crops are used to address soil compaction, or when fertilizer costs are high or there is a need to sequester nutrients (e.g., nitrogen) that are left at the end of a cash crop season (e.g., from manure).

The Economic Outcomes of Soil Health Practices Are Dynamic

The profitability of a practice, such as cover cropping or no-till, may depend on the amount of time a producer has been using the practice, as well as other management changes that might be occurring during the same period. This dependency occurs at least in part because management practices interact with climatic, environmental and soil conditions, and the natural process by which soil health responds to management. It can also occur because economic variables (such as crop prices and input prices) vary over time. As such, the economic outcomes of soil health practices and management systems are inherently dynamic. Thus, to understand how producers make decisions about adopting a practice, information is needed about how profitability changes over time for the practice and how the producer makes decisions

[20] Bowman et al. (2024) discuss the profitability of integrating cover crop and livestock systems.

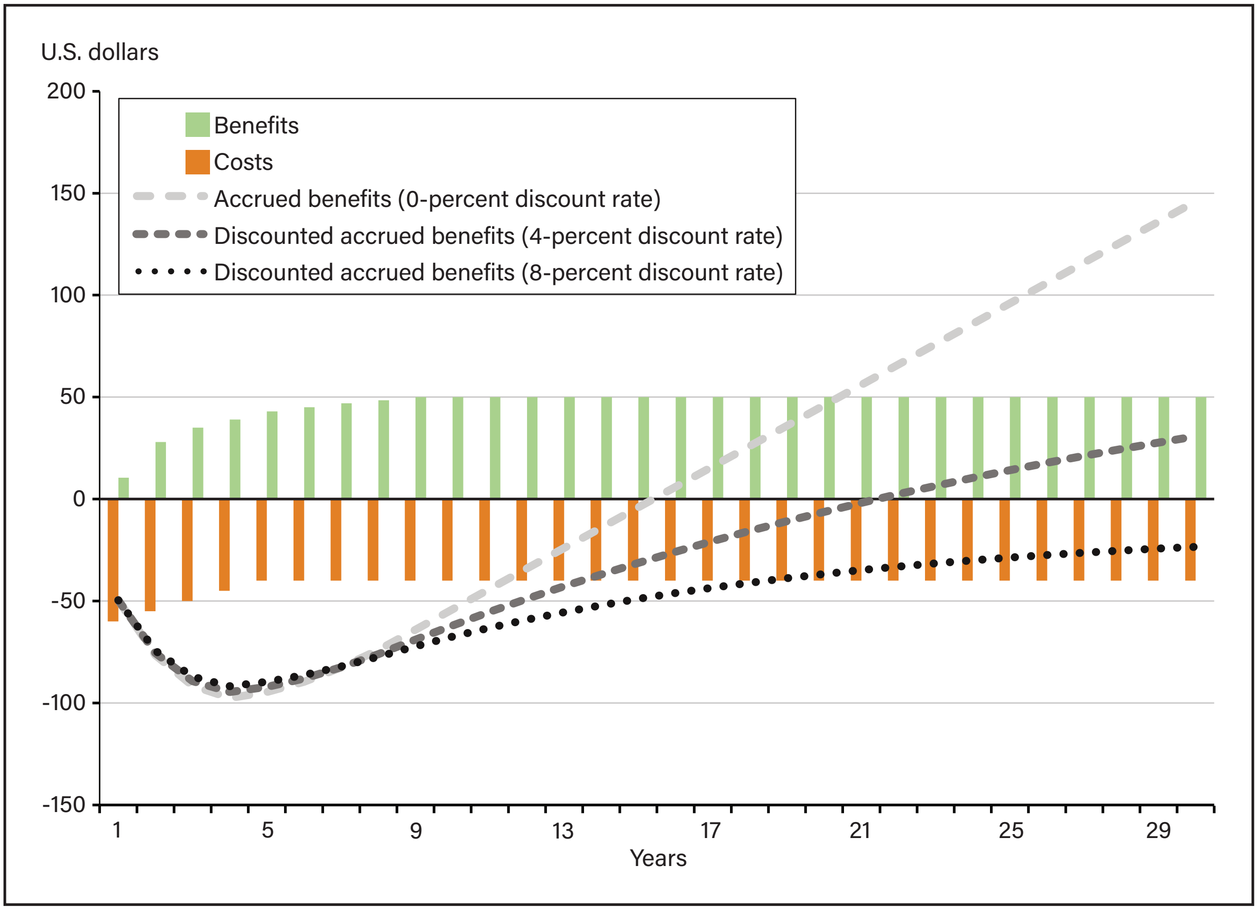
about the future. The relative importance of near-term versus long-term outcomes to a producer or group of producers is also an important factor. Economists represent this as producer "discount rates," or, in other words, the extent to which an individual values a dollar in the future less than a dollar today. Individuals with high discount rates value future outcomes much less than present outcomes and costs, which can make practices with short-term costs and long-term gains undesirable.

There is some research that has indicated that the benefits of soil health practices, such as cover cropping, may increase over time (Bergtold et al., 2019; Myers et al., 2019; Snapp et al., 2005). This increase has been hypothesized to be due to either factors such as increased benefits and decreased costs as producers gain experience with the practice or the fact that the soil health benefits of cover cropping and other soil health practices take time to accrue to economically significant levels (Wood & Bowman, 2021). Some studies have noted that over time (e.g., with 3 or more years of cover cropping) improvements in soil health may yield benefits that are greater than the costs of cover cropping (Myers et al., 2019; Cai et al., 2019), while other studies have suggested that cover crops are still not profitable over the longer-term (Boyer et al., 2018; Schipanski et al., 2014; Zhou et al., 2017). Nonetheless, if future benefits are discounted, these may not outweigh short-term costs. As cover crop adoption has increased over the last decade, research to understand the long-term profitability of cover crops will continue to emerge.

To understand the producer's decision to adopt, there is a need to understand how time preferences (discount rates previously mentioned; also see the Background section and table 2) shape producer decision making about soil health practices, but past research is somewhat limited. In general, people making decisions are assumed to discount future costs and benefits, but commonly used and estimated discount rates for agricultural producers have ranged widely from 3 to 34 percent (American Agricultural Economics Association (AAEA), 2000; Barry et al., 1996; Edwards, 2017; Lence, 2000). This would imply that $100 next year is worth between $97 and $66 in the current period. This range of discount rates can have dramatic implications for estimating the returns from a practice such as cover crops with upfront costs and future benefits.

A hypothetical example is provided in figure 7, which involves costs that decline in the first 5 years of cover cropping and the benefits that increase in the first 9 years of using the same soil management practice. For simplicity, the producer was assumed to engage in cover cropping every year. Note that cover cropping in this hypothetical was not profitable in the first 4 years. Furthermore, total cumulative net benefits (undiscounted) did not exceed zero until year 16, which implies that cover cropping is profitable over time horizons of 16 or more years. When incorporating the extent to which producers discount future values, the minimum time horizon at which a producer considers cover cropping profitable may be extended. For a 4-percent discount rate, the minimum period was 22 years. For a discount rate of 8 percent, cover crops were not profitable over any planning time horizon because future benefits were so heavily discounted relative to present costs.

Figure 7
Hypothetical net present value trajectories of the private benefits of cover cropping, across different discount rates



Note: The figure provides the within-year private costs (orange) and benefits (green) of cover cropping for the participating producer. These numbers are purely hypothetical but based on estimates in surveys and available literature. The calculations assume that a producer uses cover crops every year with benefits that are dynamic in the short-term but plateau after 10 years. Likewise, costs are hypothesized to decline over the first 5 years. The dashed and dotted lines represent the net present value at time 0 of the accrued benefits over the stated horizon. For example, the net present value for undiscounted accrued benefits over 15 years are approximately 0. For a 4-percent annual discount rate, the years to net 0 accrued benefits is around 21 years. A discount rate of 4 percent implies that a U.S. dollar next year is worth 96 cents today.

Source: USDA, Economic Research Service calculations using hypothetical values.

Risk and Uncertainty Impact Producer Adoption of New Soil Health Practices Such as Cover Cropping

The dynamic nature of soil health practice adoption discussed in the last section also highlights that the economic outcomes of soil health practices and management systems are characterized by uncertainty, including variability (or risk) in benefits and costs, which affects decision making (Ramsey et al., 2019). Agricultural producers are generally considered to be risk-averse (Chavas & Holt, 1996), which implies that they prefer to avoid large swings in yields or profits. Producer risk aversion is likely to influence adoption, as producers may avoid soil health practices that they perceive as increasing risk (e.g., yield variability) and be more likely to adopt soil health practices that they perceive as reducing risk. How much this matters to producer decision making will depend on their degree of risk aversion (Background section and table 2). Researchers agree that risk and perceived risk are salient to agricultural producers, but there is no consensus as to whether cover cropping increases or decreases net risk and over what time horizons or how it interacts with other strategies that producers use to address risk such as participation in crop insurance (Arbuckle & Roesch-McNally, 2015; Bowman et al., 2022; Connor et al., 2021; Plastina et al., 2020; Stanger et al., 2008; Thompson et al., 2021).[21]

Risk aversion alone may not adequately capture how producers make decisions. A number of researchers have questioned whether a traditional risk framework can explain observed behavior in the context of U.S. agriculture (Babcock, 2015). Producers may also be ambiguity-averse, leading them to avoid outcomes where the probability of each outcome is uncertain (Barham et al., 2014). Likewise, producers may also be loss-averse, leading them to avoid practices with the potential for large or frequent dips in yields or profits, even when the potential for large or frequent increases in yields of profit is higher. For soil health practices, there may be notable consequences if producers possess either aversion. Because producers may be unsure of the likelihood of possible outcomes, adopting a new practice may introduce ambiguity. For loss aversion, the consequences are more complicated. Whether loss aversion increases or decreases the appeal of soil health practices depends on whether producers feel those practices will increase or decrease the probability and/or magnitude of negative yield or profit outcomes.

Producer decisions about cover cropping and other practices will thus be shaped by the way they perceive risk and make decisions under uncertainty. A number of factors may also contribute to reducing risk and uncertainty about practice adoption. For example, research on how cover crops and soil health management systems perform in different regions, soils and climatic conditions and their impact on yields, revenues, costs, and profits over time may reduce uncertainty about the positive or negative net impact of adopting the practice. For an individual operation, trialing practices such as cover crops that have low fixed costs on a single field or a small portion of the operation may also reduce risk as producers learn about the management practices that work best for their cropping system and rotation.

The Profitability of Individual Practices Is Impacted by the Management System as a Whole

As discussed in the previous sections, the economic decision of whether to adopt a soil health practice (or set of practices) is inherently complex and affected by a number of variables. In many cases, producers are making decisions about management practices jointly as part of an entire management system rather than individually. Specifically, the practices a producer is already adopting may influence their willingness to adopt one or more other practices, and a producer may be making a decision regarding the adoption of multiple practices simultaneously. This can be due to complementarity or substitutability between different soil health practices or for different reasons, such as the fixed costs of adopting one practice to reduce the fixed costs of adopting another practice. For example, operations that own a no-till drill would not need to purchase a drill for cover crop seeding. In the previous section, it was noted that producers with cover crops were more likely to apply nitrogen at or after planting, which suggests that improved nutrient management is often adopted jointly with cover crops. Operations already using no-till often use a preplant herbicide application to kill weeds prior to planting—and the timing of this preplant herbicide application can serve the dual purpose of cover crop termination and weed control (thereby not requiring an additional field operation in the spring when adopting cover crops). No-till might reduce labor requirements and the number of field operations overall, which might reduce seasonal labor constraints when adopting cover crops or diversifying crop rotations relative to adding cover crops to a conventional tillage field, which may increase total number of field operations.

Hence, in some cases, it may be better to frame the adoption decision as whether to adopt a suite of practices (i.e., a holistic soil health management system) rather than adoption decisions about individual practices. Wu

[21] These studies mostly indicate that the perceived risk of the practice affects decision making. There are few studies that actually evaluate whether cover crops increase or decrease net risk.

and Babcock (1998), in an analysis of the adoption of conservation practices in the Central Nebraska Basin, found that adoption of crop rotations and soil testing increased profits in corn production while decreasing nitrogen fertilizer use relative to producers who adopted either of the practices alone. They also found that producers adopting conservation tillage and crop rotations jointly decreased soil erosion but did not reduce nitrogen fertilizer applications. Canales et al. (2020) found that producers with crop rotations were more likely to adopt continuous no-till and cover cropping together in their model, and the time to adopt cover cropping was 70 percent lower for producers who had already adopted continuous no-till. Gong et al. (2021) evaluated joint adoption of no-till, cover crops, and manure use and found that producers were more likely to adopt both cover crops and manure as a fertilizer source if they were already using no-till, controlling for other factors. These results support some of the differential adoption rates observed in Federal data in the previous section—for example, higher rates of cover cropping among no-till adopters.

Effect of Cover Crops and Conservation Tillage on Yields, Costs, and Productivity: Findings from Survey Data

The impact of soil health practices and management systems on yield and yield variability is important to consider because yield outcomes directly impact farm profitability, which in turn affects producer adoption decisions. However, the potential for practices and management systems to impact net returns at the field or operation level goes beyond measurable impacts on yield. These practices hold the potential to reduce the need for costly inputs, such as fertilizer or pesticides, if practices are less input-intensive, improve input use efficiency, or improve the productivity of the system as a whole.

In this section, data from the Agricultural Resource Management Survey (ARMS) are used to examine field-level correlations between the adoption of conservation tillage or cover crops and yield and production costs in corn and soybeans. Also investigated is how soil health management systems are associated with productivity and technical efficiency for specific crops at the farm operation level. The process begins by looking at the descriptive statistics of differences in field-level yield and input cost differences for corn and soybeans using ARMS Phase 2 data. Then, the correlation between conservation tillage and yield and input costs at the field level is discussed before closing with a discussion of the correlation between no-till/strip-till and cover crops with productivity and technical efficiency at the farm level using ARMS Phase 3 data.

Comparing Yield and Costs in Fields Based on Tillage and Cover Crop Adoption

A direct comparison of yields and costs of production for corn and soybeans using ARMS Phase 2 field-level data without controlling for other factors points to several key results (table 8):

- Conservation tillage corn and soybean fields have lower total production costs.
- Conservation tillage corn and soybeans fields have higher chemical costs.
- Conservation tillage corn and soybeans fields have lower fuel and labor costs.
- Cover cropped corn fields have higher fertilizer, labor, and seed costs than fields without cover crops.
- Cover cropped soybean fields have higher chemical and fertilizer costs than fields without cover crops.

Lower total production cost per acre in corn and soybean fields that adopted conservation tillage reflects the lower component production costs discussed in the literature review of this report. Namely, lower fuel and labor costs were associated with lower tillage intensity. Similarly, higher chemical costs for conservation tillage fields in both crops was consistent with the literature about the costs of this practice.

Despite being able to detect differences in input costs, a statistically significant difference was not found in corn or soybean yields between fields where conservation tillage and cover crops were and were not adopted. This null statistical finding is notable because of the commonly expressed concern among nonadopters that both practices may have a negative yield impact. This finding is novel from a data standpoint, considering that very few peer reviewed studies have examined yield differences based on observational data (nonexperimental) from producers. It is acknowledged, however, that the inability to detect a difference in yields may be because there are only a limited number of cover cropped fields in the most recent ARMS samples available.

Table 8

Comparison of Agricultural Resource Management Survey field-level data on yield and production costs based on adoption of conservation tillage or cover crops, 2010–18

Crop	Conservation tillage		Cover crop	
	Adopters	Nonadopters	Adopters	Nonadopters
Corn (2010, 2016)	n = 1,074	n = 688	n = 54	n = 1,708
Yield (bushel per acre)	169.8	165.0	162.2	168.2
Total cost per acre (U.S. dollars)	598.82**	625.35	745.06	604.47**
Seed cost (U.S. dollars)	88.90	87.30	95.36	88.00*
Fertilizer cost (U.S. dollars)	122.8*	131.40	153.26	125.19*
Chemical cost (U.S. dollars)	33.15	29.70**	39.45	31.56
Fuel cost (U.S. dollars)	17.39***	25.09	18.99	20.42
Labor cost (U.S. dollars)	30.28***	44.25	90.54	33.83*
Soybeans (2012, 2018)	n = 1,521	n = 657	n = 94	n = 2,084
Yield (bushel per acre)	45.2	45.6	46.2	45.3
Total cost per acre (U.S. dollars)	441.00***	476.00	441.66	452.00
Seed cost (U.S. dollars)	59.28	58.94	57.85	59.26
Fertilizer cost (U.S. dollars)	41.41	36.94	58.72	39.18**
Chemical cost (U.S. dollars)	32.40	27.82***	40.73	30.60**
Fuel cost (U.S. dollars)	12.99***	20.72	13.54	15.26
Labor cost (U.S. dollars)	24.79***	31.38	36.33	26.14

n = number of fields.

Note: Statistical significance is based on a simple linear regression of each variable on a binary adoption variable. Asterisks indicate significantly lower values for adopters (Y) or nonadopters (N) following ***p< = 0.01, **p< = 0.05, *p< = 0.1. Statistical tests account for survey weights in the Agricultural Resource Management Survey (ARMS) Phase 2 and are pairwise not controlling for any other covariates besides adoption of conservation tillage or cover crops.

Source: USDA, Economic Research Service (ERS) using USDA, ERS and USDA, National Agricultural Statistics Service ARMS data for corn (2010 and 2016) and soybeans (2012 and 2018).

It is important to note that these statistically significant differences cannot be directly attributed to the adoption of soil health or conservation practices and could instead be due to other factors that are correlated (or associated) with adoption of the practice but are not controlled for in simple correlations. For example, cover crops are more widely adopted in certain regions—and those regions may have different soils, production systems, State cost-share incentives, and climate than regions where cover crops are less common. Similarly, producers may be more likely to adopt conservation practices such as cover crops or reduced tillage on land that is highly erodible or has lower soil quality relative to other fields they operate. Producers who adopt conservation practices may manage their land more intensively than those who do not, or they may have other unobservable characteristics that affect their yields or costs of production.

Effect of Conservation Tillage on Yield and Costs of Production in Corn and Soybeans

Using data from corn and soybean fields in ARMS, the authors analyzed the effect of conservation tillage (combining no-till, strip-till, and reduced-till) on yields and production costs for corn (2010 and 2016) and soybeans (2012 and 2018).[22] In this analysis, conservation tillage was defined as tillage management that results in a Soil Tillage Intensity Rating (STIR) of 80 or lower, which included roughly 65 percent of the acres for corn and 70 percent of the acres for soybeans (see Claassen et al. (2018a) for more information on categorizing tillage practices using the STIR rating). By matching similar fields only within the same State and year that used (versus did not use) conservation tillage, the authors tried to replicate as closely as possible a controlled experiment with everything that was observable in the data held constant between the treated (conservation tillage) and untreated (more intensive tillage practices) fields. More specifically, a modern matching technique that minimizes the combined differences between treated and untreated fields across all explanatory variables included in the yield and production cost models was used to maximize the observable similarity of matched fields (appendix D).

This approach enabled the authors to control for the most observable differences between fields possible to determine how conservation tillage adoption was correlated with crop yields and total production costs (table 9). Conservation tillage adoption was estimated to be correlated with higher corn yield, but a statistically significant correlation was not found between conservation tillage and soybean yields.

Yield and production costs combine with crop output price to impact per-acre profitability of crop production and conservation practice adoption. Even if a conservation practice like conservation tillage has no statistically significant effect on yields, it could improve profitability by reducing input costs. Applying the same matching methodology used to understand the relationship between yield and adoption was also used to quantify the correlation between conservation tillage on the total costs of production for corn and soybeans. Conservation tillage was negatively correlated with crop production costs in both corn and soybean fields. As discussed in the previous section (table 8), conservation tillage can reduce costs of production by reducing the number of tillage passes across the field—saving labor, machinery, and fuel costs (though at the same time, other cost categories may increase, such as herbicide use for weed control). These results indicate that, even after controlling for many other factors, conservation tillage is associated with a decrease in overall production costs in corn and soybeans.

Table 9

Correlation between conservation tillage adoption and crop yields and costs of production in the Agricultural Resource Management Survey data, 2010–18

	Field-level outcome	Corn (2010, 2016)	Soybeans (2012, 2018)
Correlation between conservation tillage adoption and…	…crop yield	Positive; correlated with increased crop yield	No significant effect
	…production cost	Negative; correlated with decreased production costs	Negative; correlated with decreased production costs

Note: Estimates generated using a matching analysis that compares yield and total production costs per acre in fields that adopt and do not adopt each practice. All reported directional correlations are significantly different from 0, with 95-percent confidence.

Source: USDA, Economic Research Service using data from the USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS) for corn (2010 and 2016) and soybeans (2012 and 2018).

[22] We are not able to conduct this same analysis for cover crops due to the relatively small number of observations for operations with cover crops in ARMS Phase 2 data.

Effect of Soil Health Practices on Productivity and Technical Efficiency

In addition to the field-level effects of conservation tillage on yields and production costs described in the last section, a matching approach was used to estimate the effect of no-till/strip-till use and/or cover cropping on productivity and technical efficiency at the farm level. No-till/strip-till and cover cropping were analyzed as two separate technologies (practices) that can be used on the same farm individually, in combination, or not at all (conventional tillage without cover crops). For this analysis, productivity refers to the direct effect of using a practice on farm output—for example, the effect of more acres in no-till soybeans on total soybean output. Productivity effects were established by evaluating the coefficient estimates for the production technologies (no-till/strip-till use and/or cover cropping). In contrast, technical efficiency refers to how proficient users of the practice/technology are in combining available inputs to maximize production (compared with nonusers) (table 10). Technical efficiency is usually considered to be synonymous with managerial ability[23] (see appendix E for more discussion of productivity versus technical efficiency). The following are estimated in this report (estimated results presented in table 10):

- Effect of no-till or strip-till use on farm-level productivity and technical efficiency in corn, soybean, and cotton production, using data from the 2018 and 2019 ARMS Phase 3 (farm-level) surveys.
- Effect of no-till/strip-till and/or cover cropping on farm-level productivity for crop production (overall), using data from the 2018–20 ARMS Phase 3 (farm-level) surveys.
- Effect of no-till/strip-till and cover cropping on farm-level technical efficiency in crop production, using data from the 2018–20 ARMS Phase 3 (farm-level) surveys.

In each estimate for these key areas, the authors controlled for other variables driving crop productivity, such as acres harvested; labor, capital, and materials used; whether the operation also had livestock; and geography (USDA, ERS Farm Resource Region). They also used a propensity score matching approach to compare farms that were similar except for their use of no-till/strip-till and/or cover crops.[24]

Across all three crops (corn, soybeans, and cotton), no-till/strip-till was estimated to have a modest, positive impact on production, with no-till/strip-till use in cotton having a slightly lower effect on production than in corn and soybeans (table 10).[25] At the same time, operations using no-till/strip-till to produce corn and soybeans were estimated to be slightly less technically efficient overall than nonadopters of no-till/strip-till. Although why this is the case was not observed, it is possible that there may have been output substitutions (e.g., producing more corn and raising fewer livestock) occurring alongside input substitutions as producers shift technologies/practices.

When the authors estimated the impact of no-till/strip-till acres and cover crop acres on aggregate output, they did not find a significant impact of the reported acreages of soil health practices on productivity. However, they did find that producers who adopted cover cropping and no-till/strip-till had production systems that were modestly more technically efficient than nonadopters. This difference in technical efficiency

[23] Productivity is measured by evaluating the parameter estimates. The input-output measures are in logarithmic form, therefore changes in productivity refer to percent change in output following a percent change in factor input use. On the other hand, technical efficiency measures distance from the production frontier or producing maximum output using a given level of inputs. Technical efficiency measures are derived from analyzing the composed error term in the stochastic production frontier, $\varepsilon = v - u$, where u captures the said distance from the production frontier. Additional details on the empirical strategy are provided in the Appendix.

[24] Farms are matched based on characteristics of the principal farm operator (e.g., sex, age, ethnicity, education, experience); the value of farm assets, amount of commodity payments, and level of farm specialization (e.g., cash crop, grain, high value, livestock); and the region and year of the data being reported.

[25] The authors do not estimate the crop-specific impact of cover crops because they do not have crop-specific cover crop acreage data in the ARMS Phase 3 (only operation-level) survey.

is typically considered to be due to differences in managerial ability, which might reflect the fact that more intensive land managers are more likely to be early adopters of cover cropping and no-till/strip-till.[26]

Table 10

Estimated results of the effects of no-till/strip-till and cover cropping on farm-level crop productivity and technical efficiency based on Agricultural Resource Management Survey data, 2018–20

Scenario	Effects of no-till/strip till on productivity	Effects of cover crops on productivity	Difference in efficiency between adopters and nonadopters
Corn production	Positive and significant; a 1-percent increase in no-till/strip-till acreage raises corn output by 0.15 percent. This may be large enough to influence producers' decisions on no-till/strip-till acreage.	Not estimated due to data limitations	Adopters of no-till/strip-till are slightly less technically efficient (74 percent versus 75 percent).
Soybean production	Positive and significant; a 1-increase in no-till/strip-till acreage raises soybean output by 0.13 percent. This margin may be large enough that it could influence producers' decisions on no-till/strip-till acreage.	Not estimated due to data limitations	Adopters of no-till/strip-till are slightly less technically efficient (82 percent versus 84 percent).
Cotton production	Positive and significant; a 1-percent increase in no-till/strip-till acreage raises soybean output by 0.09 percent. This margin may not be large enough to influence producers' decisions on no-till/strip-till acreage.	Not estimated due to data limitations	Adopters and nonadopters of no-till/strip-till have roughly equal levels of technical efficiency.
Aggregate production	Estimated effect is not statistically significant.	Estimated effect is not statistically significant	Producers adopting both cover crops and no-till/strip-till have higher estimated technical efficiency (74.5 percent) compared with non-adopters (70.9 percent).

Note: For individual crops (rows 1–3), estimates use data from the 2018 and 2019 Agricultural Resource Management Survey (ARMS) years. For crop production overall (row 4), analysis includes the 2018–20 crop years. Productivity refers to the direct impact of using a practice on total crop output at the farm level—for example, the effect of more acres in no-till soybeans on total soybean output. Technical efficiency refers to how efficient users of the practice/technology are in combining available inputs to maximize production (compared with nonusers).

Source: USDA, Economic Research Service using data from the USDA, Economic Research Service and USDA, National Agricultural Statistics Service, 2018, 2019, and 2020 Phase 3 ARMS.

Discussion and Conclusions

This report provided framing and background on soil health management, producer decision making, and economic outcomes, and it summarized what is known from several Federal data sources about producer adoption of soil health and conservation practices on U.S. cropland. This report also highlighted key findings

[26] Estimated differences in technical efficiency could also reflect unobserved factors correlated with the conservation practice adoption decision, such as differences in land or soil quality.

from the literature on the economic outcomes associated with soil health practices. Finally, it provided new results on associations between selected soil health practices and yields and costs at the field level, as well as productivity and technical efficiency at the farm level.

This report also focused on a number of gaps in the current understanding of economic outcomes. For example, in the literature review, the authors summarized what is known about how behavioral factors might affect the adoption of soil health practices and management systems. Yet it is not always understood how—or to what extent—these factors affect decision making in practice. This report also summarized trends in the ways that many farmers started, continued, and discontinued cover cropping between the 2012 and 2022 census years, highlighting a limited understanding of the factors affecting whether a producer continues to use a practice such as no-till or cover cropping.

Findings were presented on economic outcomes associated with some conservation and soil health practices but without an evaluation on how these outcomes might change over time, whether they extend to diverse crops or other practices, or what the economic effects of different types of management systems might be when compared with performing one or two practices at a time. To the extent that early adopters of practices such as cover cropping are not representative of agricultural producers overall, there is also the risk that estimated results do not represent the results that an average producer might expect when adopting cover crops.[27] If cover crop adoption and adoption of other practices of interest continue to increase, increased data availability about management practices and economic variables will increase researchers' ability to estimate economic effects on farms where these practices are being implemented.

To summarize, the factors affecting a producer's decision to implement soil health and conservation practices are complex and include expectations about short- and long-run profitability, the risk and uncertainty associated with the practices, and behavioral factors such as time and risk preferences, peer effects, and stewardship identity. At the same time, the potential costs and benefits to the producer and society depend on how the practice is being implemented, the crop and/or livestock management system, weather, climate, soils, and many other variables.

With these insights in mind, this report included a review and summary of adoption rates and trends for several key soil health and conservation practices. These rates and trends were estimated from Federal census and survey data for a few key practices, including no-till and reduced tillage, cover crops, nutrient management, and joint adoption of practices (e.g., no-till and cover cropping together or nutrient management timing in cover crop systems). While acknowledging that the adoption of practices and practice combinations varies with a variety of factors (e.g., crop, region and production system), there were several key points from this section of the report:

- The share of acreage under conservation tillage (no-till and reduced tillage combined) for corn, soybean, wheat, and cotton has increased over the last 20 years (figure 1).
- Cover crop adoption varied with the cash crop being planted but generally continued to increase over time. The highest rates of cover crop adoption were on corn-for-silage and cotton fields (figure 2). Looking at data from the Census of Agriculture, the authors estimate that discontinuation of cover crops was common.
- For winter and durum and other spring wheat fields, the total share of nitrogen applied at or after planting has increased, while corn fields shifted to more fall application in the most recent survey

[27] Also, because cover crop adoption is still relatively low, Federal surveys, such as ARMS, do not pick up large sample sizes of cover croppers without an oversample for the practice. This means that it can be difficult to have enough statistical power to compare economic outcomes (e.g., yield or production costs) for cover croppers to non-cover croppers or to evaluate heterogeneity in cover crop management due to small sample sizes.

year. For winter wheat fields not receiving manure, the share of nitrogen applied at or after planting increased from 44 percent in 2004 to 60 percent in 2022, and for durum and other spring wheat fields, the same share increased from 37 percent in 2004 to 54 percent in 2022 (table 5).

- In general, crop acreage in no-till or reduced tillage was more likely to be cover cropped than conventionally tilled acreage. Also, corn and cotton acreage that was cover cropped had a higher share of nitrogen applied at or after crop planting (figure 6).

Adoption rates for conservation and soil health practices and trends in adoption provide an understanding of what practices and systems are profitable since producers typically adopt practices when the benefits outweigh the costs. In this report, the authors also directly analyzed several economic outcomes of soil health practice adoption using data from the Agricultural Resource Management Survey (ARMS), focusing on the relationships between conservation tillage and cover crops, yields, and the production costs at the field level and with productivity and technical efficiency[28] at the farm level. Noteworthy findings were as follows:

- At the field level, conservation tillage was estimated to be associated with higher corn yield per acre and estimated to reduce per-acre costs of production in corn and soybeans (table 9).
- At the farm operation level, no-till and strip-till acreage were positively and significantly associated with corn, soybean, and cotton productivity, but cover crops alone were not estimated to have a significant impact on crop production (table 10).
- Adopters of no-till or strip-till only were estimated to be slightly less technically efficient in corn and soybean production than nonadopters, whereas adopters of both cover crops and no-till/strip-till were estimated to have a higher technical efficiency compared with nonadopters at the farm operation level (table 10).

Although the authors did not observe why these practices were associated with these economic outcomes, adopters of certain technologies may be making output substitutions at the same time as input substitutions, which could result in an adjustment period or reduced technical efficiency. Alternatively, these economic outcomes might be due to differences in management intensity or technical knowledge required to adopt individual or multiple conservation practices.

[28] A productivity impact refers to the direct impact of using a practice on crop output, and technical efficiency refers to how efficient users of the practice/technology are in combining available inputs to maximize production (compared with nonusers).

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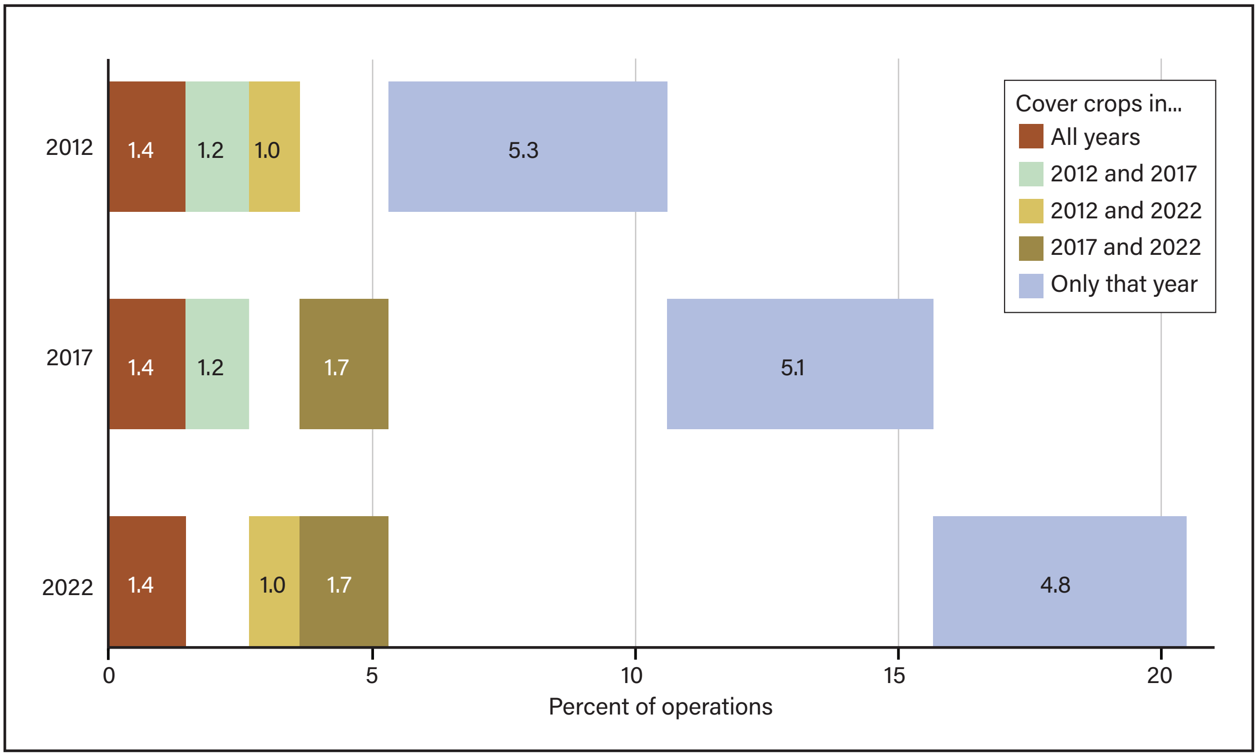
Appendix A: Share of Operations That Used Cover Crops in the 2012, 2017, and/or 2022 Censuses of Agriculture by USDA, Economic Research Service Farm Resource Region

Figure A.1

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Basin and Range Region

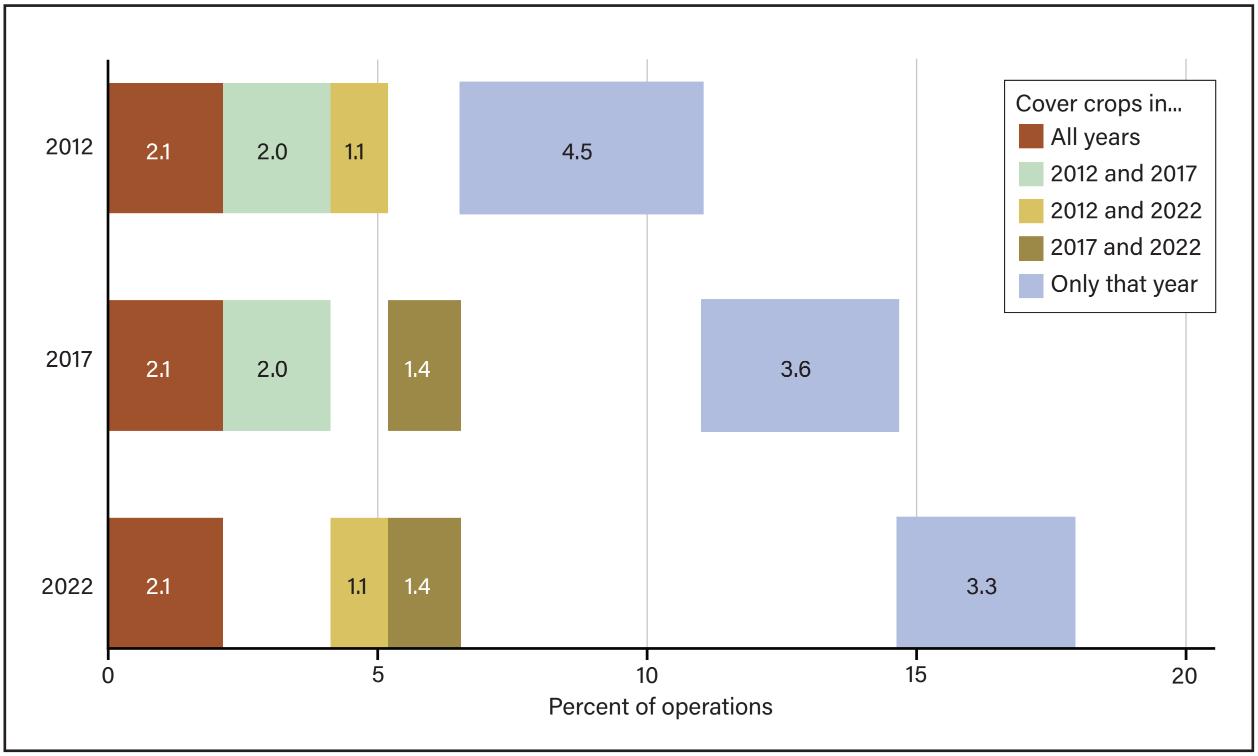


Note: This figure shows the share of operations in the Basin and Range Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 20,750 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.2

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Eastern Uplands Region

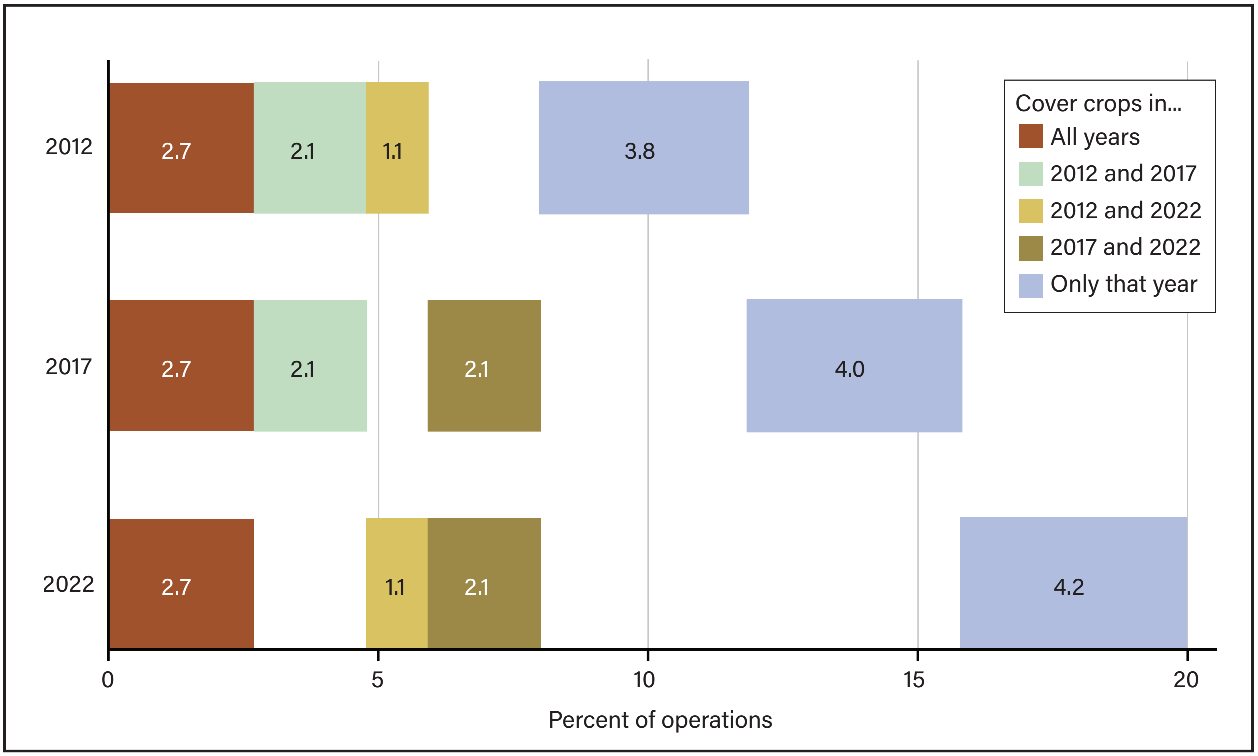


Note: This figure shows the share of operations in the Eastern Uplands Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 70,300 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.3

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Fruitful Rim Region

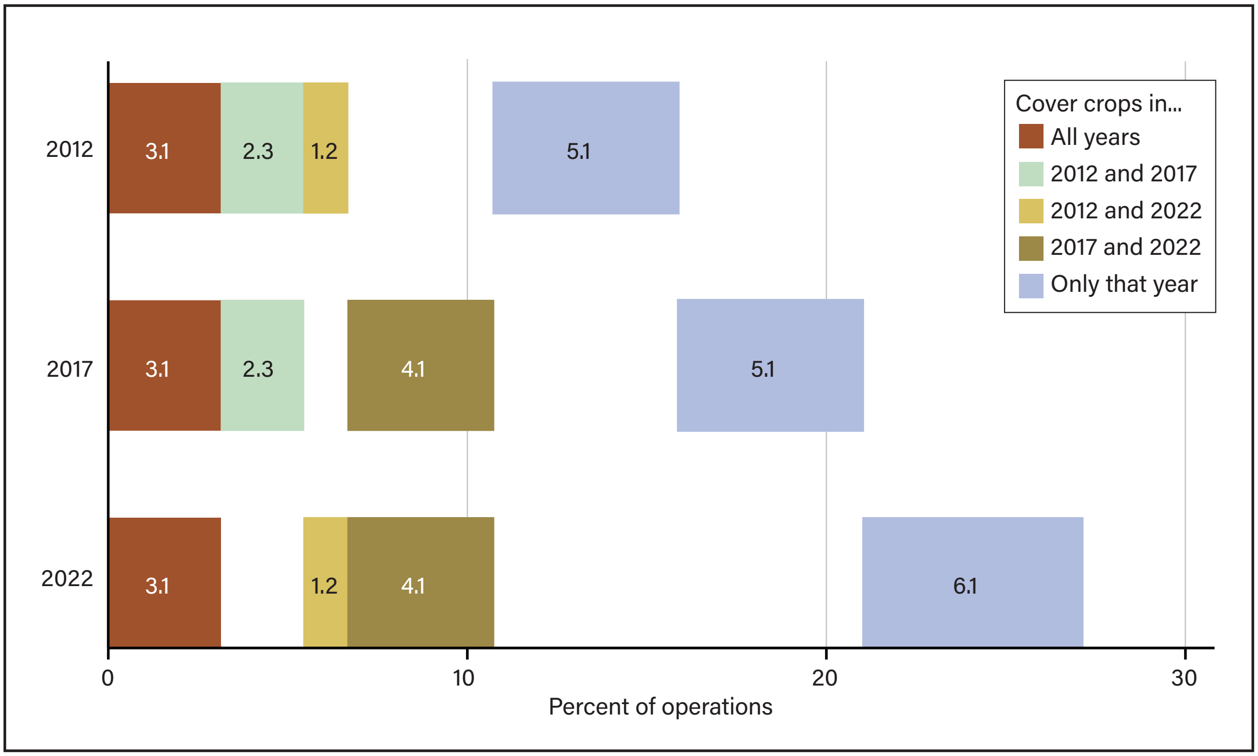


Note: This figure shows the share of operations in the Fruitful Rim Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 48,100 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.4

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Heartland Region

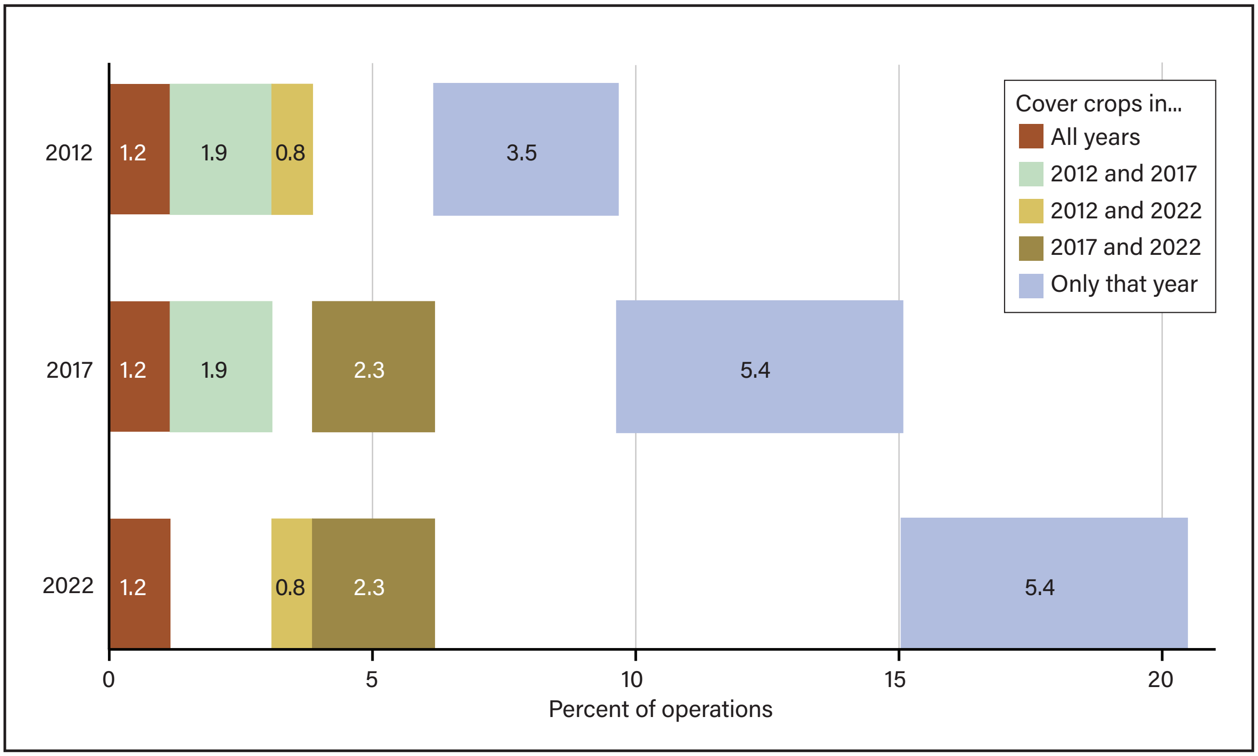


Note: This figure shows the share of operations in the Heartland Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 130,400 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.5

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Mississippi Portal Region

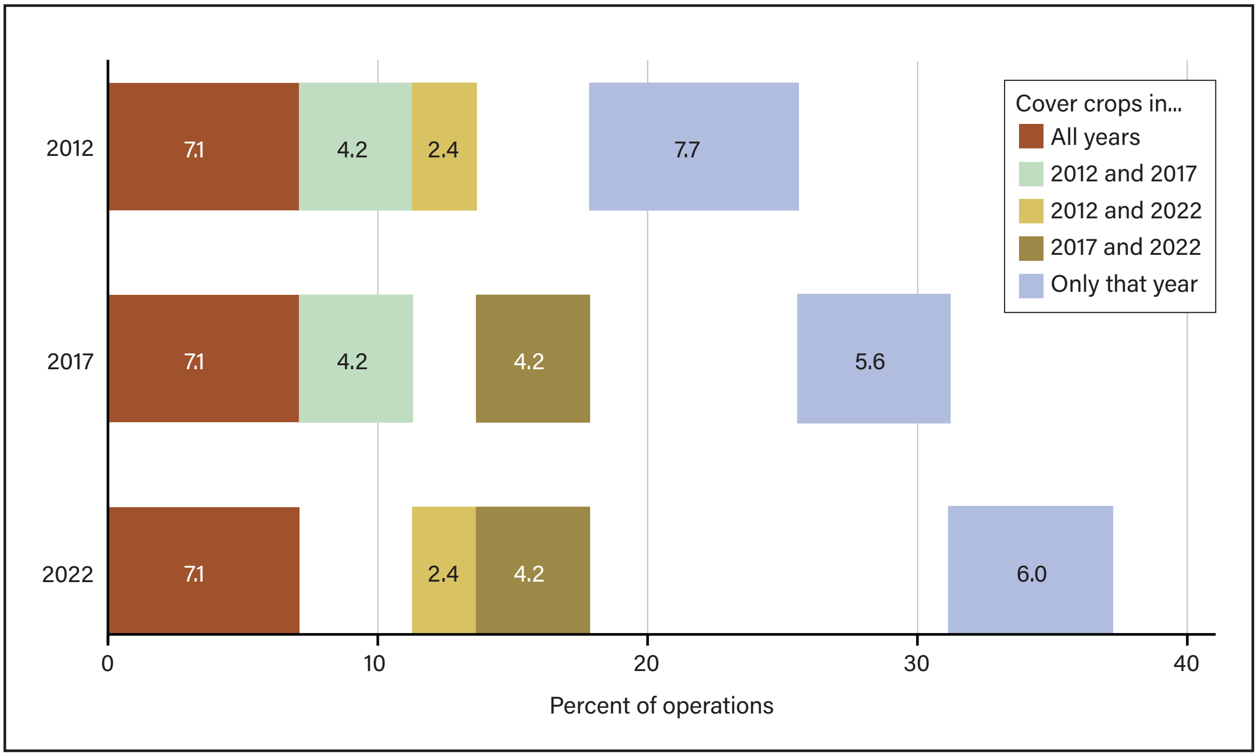


Note: This figure shows the share of operations in the Mississippi Portal Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 130,400 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.6

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Northern Crescent Region

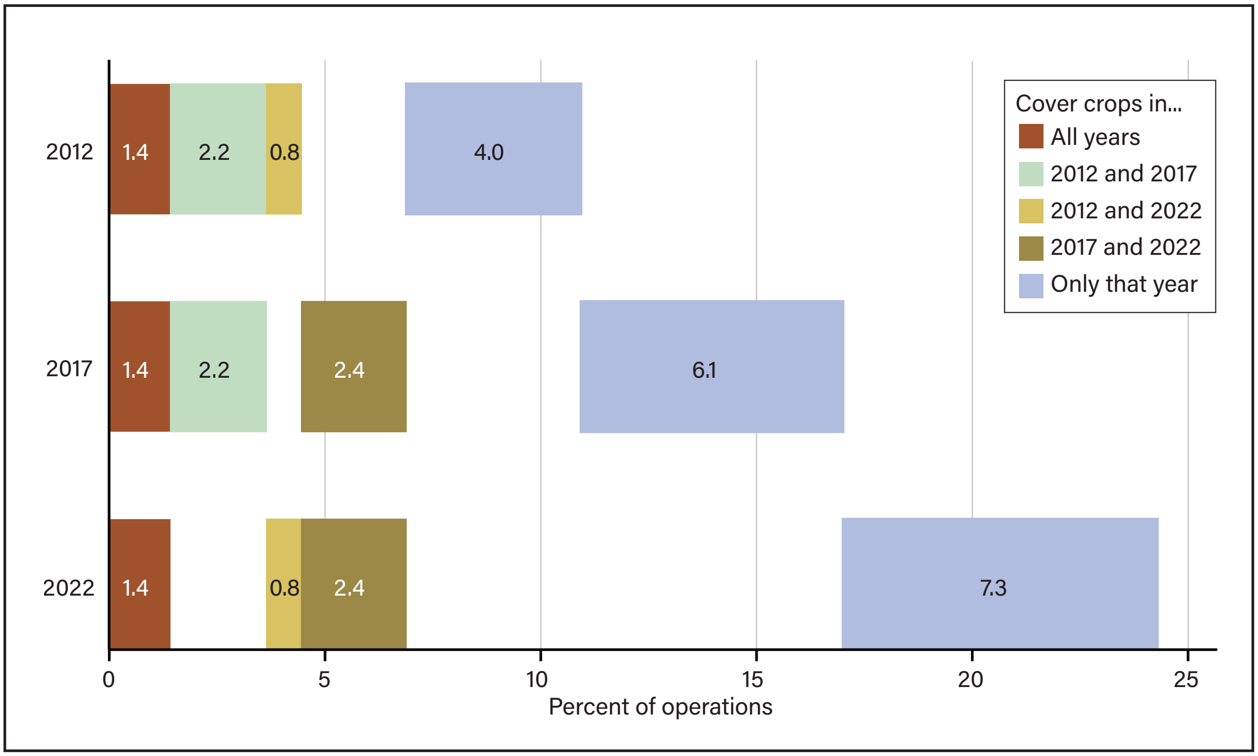


Note: This figure shows the share of operations in the Northern Crescent Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 93,000 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.7

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Northern Great Plains Region

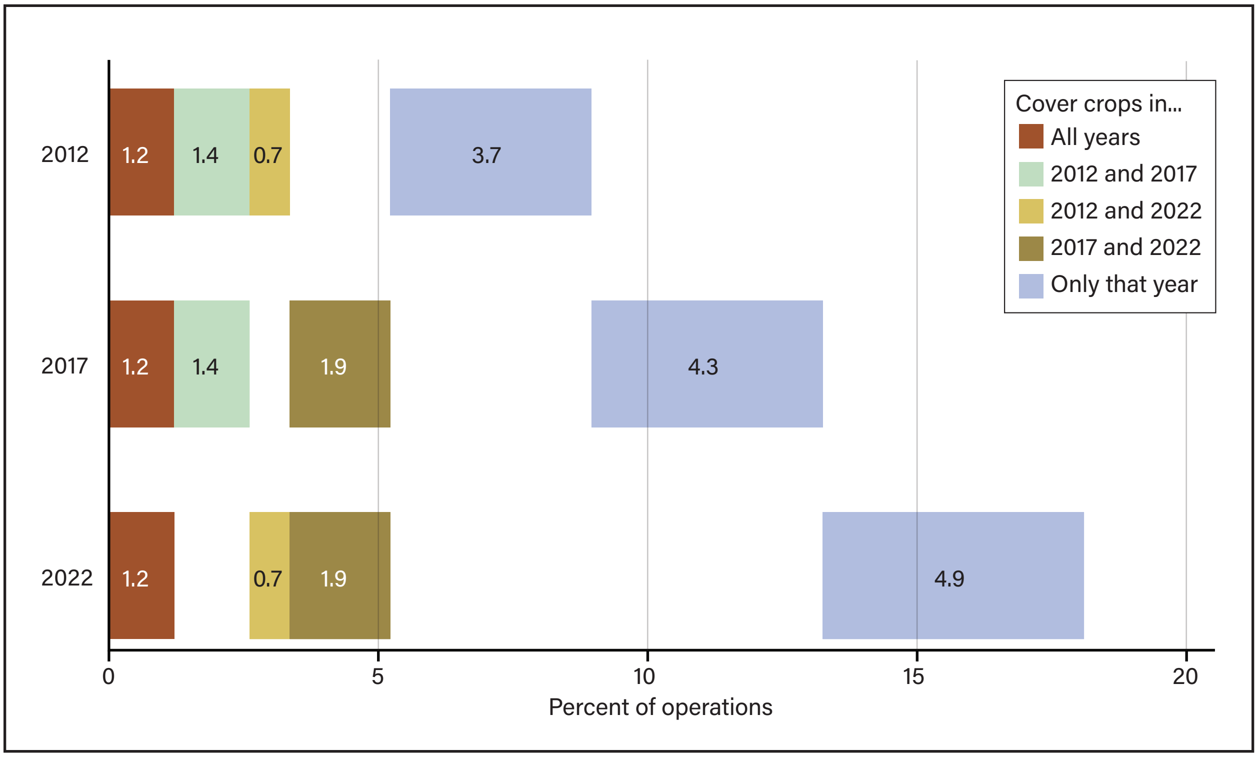


Note: This figure shows the share of operations in the Northern Great Plains Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 24,700 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.8

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Prairie Gateway Region

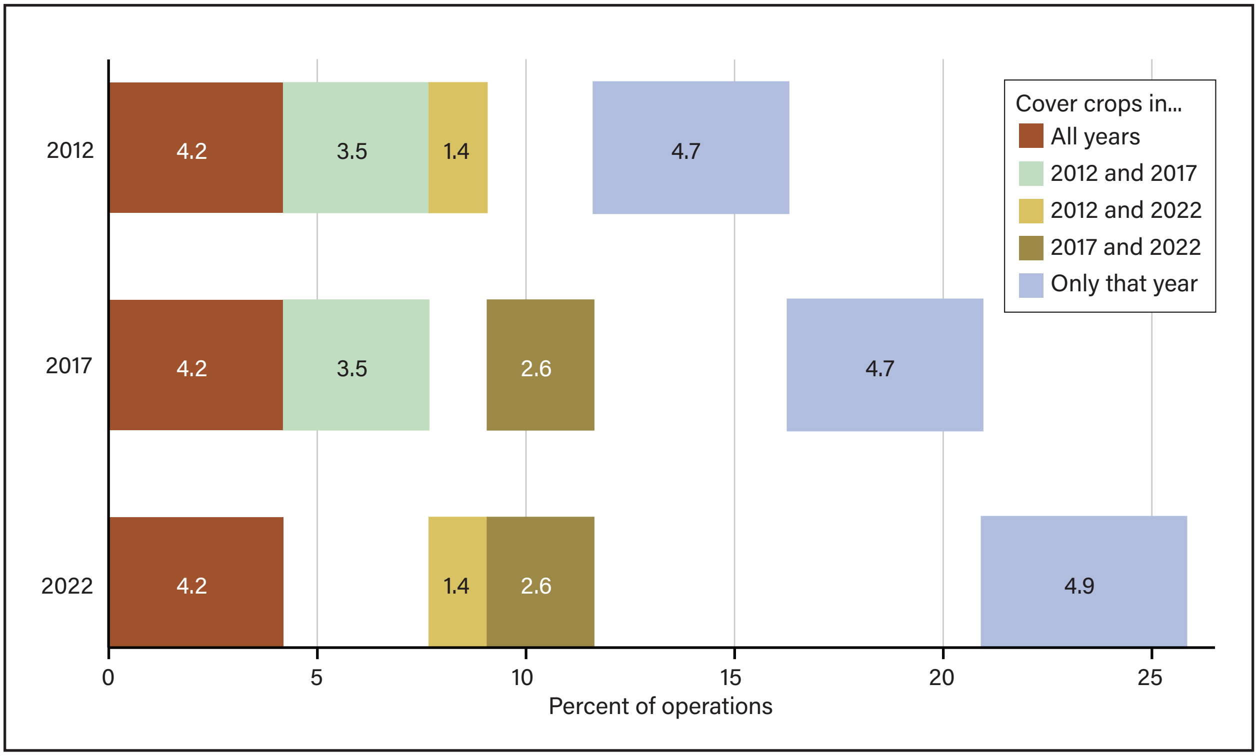


Note: This figure shows the share of operations in the Prairie Gateway Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 53,600 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Figure A.9

Share of operations that used cover crops in the 2012, 2017, and/or 2022 Censuses of Agriculture in the Southern Seaboard region



Note: This figure shows the share of operations in the Southern Seaboard Farm Resource Region with cropland that responded to the 2012, 2017, and 2022 Censuses of Agriculture that reported cover cropping (positive cover cropped acreage) in 1 or more census years. The population is the 43,000 (weighted) operations that appear in all 3 census years, which may not be representative of the population of all census respondents in a given year. To obtain total share of operations cover cropping in each year, add all colored sections of the bar.

Source: USDA, ERS using data from the USDA, National Agricultural Statistics Service 2012, 2017, and 2022 Censuses of Agriculture.

Appendix B: Timing of Nitrogen Applications by USDA, Economic Research Service Farm Resource Region

Table B.1

Proportion of nitrogen applied by season for corn (2021), cotton (2019), and winter wheat (2022) acreage in the most recent survey year for acreage with no manure application

		Percent of nitrogen applied in each timing category			
Crop	**Region**	**Fall**	**Spring**	**At planting**	**After planting**
Corn (2021)	Eastern Uplands	1.4 (1.3)	45.9 (10.6)	9.6 (5.7)	43.1 (8.2)
	Southern Seaboard	0.0 (0.0)	26.9 (5.0)	25.5 (7.0)	47.6 (5.0)
	Northern Great Plains	10.6 (5.3)	69.7 (6.4)	12.1 (3.3)	7.7 (2.1)
	Prairie Gateway	38.0 (7.6)	33.9 (9.0)	8.3 (2.2)	19.8 (7.7)
	Northern Crescent	1.8 (0.8)	26.7 (5.0)	20.7 (3.3)	50.8 (5.0)
	Heartland	28.3 (3.8)	41.7 (4.9)	5.3 (1.0)	24.6 (3.1)
Cotton (2019)	Eastern Uplands	2.1 (1.3)	32.5 (8.2)	17.0 (7.2)	48.4 (9.6)
	Heartland	7.2 (3.3)	13.9 (4.0)	3.7 (1.4)	75.2 (5.9)
	Prairie Gateway	4.7 (3.9)	41.0 (7.4)	4.7 (1.9)	49.6 (6.4)
	Fruitful Rim	28.7 (8.7)	31.5 (13.1)	9.6 (4.2)	29.8 (7.1)
	Mississippi Portal	1.3 (0.8)	28.3 (3.4)	6.4 (1.6)	61.6 (4.0)
	Southern Seaboard	2.0 (0.6)	27.8 (3.5)	13.4 (4.0)	56.7 (5.0)
Winter wheat (2022)	Fruitful Rim	28.7 (13.9)	23.3 (10.0)	29.2 (14.2)	14.8 (8.1)
	Northern Crescent	15.4 (2.1)	0.2 (0.3)	3.5 (1.9)	80.9 (2.3)
	Basin and Range	35.5 (12.6)	1.1 (1.0)	43.4 (15.0)	20.0 (8.9)
	Northern Great Plains	18.2 (8.2)	21.6 (17.0)	24.4 (5.6)	35.9 (12.3)
	Heartland	24.4 (7.8)	3.6 (1.5)	5.5 (2.1)	66.6 (7.2)
	Prairie Gateway	30.4 (5.8)	8.5 (3.1)	12.1 (2.4)	48.9 (5.3)
	Eastern Uplands	56.6 (11.6)	16.1 (8.1)	3.7 (3.1)	23.5 (15.8)
	Southern Seaboard	15.3 (6.5)	7.8 (7.8)	16.2 (10.8)	60.7 (12.4)

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		Percent of nitrogen applied in each timing category			
Crop	**Region**	**Fall**	**Spring**	**At planting**	**After planting**
Durum and other spring wheat (2022)	Basin and Range	27.9 (13.3)	29.1 (9.8)	32.4 (8.4)	8.2 (4.4)
	Fruitful Rim	6.8 (2.4)	34.5 (9.0)	21.7 (9.4)	36.8 (8.2)
	Northern Great Plains	16.2 (2.9)	38.4 (3.4)	38.1 (4.4)	7.3 (1.3)

Note: Standard errors are in parentheses. Totals across columns may not sum to 100 due to rounding. "At planting" and "after planting" may refer to nitrogen application in different seasons for different crops. For example, winter wheat is typically planted in the fall, which means that both the fall application and the application at planting would occur in the fall. Similarly, nitrogen applied in the spring can likely be interpreted as being applied before planting for corn but after planting for winter wheat. The seasonality of the percent of nitrogen applied after planting is ambiguous for winter wheat.

Source: USDA, Economic Research Service (ERS) using data from USDA, ERS and USDA, National Agricultural Statistics Service Agricultural Resource Management Survey (ARMS) for corn (2021), cotton (2019), and wheat (2022).

Appendix C: Literature Examining the Profitability of Cover Crops and Conservation Tillage

Table C.1
Selected literature that reports profitability effects of no-till

Studies	Profit impact range (U.S. dollars per acre)	Description	Strengths (S)/weaknesses (W) of analysis
Doster et al., 1983	-11 to 26	Early study of no-till versus alternative tillage practices in Indiana; based on 16-year field trial data (for yields) merged with hypothetical cost budgets; continuous corn and corn-soy rotations; used fall plow as control (conventional tillage)	S: Yields based on long-run field trial data; W: Analysis only for Indiana; inferred costs from budgets, not from field trials
Liu and Duffy, 1996	-3.71 to 38.39	Study that compared various conservation tillage practices (including no-till) versus conventional till; used survey data from producers; corn and soybeans; profits for no-till corn and no-till soybeans were statistically higher than conventional	S: Based on producer survey data at the field level W: Only analyzed 2 years of data; nonrepresentative sample
Marra and Kaval, 2000	-40.14 to 23.76	Meta-analysis of studies that compared no-till and conventional systems; 144 total studies for various grain crops and locations within the United States; no-till tended to have lower profitability relative to conventional till in most scenarios	S: Used meta-analysis to analyze mean effects for different locations and crops; W: Considered old studies from 1974 to 1996
Williams et al., 2000	-33.25 to -13.49	Study using Kansas experiment station data from 1986–1995; wheat and grain sorghum; no-till tended to have lower returns in cases examined	S: Multiyear analysis; W: Only for 1 location; older study
Al-Kaisi and Yin, 2004	-13.49 to 16.59	Study that used field experiment data in Iowa from 1978–2001; corn; variety of conservation till practices (including no-till); no-till generally had equal or greater economic return relative to other tillage system; comparable return for whole time	S: Multiyear analysis for multiple tillage practices; W: Only for several locations within Iowa
Karlen et al., 2013	0.81 to 24	Long-term study of various tillage practices (including no-till) in Iowa from 1975–2006; corn and soybeans; used field experiment data; no-till systems were more profitable than various conventional till methods although grain yields are slightly lower	S: Multiyear analysis for multiple tillage practices; W: Only for 1 field location in Iowa
Al-Kaisi et al., 2016	-2.83 to 63.13	10-year (2003–13) study of various tillage practices and corn-soybean rotations for several locations in Iowa; use of field experiment data; in general, net returns were higher for no-till corn and soybean rotations (relative to conventional) due to lower input costs and comparable yields	S: Multi-year analysis for multiple tillage practices; W: Only for several field locations in Iowa (geographic scope limited)

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Studies	Profit impact range (U.S. dollars per acre)	Description	Strengths (S)/weaknesses (W) of analysis
Trlica et al., 2017	-80 to -40 (based on bar graphs)	Study examining profitability of various tillage practices over 45 years in Illinois; continuous corn and corn-soybean rotations; field experiment data; cumulative profits in no-till were comparable with other tillage practices; mean annual profits for no-till typically lower than conventional	S: 45-year analysis for multiple tillage practices; W: Only for 1 location in Illinois (geographic scope limited)
Cusser et al., 2020	0 to 768 (yearly accumulated difference in profit after 13 years)	Long-term study investigating no-till versus conventional till in Michigan (29 years); corn; used partial budget to assess long-term profitability; over a decade is needed to see consistent profit effects of no-till over conventional; 13 years to recoup initial expenses; profit differential increased with longevity of use; no-till had consistently higher profits than conventional after 13 years	S: 29-year analysis for no-till vs conventional tillage practices; W: Only for 1 location in Southern Michigan (geographic scope limited)
Fan et al., 2020a	3	Field experiments for cotton in Texas (6 years), net return analysis; compared conventional till without cover crops versus no-till with cover crops (wheat and mix); profit difference on left is for conventional without cover crops versus. no-till without cover crops	S: Used cover crop mixture; W: Only 1 location in Texas
Fan et al., 2020b	2	Field experiments for cotton in Texas (4 years), net return analysis; compares conventional till without cover crops versus no-till with cover crops (wheat, clover, pea, vetch mix); profit difference on left is for conventional till without cover crops versus no-till without cover crops	S: Separated out net returns for different cover crop types plus mixture; W: Only 1 location in Texas
Singh et al., 2021	-46.54 to 24.68	Study that examined profitability of no-till and conventional till (together with cover crops in some treatments); South Dakota field experiments; 4-year study (2014–18); examined several rotations (like corn-soybeans-oats); comparable profitability of no-till and conventional in rotations examined; no-till with cover crops did not have consistently higher profits compared with conventional till (with or without cover crops)	S: Multiyear analysis for no-till and conventional; together with cover crops; W: Only for 1 location in South Dakota (limited geographical scope)

Source: USDA, Economic Research Service using published literature listed in the Studies column.

Table C.2

Selected literature that reports profitability effects of reduced tillage practices (i.e., reduced till, ridge till, strip till)

Studies	Profit impact range (U.S. dollars per acre)	Description	Strengths (S)/weaknesses (W) of analysis
Doster et al., 1983	-19 to 29	Early study of no-till versus alternative tillage practices in Indiana; based on 16-year field trial data (for yields) merged with hypothetical cost budgets; continuous corn and corn-soy rotations; used fall plow as control (conventional tillage); in 5 out of 6 cases, ridge till had higher profits than fall plow	S: Yields based on long run field trial data; W: Analysis only for Indiana; Inferred costs from budgets, not from field trials
Liu and Duffy, 1996	0.02 to 49	Study that compared various conservation tillage practices (including reduced till) versus conventional till; used survey data from producers; corn and soybeans; profits for ridge till (or reduced till) corn and soybeans tended to be greater than conventional till	S: Based on producer survey data at the field level W: Only analyzed 2 years of data; nonrepresentative sample
Williams et al., 2000	-2.81 to 13.77	Study using Kansas experiment station data from 1986 to 1995; wheat and grain sorghum; reduced till had comparable returns to conventional till; reduced till was preferred in some cases by risk-averse producers	S: Multiyear analysis; W: Only for 1 location; older study
Al-Kaisi and Yin, 2004	-4 to 8.9	Study that used field experiment data in Iowa from 1978 to 2001; corn; variety of conservation till practices (including reduced till); reduced till had comparable returns to conventional till	S: Multiyear analysis for multiple tillage practices; W: Only for several locations within Iowa
Karlen et al., 2013	4.45 to 10.11	Long-term study of various tillage practices (including no-till) in Iowa from 1975 to 2006; corn and soybeans; used field experiment data; reduced till systems were more profitable than conventional moldboard plow, although grain yields are slightly lower	S: Multiyear analysis for multiple tillage practices; W: Only for 1 field location in Iowa
Al-Kaisi et al., 2016	-3.23 to 0.4	10-year (2003–13) study of various tillage practices and corn-soybean rotations for several locations in Iowa; used field experiment data; in general, net returns for strip-till were fairly close to conventional moldboard plow with similar yields	S: Multiyear analysis for multiple tillage practices; W: Only for several field locations in Iowa (geographic scope limited)

Source: USDA, Economic Research Service using published literature listed in the Studies column.

Table C.3

Selected literature that reports the profitability effects of cover crops

Studies	Profit impact range (U.S. dollars per acre)	Description	Strengths (S)/weaknesses (W) of analysis
Schipanski et al., 2016	-55.44 to -25.88	Simulation based analysis for 1 year and 10 years, soybean-wheat-corn rotation; Mid-Atlantic context; negative profit effect of cover crops	S: Conducted both short-term and long-term simulation analysis; W: Based on simulated data; only for Mid-Atlantic
Bergtold et al., 2017	-28.01 to 7.04	Based on data from Kansas only; dryland and irrigated corn; positive profit impact for irrigated operations and negative impact for dryland operations	S: Differentiated dryland and irrigated; W: Limited geographical scope; simple net return calculation only
Zhou et al., 2017	-36 to -200	Long-term economic analysis based on 29-year cotton field experiment data in Tennessee; considered hairy vetch, crimson clover, and winter wheat; largest negative profit differential when comparing cover crops in conventional till with no-cover crops in conventional till; differential was smaller in no-till case	S: Long-term analysis; considered different cover crops; W: Only for cotton; limited geographic scope (only Tennessee)
Boyer et al., 2018	-692 to -620 (net present value effect over 29 years)	Long-term, simulation-based analysis based on 29-year cotton field experiment data in Tennessee; considered cover crops as an "investment"; optimal choice for a risk neutral producer was still conventional till with no cover crops; risk averse producer preferred no-till with no cover crops	S: Long-term analysis; considered both no-till and cover crops; considers risk aversion; W: Only for cotton; limited geographic scope (only Tennessee)
Plastina et al., 2018a	-20.76 to 25.13	For Midwest (multiple states: Iowa, Illinois, and Minnesota); corn and soybeans; included cost-share payments; partial budget approach; generally, negative profit impact (especially without cost share)	S: Based on survey data (from 79 respondents); W: 1-year (short-term) analysis (2015); nonrepresentative selected sample
Plastina et al., 2018b	-50.23 to -1.34	For Iowa only; corn and soybeans; included cost-share payments; partial budget approach; consistently negative profit impact if cover crops not grazed	S: Based on survey data (233 respondents in Iowa); W: One-year short-term analysis (2017); Iowa only; nonrepresentative selected sample
Cai et al., 2019	-39.15 to 39.73	Based on 4-year field experiment data; wheat-corn-soybean rotation; only for a specific county in Missouri; profit effects were negative for the first couple of years; positive profit only after 4 years	S: Multiyear analysis; data based on field experiments; W: Only 1 location
Myers et al., 2019	-31.36 to 110.45	Based on nationwide survey; different crops; partial budget approach; mix of negative and positive profit impact; mostly negative for 1 year and all positive profits were for 3- and 5-year use	S: Considered multiple year analysis (over 5 years); nationwide; examined various scenarios; W: Nonrepresentative selected sample
Plastina et al., 2020	-55.37 to 14.22	For Midwest (multiple states Iowa, Illinois, Minnesota); corn and soybeans; included cost-share payments; partial budget approach; generally, negative profit impact (especially if not grazed)	S: Based on focus groups and comparisons for same producers in field with and without cover crops; W: 1-year short-term analysis; only 15 respondents (or less)

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Studies	Profit impact range (U.S. dollars per acre)	Description	Strengths (S)/weaknesses (W) of analysis
Fan et al., 2020a	11 to 29	Field experiments for cotton in Texas (6 years), net return analysis; compared conventional till without cover crops versus no till with cover crops (wheat and mix); profit difference on left is for no-till with cover crops versus no-till without cover crops	S: Used cover crop mixture; W: Only 1 location, in Texas
Fan et al., 2020b	-49 to -46	Field experiments for cotton in Texas (4 years), net return analysis; compared conventional till without cover crops versus no till with cover crops (wheat, clover, pea, vetch mix); profit difference on left is for no-till with cover crops versus no-till without cover crops	S: Separated out net returns for different cover crop types plus mixture; W: Only 1 location, in Texas
Hansen and Langemeier, 2020	5.59 to 32.34	Data based on producer-led agronomic trials in Indiana only; partial budget approach, conducted stochastic simulations; optimized nitrogen use; different cover crops; mostly positive profit impact in static and stochastic partial budgets (only negative with annual rye in some cases)	S: Different cover crop types (annual rye, cereal rye, oats/radish); W: Based on plot data from only 1 location

Source: USDA, Economic Research Service using published literature listed in the Studies column.

Appendix D: Estimating the Effect of Conservation Tillage Adoption on Field-Level Corn and Soybean Yield and Production Costs

The Agricultural Resource Management Survey (ARMS) Phase 2 data are collected for different crop fields in different years by the USDA, National Agricultural Statistics Service (NASS) for the USDA, Economic Research Service (ERS). These data are not repeated observations of the same fields and thus do not allow for longitudinal or panel analysis. The data are, however, one of the most detailed sources of farm production practices and economics data available at the individual field level. Because ARMS data are so rich, matching methods are able to be used to estimate the causal impact of adopting conservation tillage on field-level outcomes. Specifically, for this USDA, ERS report, the authors used a bias-corrected (Abadie & Imbens, 2011) matching method based on the Mahalanobis distance (a measure of similarity or difference) between fields of a given crop that adopted and did not adopt conservation tillage.

Matching is a quasi-experimental method that aims to mimic randomization by matching treatment units to untreated units with similar covariate values (Rubin, 1980). The average effect of the treatment was estimated by averaging the differences in the outcome variable, yield, or production cost per acre between matched units. The authors followed Imbens and Rubin (2015) and Colson et al. (2016) there is limited evidence on how to optimally combine matching with subsequent analysis approaches to minimize bias and maximize efficiency for the quantity of interest. We conducted simulations to compare the performance of a wide variety of matching methods and analysis approaches in terms of bias, variance, and mean squared error (MSE) to rely on a commonly used balance measure in the literature—the standardized mean difference (SMD)—to assess covariate balance. Specifically, SMD refers to the absolute difference in means between the treatment and control groups divided by the pooled standard deviation of the groups. The authors incorporated sample weights into the SMD by calculating the weighted mean differences divided by the pooled weighted standard deviation of the groups to allow for population inference. The authors included many variables from ARMS and external sources as covariates that can affect producers' tillage decisions and the outcome variables studied by the authors. All covariates and their definitions are listed in table D.1. The authors excluded fields that were classified as highly erodible land (HEL) by the Natural Resources Conservation Service (NRCS) as reported in ARMS, primarily because more than 70 percent of those fields were treated. Thus, it was difficult to find untreated fields that were also highly erodible to be matched with those fields.

The authors conducted one-to-one nearest neighbor Mahalanobis metric matching with replacement and corrected for conditional bias to estimate the average treatment effect on the treated (ATT) and the average treatment effect on the untreated (ATU) for yield and production costs per acre. Treated in the current context means fields that implement conservation tillage and untreated fields use more intensive tillage practices that are not classified as conservation tillage. The point estimates for each crop and outcome variable are summarized in table 8 in the main text, and the descriptive statistics for the underlying sample of treated and untreated fields by crop are reported in table D.2.

Table D.1
Definition of variables

Group	Variable	Definition	Level
	Crop yield	Crop produced per area of land (bushels per acre)	Field
	Cost per acre	Total production cost per acre (U.S. dollars per acre)	Field
	Conservation tillage	1 if STIR rating of the field ≤ 80 0 otherwise	Field
Land and soil characteristics			
	Wetland	1 if the field is adjacent to a wetland 0 otherwise	Field
	Available water capacity	Area weighted depth of water covering a 100m^2 cell	County
	K-factor	Soil erodibility factor by water	County
	spH	Soil pH	County
	Organic matter	Log of organic matter in 2 millimeters of topsoil (percent)	County
Weather and climate conditions			
	Extreme GDD	Extreme growing season degree days (100 days)	County
	Moderate GDD	Moderate growing season degree days (100 days)	County
	Precipitation	Growing season precipitation (100 millimeters)	County
	Spring wetness	SPEI in April	County
	Historical temperature	30-year average temperature for February–April since 1981	County
	Historical precipitation	30-year average annual precipitation since 1981	County
	Dry years	Number of dry years (PDSI < -1.5) in the last 5 years	County
	Drought risk1	30-year standard deviation of June PDSI since 1985	County
	Drought risk2	30-year coefficient of variation in annual values of total June–August precipitation since 1981	County
	Drought risk3	30-year correlation coefficient between the June average daily maximum temperature and total precipitation values since 1981	County
Household and farm characteristics			
	Age	Age of the principal operator	Farm
	Education	1 if principal operator has some college or higher education 0 otherwise	Farm
	Experience	Number of years operating the field	Field
	Farm size	Log of total planted acres in the farm	Farm
	Land tenure	1 if the field is owned by the operator 0 other wise	Field
	Corn-soy ratio	Fraction of the farm acres planted to corn or soybeans	Farm
Field management			
	Seeding rate	Number of seeds per acre (divided by 10,000)	Field
	HT seed	1 if the GM seeds contain herbicide-tolerant (HT) traits 0 otherwise	Field
	Bt seed (Corn only)	1 if the GM seeds contain pesticide-resistant traits 0 otherwise	Field
	TR seed	1 if the seeds are treated 0 otherwise	Field
	Rotation	1 if the previous summer crop is different from the current summer crop 0 otherwise	Field
	Cover crop	1 if cover crop was planted in the field 0 otherwise	Field
	Planting days	Days of planting from April 1	Field

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Group	Variable	Definition	Level
Field management			
	Federal insurance	1 if the field is covered by Federal Crop Insurance 0 otherwise	Field
	Government payment	1 if the field receives conservation payment 0 otherwise	Field
	Nutrient management	1 if nutrient management is applied on the field 0 otherwise	Field
	Pest management	1 if pest management is applied on the field 0 otherwise	Field

STIR = Soil Tillage Intensity Rating; SPEI = Standardized Precipitation Evapotranspiration Index; spH = soil pH; PDSI = Palmer Drought Severity Index; GDD = growing degree days; HT = herbicide-tolerant; Bt = Bacillus thuringiensis (a biopesticide); GM = genetically modified; TR = seed treated with a pesticide.

Note: The growing season is from March to August. The K-factor is a measure of soil erodibility by water.

Source: USDA, Economic Research Service using data from the Agricultural Resource Management Survey (ARMS) Phase 2 (field level), ARMS Phase 3 (farm level), and the PRISM database (weather data), which is the official spatial climate dataset of the USDA developed using the Parameter-Elevation Regression on Independent Slopes Model (PRISM). Soils data are originally from the gridded Soil Survey Geographic (gSSURGO) Database and aggregated to the county level, which are available in Yun and Gramig (2019).

Table D.2

Weighted mean and mean differences of variables between fields with and without conservation tillage (CT)

	Corn				Soybeans			
Variable	**CT**	**No CT**	**Difference**		**CT**	**No CT**	**Difference**	
Logged yield	5.10	5.07	0.03	*	3.60	3.61	-0.01	
Logged cost per acre	6.36	6.40	-0.04	***	5.98	6.07	-0.10	***
Land and soil characteristics								
Wetland	0.02	0.03	0.00		0.01	0.02	-0.00	
Available water capacity	27.77	25.16	2.61	***	26.38	27.32	-0.94	***
K-factor	0.36	0.34	0.02	***	0.34	0.35	-0.00	
spH	6.57	6.66	-0.09	**	6.50	6.84	-0.33	***
Organic matter	5.35	5.53	-0.18	***	5.22	5.43	-0.21	***
Weather and climate conditions								
Moderate GDD	1.33	1.33	0.00		1.42	1.40	0.02	***
Extreme GDD	0.18	0.14	0.03	***	0.23	0.20	0.02	***
Precipitation	6.71	6.35	0.36	***	4.49	4.38	0.11	
Spring wetness	-0.35	-0.44	0.10	**	-0.95	-0.69	-0.26	***
Historic temperature	3.66	2.79	0.87	***	4.79	3.10	1.70	***
Historic precipitation	9.28	9.09	0.19	**	9.84	9.03	0.81	***
Dry years	0.59	0.70	-0.11	***	1.17	0.90	0.27	***
Drought risk 1	2.01	1.99	0.01		1.94	2.02	-0.08	***
Drought risk 2	0.31	0.29	0.02	***	0.30	0.30	0.00	
Drought risk 3	-0.38	-0.39	0.01	***	-0.38	-0.40	0.03	***
Household and farm characteristics								
Age	56.35	56.13	0.22		56.28	56.54	-0.26	
Education	0.54	0.48	0.06	**	0.49	0.53	-0.03	
Experience	18.40	18.72	-0.32		17.72	17.87	-0.15	

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	Corn				Soybeans			
Variable	**CT**	**No CT**	**Difference**		**CT**	**No CT**	**Difference**	
Farm size	6.73	6.41	0.32	***	6.62	6.58	0.04	
Land tenure	0.48	0.56	-0.09	***	0.46	0.44	0.02	
Corn-soy ratio	0.75	0.65	0.11	***	0.72	0.72	0.00	
Field management								
Seeding rate	3.10	3.07	0.03		16.51	16.46	0.05	
HT seed	0.79	0.74	0.05	**	0.97	0.94	0.03	**
Bt seed (corn only)	0.78	0.73	0.05	***	NA	NA	NA	
TR seed	0.73	0.63	0.10	***	0.30	0.31	-0.01	
Rotation	0.82	0.63	0.18	***	0.81	0.85	-0.03	
Cover crop	0.03	0.01	0.02	**	0.02	0.01	0.02	**
Planting days	26.81	28.97	-2.17	***	43.39	41.64	1.75	***
Federal insurance	0.84	0.72	0.12	***	0.77	0.79	-0.02	
Government payment	0.12	0.09	0.03	**	0.08	0.06	0.02	*
Nutrient management	0.19	0.17	0.02		0.07	0.08	-0.00	
Pest management	0.15	0.10	0.05	***	0.02	0.02	-0.00	
Observations	1,103	717			880	398		

CT = conservation tillage; PDSI = Palmer Drought Severity Index; GDD = growing degree days; HT = herbicide-tolerant; Bt = Bacillus thuringiensis (a biopesticide); TR = treated.

Note: Drought risk 1 is measured by a 30-year standard deviation of the June Palmer Drought Severity Index (PDSI) since 1985. Drought risk 2 is measured by a 30-year coefficient of variation in annual values of total June–August precipitation since 1981. Drought risk 3 is measured by a 30-year correlation coefficient between the June average daily maximum temperature and the total precipitation values since 1981. Data followed by *, **, and *** indicate significance at the 10-percent, 5-percent, and 1-percent levels, respectively. P-values are generated by 2-sample t-tests that account for sampling weights with bootstrapped standard errors (1,000 replications). The K-factor is a measure of soil erodibility by water.

Source: USDA, Economic Research Service (ERS) estimates using data from the USDA, ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS) for corn (2010 and 2016) and soybeans (2012 and 2018).

Appendix E: Estimating the Impact of Soil Health Practices on Productivity in the Agricultural Resource Management Survey

Estimating Production Using Stochastic Production Frontier Methods

This section relies on data generated from Phase 3 of ARMS because the authors were interested in evaluating the extent to which field-level conservation practices (no-till, strip till, and cover cropping) impact farm level productivity. An output distance function (ODF) approach was used to analyze the impact of cover cropping and no-till/strip-till practices on productivity. The ODF is written as, $\ln q_{1it} = -\ln D_O^t(x_{it}, q_{2it}, z_{it}) - u_{it}$, where $\ln D_O^t$ (,.,) is the log of the output distance function, $\ln q_{1it}$ is the log of the output of the commodity in question (i.e., corn, soybeans, and cotton), x_{it}, q_{2it}, and z_{it} are conventional inputs (land, labor, capital, and intermediate materials), other outputs, and the conservation practice (i.e., cover cropping, no-till and strip-till), respectively. Furthermore, $u_{it} \equiv -\ln D_O^t(x_{it}, q_{mit}, z_{it})$, is the output-oriented technical inefficiency effect that measures the distance from the frontier. These ODFs were estimated using stochastic production methods (Kumbhakar & Lovell, 2000). In practice, the authors estimated the functional form of an ODF such that the relationship between the input-output variables involved in the production process could be written as: $q_{1it} = f(x_{it}, \tilde{q}_{2it}, z_{it}) + (v_{it} - u_{it})$, where q_{1it} represents the output of the crop being estimated (i.e., corn, cotton, and soybeans); $f(.)$ is an approximating function chosen by the researcher; x_{it} are conventional inputs (i.e., land, labor, capital, intermediate materials, and livestock) that are combined to generate output q_{1it} ; $\tilde{q}_{2it}$ represents all other outputs produced on the farm—this is weighted against the left-hand side variable such that, $\tilde{q}_{2it} = q_{2it} / q_{1it}$; z_{it} captures environmental characteristics of the production regions (i.e., Heartland, Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin and Range, Mississippi Portal); finally, $(v_{it} - u_{it})$ is a composed error term such that v_{it} captures statistical noise, and u_{it} captures technical inefficiency. The stochastic production frontier that evaluates aggregate production was estimated to determine if adopters of no-till, strip-till, and cover cropping share the same production technologies as their nonadopting counterparts and can be written in logarithmic form as:

$$\ln q_{1it} = \theta_i + \gamma_1 \ln \tilde{q}_{2it} + \tau_t t + \sum_{m=1}^{M} \beta_m \ln x_{mit} + \sum_{n=1}^{N} \rho_n \ln z_{nit} + v_{it} - u_{it}$$

where θ_i and t are dummy variables that capture the conservation practice (no-till/strip-till, and cover cropping) and year fixed effects, respectively. Finally, γ_1, τ_t, β_m, and ρ_n and are parameters to be estimated. The estimated parameters were evaluated to establish the marginal contribution of cover cropping and no-till/strip-till practices to the production of the commodity in question (i.e., corn, soybeans, and cotton).

Matching and Causal Inference

Short of conducting a natural experiment, such as a randomized controlled trial, a researcher has no control over the treatment assignment process. In this case, a researcher only observes that one group of producers fall into the treated group (i.e., adopters of no-till/strip-till and cover cropping practices), while other producers fall into the control group (i.e., nonadopters of no-till/strip-till and cover cropping practices). Outcomes may be a result of (caused by) the inherent qualities of the producers and have less to do with the adoption of no-till/strip-till and cover cropping practices. Such inherent qualities may act as confounding variables. For example, adopting producers may be motivated, better land managers, and environmental stewards and thus would be better performers compared with their nonadopting counterparts, even if they did not adopt no-till/strip-till and cover cropping practices. To minimize the effects of confounding, propensity score matching was conducted whereby each adopting producer (the treated) was matched against one or more nonadopting producers (the control) based on a set of observable covariates. For the purposes of this study, the matching covariates comprised characteristics of the principal operator (e.g., gender, age, ethnicity, education, experience), value of farm assets, amount of commodity payments, farm specialization (e.g., cash crop, grain, high value, livestock), and regional and year fixed effects. Propensity scores were generated from a Probit model of the likelihood of a producer adopting no-till/strip-till and cover cropping practices such that:

$$P_i = \Phi\,(X'\,\omega) + \varepsilon_i$$

Where P_i equals 1 for adopting producers and 0 for nonadopting producers, X is a set of matching covariates, ω is a parameter to be estimated, ε_i is an error term, and $\Phi(.)$ is the cumulative distribution function. A radius matching caliper within 0.1 standard deviations of the propensity scores using the nearest neighbor matching approach is used. All nonadopting producer observations that cannot be matched were discarded.

Results and Discussion

Phase 3 ARMS data from 2018 and 2019 were used to evaluate no-till and strip-till practices for corn, soybean, and cotton producers. Using acreage allocated to no-till/strip-till practices as an indicator, the results show that for corn producers, all else equal, a 1-percent increase in no-till/strip-till raised corn output by 0.1485 percent, a finding that is significantly different from zero (table E.1). Note that adopters of no-till/strip-till practices were slightly less technically efficient compared with their nonadopting counterparts.
For soybean producers, all else equal, a 1-percent increase in no-till/strip-till raised soybeans production by 0.1322 percent, a finding that is significantly different from zero (table E.2). Technical efficiency was only marginally lower for adopters compared with nonadopters. For cotton production, all else equal, a 1-percent increase in no-till and strip till acreage raised cotton output by 0.0902 percent, a finding that is significantly different from zero (table E.3). Technical efficiency estimates appeared to be equal for adopters and nonadopters alike. Finally, Phase 3 ARMS data from 2017, 2018, and 2019 were used to evaluate the effect of no-till, strip-till, and cover cropping practices on aggregate production. The coefficient estimates for no-till/strip-till, and cover cropping have alternating signs. However, neither estimate is significantly different from zero (table E.4). However, adopters of no-strip/strip-till, and cover cropping practices, on average, had higher levels of technical efficiency, at 74.5 percent compared with nonadopters at 70.9 percent.

Table E.1

Estimated coefficients of the stochastic production frontier model for adopters and nonadopters of no-till and strip-till practices in corn production

		Adopters		Nonadopters	
Parameter/variable		Coefficient	(Standard error)	Coefficient	(Standard error)
γ_1	Other output	-0.4464***	(0.0138)	-0.5644***	(0.0124)
β_0	Constant	6.3880***	(0.1178)	6.9660***	(0.1014)
β_1	Harvested acres	0.3480***	(0.0235)	0.3624***	(0.0189)
β_2	Labor	0.0245***	(0.0098)	0.0422***	(0.0087)
β_3	Capital	0.0871***	(0.0127)	0.0862***	(0.0106)
β_4	Materials	0.3890***	(0.0216)	0.4870***	(0.0184)
β_5	Animals	0.0087***	(0.0014)	0.0157***	(0.0013)
θ_1	No-till/strip-till	0.1485***	(0.0103)		
τ_1	2019	-0.0293	(0.0200)	-0.0785***	(0.0175)
ρ_1	Heartland	0.4741***	(0.0448)	0.4544***	(0.0312)
ρ_2	Northern Crescent	0.3519***	(0.0511)	0.2794***	(0.0380)
ρ_3	Northern Great Plains	0.1473**	(0.0712)	0.0243	(0.0470)
ρ_4	Prairie Gateway	0.1996***	(0.0500)	0.0148	(0.0459)
ρ_5	Eastern Uplands	0.1419**	(0.0663)	-0.0580	(0.0734)
ρ_6	Southern Seaboard	-0.0857*	(0.0482)	-0.0938**	(0.0426)

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Parameter/variable		Adopters Coefficient	Adopters (Standard error)	Nonadopters Coefficient	Nonadopters (Standard error)
ρ_7	Fruitful Rim	0.0208	(0.0990)	-0.4651***	(0.0602)
ρ_8	Basin Range	-2.7026***	(0.4548)	-0.6519***	(0.1397)
σ_v	Sigma (v)	0.3826	(0.0112)	0.4171	(0.0107)
σ_u	Sigma (u)	0.3486	(0.0177)	0.3340	(0.0171)
λ	Lambda	0.9111	(0.0263)	0.8009	(0.0257)
	Log likelihood	-1,841.50		-2,719.06	
	Observations	2,495		3,488	
	Average technical efficiency	0.744		0.751	

Note: Estimates followed by ***, **, and * represent significance at the 1-percent, 5-percent, and 10-percent levels, respectively. The parameters β,θ,τ, and ρ represent coefficient estimates for conventional inputs, a dummy variable representing no-till/strip-till practice, a year fixed effect, and regional fixed effects, respectively, in corn production. The parameters σ_v and σ_u represent the standard deviation of the statistical error term (v) and the inefficiency term (u), respectively. Finally, λ measures the relative contribution of inefficiency and statistical errors to the total composed error. Standard errors are in parentheses.

Source: USDA, Economic Research Service (ERS) estimates using data from the USDA, ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Phase 3 Survey in 2018 and 2019.

Table E.2

Estimated coefficients of the stochastic production frontier model for adopters and nonadopters of no-till and strip-till practices in soybean production

Parameter/variable		Adopters Coefficient	Adopters (Standard error)	Nonadopters Coefficient	Nonadopters (Standard error)
γ_1	Other output	-0.3811***	(0.0253)	-0.5786***	(0.0255)
β_0	Constant	4.7360***	(0.3351)	5.7840***	(0.1816)
β_1	Harvested acres	0.6188***	(0.0274)	0.6681***	(0.0259)
β_2	Labor	0.0183***	(0.0066)	0.0330***	(0.0081)
β_3	Capital	0.0480***	(0.0108)	0.0216**	(0.0107)
β_4	Materials	0.1688***	(0.0242)	0.2618***	(0.0247)
β_5	Animals	0.0010	(0.0010)	0.0061***.	(0.0014)
θ_1	No-till/strip-till	0.1322***	(0.0141)		
τ_1	2019	-0.0764***	(0.0150)	-0.1308***	(0.0157)
ρ_1	Heartland	0.8806***	(0.3112)	0.7123***	(0.1143)
ρ_2	Northern Crescent	0.6186**	(0.3112)	0.4595***	(0.1119)
ρ_3	Northern Great Plains	0.5357*	(0.3144)	0.3346***	(0.1173)
ρ_4	Prairie Gateway	0.6149**	(0.3121)	0.3186***	(0.1233)
ρ_5	Eastern Uplands	0.6745**	(0.3127)	0.4575***	(0.1368)
ρ_6	Southern Seaboard	0.5785*	(0.3119)	0.5448***	(0.1320)
ρ_7	Mississippi Basin	0.8064***	(0.3131)	0.6823***	(0.1202)
σ_v	Sigma (v)	0.3078	(0.0113)	0.3405	(0.0144)
σ_u	Sigma (u)	0.2261	(0.0162)	0.1964	(0.0212)
λ	Lambda	0.7346	(0.0235)	0.5767	(0.0313)
	Log likelihood	-1,413.01		-1,527.45	
	Observations	3,153		3,154	
	Average technical efficiency	0.817		0.837	

Note: Estimates followed by ***, **, and * represent significance at the 1-percent, 5-percent, and 10-percent levels, respectively. The parameters β,θ,τ, and ρ represent coefficient estimates for conventional inputs, a dummy variable representing no-till/strip-till practice, a year fixed effect, and regional fixed effects, respectively, in corn production. The parameters σ_v and σ_u represent the standard deviation of the statistical error term (v) and the inefficiency term (u), respectively. Finally, λ measures the relative contribution of inefficiency and statistical errors to the total composed error. Standard errors are in parentheses.

Source: USDA, Economic Research Service (ERS) estimates using data from the USDA, ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Phase 3 Survey in 2018 and 2019.

Table E.3

Estimated coefficients of the stochastic production frontier model for adopters and nonadopters of no-till and strip-till practices in cotton production

		Adopters		Nonadopters	
Parameter/variable		Coefficient	(Standard error)	Coefficient	(Standard error)
γ_1	Other output	-0.6805***	(0.0310)	-0.7205***	(0.0211)
β_0	Constant	9.7355***	(0.2626)	9.5324***	(0.1879)
β_1	Harvested acres	0.5260***	(0.0480)	0.4564***	(0.0319)
β_2	Labor	0.0458**	(0.0210)	0.0356**	(0.0161)
β_3	Capital	0.0381*	(0.0214)	0.0499***	(0.0174)
β_4	Materials	0.2639***	(0.0418)	0.4470***	(0.0330)
β_5	Animals	-0.0005	(0.0030)	0.0004	(0.0024)
θ_1	No-till/strip-till	0.0902***	(0.0190)		
τ_1	2019	0.1940***	(0.0426)	0.1559***	(0.0339)
ρ_1	Heartland	0.0683	(0.1565)	0.0017	(0.0985)
ρ_2	Prairie Gateway	-0.2239**	(0.1127)	-0.3698***	(0.0902)
ρ_3	Southern Seaboard	0.0857	(0.1032)	-0.0294	(0.0838)
ρ_4	Fruitful Rim	0.1087	(0.1272)	0.2189**	(0.0904)
ρ_5	Mississippi Basin	-0.0305	(0.1080)	-0.0644	(0.0841)
σ_v	Sigma (v)	0.3010	(0.0197)	0.3556	(0.0158)
σ_u	Sigma (u)	0.2407	(0.0324)	0.2387	(0.0266)
λ	Lambda	0.7996	(0.0474)	0.6711	(0.0387)
	Log pseudolikelihood	-187.84		-459.76	
	Observations	418		814	
	Average technical efficiency	0.807		0.808	

		Adopters		Nonadopters	
Parameter/variable		Coefficient	(Standard error)	Coefficient	(Standard error)
γ_1	Other output	-0.6805***	(0.0310)	-0.7205***	(0.0211)
β_0	Constant	9.7355***	(0.2626)	9.5324***	(0.1879)
β_1	Harvested acres	0.5260***	(0.0480)	0.4564***	(0.0319)
β_2	Labor	0.0458**	(0.0210)	0.0356**	(0.0161)
β_3	Capital	0.0381*	(0.0214)	0.0499***	(0.0174)
β_4	Materials	0.2639***	(0.0418)	0.4470***	(0.0330)
β_5	Animals	-0.0005	(0.0030)	0.0004	(0.0024)
θ_1	No-till/strip-till	0.0902***	(0.0190)		
τ_1	2019	0.1940***	(0.0426)	0.1559***	(0.0339)
ρ_1	Heartland	0.0683	(0.1565)	0.0017	(0.0985)

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		Adopters		Nonadopters	
Parameter/variable		**Coefficient**	**(Standard error)**	**Coefficient**	**(Standard error)**
ρ_2	Prairie Gateway	-0.2239**	(0.1127)	-0.3698***	(0.0902)
ρ_3	Southern Seaboard	0.0857	(0.1032)	-0.0294	(0.0838)
ρ_4	Fruitful Rim	0.1087	(0.1272)	0.2189**	(0.0904)
ρ_5	Mississippi Basin	-0.0305	(0.1080)	-0.0644	(0.0841)
σ_v	Sigma (v)	0.3010	(0.0197)	0.3556	(0.0158)
σ_u	Sigma (u)	0.2407	(0.0324)	0.2387	(0.0266)
λ	Lambda	0.7996	(0.0474)	0.6711	(0.0387)
	Log pseudolikelihood	-187.84		-459.76	
	Observations	418		814	
	Average technical efficiency	0.807		0.808	

Note: Estimates followed by ***, **, and * represent significance at the 1-percent, 5-percent, and 10-percent levels, respectively. The parameters β,θ,τ, and ρ represent coefficient estimates for conventional inputs, a dummy variable representing no-till/strip-till practice, a year fixed effect, and regional fixed effects, respectively, in corn production. The parameters σ_v and σ_u represent the standard deviation of the statistical error term (v) and the inefficiency term (u), respectively. Finally, λ measures the relative contribution of inefficiency and statistical errors to the total composed error. Standard errors are in parentheses.

Source: USDA, Economic Research Service (ERS) estimates using data from USDA, ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Phase 3 Survey in 2018 and 2019.

Table E.4

Estimated coefficients of the stochastic production frontier model for adopters and nonadopters of no-till /strip-till and cover crop practices on aggregate farm production

		Adopters		Nonadopters	
Parameter/variable		Coefficient	(Standard error)	Coefficient	(Standard error)
β_0	Constant	1.6542***	(0.1916)	0.9926***	(0.0908)
β_1	Harvested acres	0.1240***	(0.0403)	0.0821***	(0.0123)
β_2	Labor	0.1145***	(0.0197)	0.1595***	(0.0111)
β_3	Capital	0.1783***	(0.0267)	0.1175***	(0.0114)
β_4	Materials	0.5691***	(0.0442)	0.6854***	(0.0144)
β_5	Animals	0.0081***	(0.0027)	-0.0025	(0.0021)
θ_1	No-till/Strip till	0.0016	(0.0215)		
θ_2	Cover crops	-0.0110	(0.0168)		
τ_1	2019	0.0022	(0.0543)	-0.0096	(0.0244)
τ_2	2020	0.0414	(0.0493)	-0.0200	(0.0273)
ρ_1	Heartland	0.0106	(0.0656)	0.1782***	(0.0366)
ρ_2	Northern Crescent	-0.0434	(0.0747)	0.0893**	(0.0456)
ρ_3	Northern Great Plains	-0.1339	(0.1091)	0.2583***	(0.0569)
ρ_4	Prairie Gateway	-0.0089	(0.0898)	0.0841*	(0.0478)
ρ_5	Eastern Uplands	-0.0174	(0.1189)	0.3038***	(0.0714)
ρ_6	Southern Seaboard	0.3333***	(0.1035)	0.3849***	(0.0673)
ρ_7	Fruitful Rim	0.3731***	(0.1052)	0.4690***	(0.0530)
ρ_8	Basin Range	0.0291	(0.1598)	0.4191***	(0.0687)
σ_v	Sigma (v)	0.6006	(0.0303)	0.8757	(0.0205)
		Adopters		Nonadopters	

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	Parameter/variable	Coefficient	(Standard error)	Coefficient	(Standard error)
σ_u	Sigma (u)	0.3453	(0.0456)	0.4121	(0.0263)
λ	Lambda	0.5750	(0.0660)	0.4706	(0.0403)
	Log pseudolikelihood	-1,562.08		-13,492.59	
	Observations	1,484		9,724	
	Average technical efficiency	0.745		0.709	

Note: Estimates followed by ***, **, and * represent significance at the 1-percent, 5-percent, and 10-percent levels, respectively. The parameters β,θ,τ, and ρ represent coefficient estimates for conventional inputs, a dummy variable representing no-till/strip-till practice, a year fixed effect, and regional fixed effects, respectively, in corn production. The parameters σ_v and σ_u represent the standard deviation of the statistical error term (v) and the inefficiency term (u), respectively. Finally, λ measures the relative contribution of inefficiency and statistical errors to the total composed error. Standard errors are in parentheses.

Source: USDA, Economic Research Service (ERS) estimates using data from the USDA, ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Phase 3 Survey in 2018 and 2019.