



# Using three consecutive years of farmer survey data to identify prevailing conservation practices in four Midwestern US states

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## Research Paper

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## Abstract

Granular temporal and spatial scale observations of conservation practices are essential for identifying changes in the production systems that improve soil health and water quality and inform long-term agricultural research and adaptive policy development. In this study, we demonstrate an innovative use of farmer practice survey data and what can be uniquely known from a detailed survey that targets specific farm groups with a regional focus over multiple consecutive years. Using three years of survey data ( $n = 3914$  respondents), we describe prevailing crop rotation, tillage, and cover crop practice use in four Midwestern US states. Like national metrics, the results confirm dominant practices across the landscape, including corn-soybean rotation, little use of continuous no-till, and the limited use of cover crops. Our detailed regional survey further reveals differences by state for no-till and cover crop adoption rates that were not captured in federal datasets. For example, 66% of sampled acreage in the Midwest has corn and soybean rotation, with Illinois having the highest rate (72%) and Michigan the lowest (41%). In 2018, 20% of the corn acreage and 38% of the soybean acreage were in no-till, and 13% of the corn acres and 9% of the soybean acres were planted with a cover crop. Cover crop adoption rates fluctuate from year to year. Results demonstrate the value of a farmer survey at state scales over multiple years in complementing federal statistics and monitoring state and yearly differences in practice adoption. Agricultural policies and industry heavily depend on accurate and timely information that reflects spatial and temporal dynamics. We recommend building an agricultural information exchange and workforce that integrates diverse data sources with complementary strengths to provide a greater understanding of agricultural management practices that provide baseline data for prevailing practices.

## Introduction

The defining challenge of agriculture is to increase the production of food, fiber, and fuel for the growing population while reducing environmental harms, providing ecosystem services, and sustaining social equity and prosperity (Matson, 1997; Tilman et al., 2011; Robertson, 2015). The dominant crop production systems in the US relies heavily on chemical inputs, limited crop choices, and intensive soil disturbance, leading to soil loss and degradation, water quality issues, and loss of biodiversity (Prokopy et al., 2020; Davis et al., 2012). Change has been called to diversify the crop production systems from conventional or ‘business as usual’ to move toward various practical or aspirational systems that can balance production and profits with environmental and social well-being (Davis et al., 2012; Hunt, Hill and Liebman, 2017; Spiegel et al., 2018; Robertson et al., 2022). Agricultural researchers are working on interdisciplinary, multi-scale, long-term studies since many agroecological processes operate on landscape-farm-field scales and over long periods of time (Robertson et al., 2008; Walbridge and Shafer, 2011; Cusser et al., 2020). This work includes topics such as soil health, climate change resilience, biodiversity, and rural prosperity.

To support agricultural research and the adaptability of agricultural policies, we need to improve our understanding of how fast and widely the production system is changing by gauging prevailing practices at different time and spatial scales. Federal datasets such as the USDA Census of Agriculture (Ag Census) and the Agricultural Resource Management Survey (ARMS) endeavor to provide an accurate picture at the national level. Sometimes, the survey data are supplemented by geospatial data products like the Cropland Data Layer (CDL). These federal datasets are also often the sole source for information at the regional, state, and other local scales. However, when designing research and developing policy and education programs, researchers and local practitioners often need more nuanced information than can be gleaned from large-scale national surveys. The detail needed might instead be provided by surveys that provide coverage of specific regions.

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Farmer surveys need to be tailored to specific regions and types of farms and may need to be collected more frequently. First, farms in the US vary widely in terms of the crops they grow, their acreage, and other characteristics. For instance, corn and soybean farms will differ from vegetable farms in their land management and production practices such as tillage, planting seasons, and nutrient needs. For projects focused on specific types of farms such as cash grain farms (e.g., corn and soybean) federal datasets only provide aggregated descriptions for all farm types and may miss the details needed for describing certain types of farms. Second, some questions have a local focus, and require a larger sample size for their particular states than what the federal datasets provided. For example, for the 2019 ARMS phase three survey, the combined sample size for Michigan and Ohio was 754 farms, compared to Illinois, for which 1370 farms were surveyed as one of the fifteen core production states (USDA-NASS, 2020). Third, monitoring the continuity of practices in the same fields over consecutive years provides valuable information for agricultural research, policy, and education (Mcfadden, Smith and Wallander, 2022). The Ag Census is conducted every five years at the county level, while ARMS collects data about the same crop every five or more years. Wade, Claassen and Wallander (2015) noticed the difficulty in conducting time series analysis using ARMS due to a lack of examining the same targeted field every year of data collection. For at least these three reasons, surveys that focus on a specific type of farm for a specific region and cover consecutive years can fill gaps in federal datasets.

Here we propose reframing typical collection and analyses of survey data to focus on time and spatial details (resolution), consecutive sampling and surveying, and targeted farm types. Our survey was part of an interdisciplinary project at W.K. Kellogg Biological Station (KBS) which is a Long-Term Ecological Research (LTER) and United States Department of Agriculture (USDA) Long-Term Agroecosystem Research (LTAR) site. Sites in the LTAR network conduct common experiments which compare conventional agriculture with proposed aspirational systems across the country to form strategies at the national and regional levels (Meredith et al., 2022). This analysis is part of an interdisciplinary effort to determine baseline treatments for the common experiment at KBS. We demonstrate the use of multi-year targeted survey data from the same farm and field over three years to inform prevailing crop rotation, tillage, and cover crop practices in Illinois, Indiana, Michigan, and Ohio. In doing so, we introduce unique knowledge about the cash crop production system in the four Midwest states. Crop rotation, cover crops, and tillage are key conservation practices, since they set the baseline for crop diversity on farms and levels of soil disturbance, further affecting biodiversity; nutrient management; soil moisture, soil structure, and organic matter; soil carbon emission and sequestration; and many other farm and landscape level ecosystem services (Kaspar and Singer, 2011; Robertson et al., 2014; Syswerda and Robertson, 2014; Wezel et al., 2014; Spiegel et al., 2018).

Our analyses of consecutive farm-field data also contribute to social science research on farmer practice adoption by highlighting the importance of observational units in interdisciplinary research. Many social science studies collected farm practice data at the farm or household scale. These data, although collected for purposes other than describing prevailing practices, can provide estimations of adoption levels at regions with varied boundaries. For example, Fleckenstein et al. (2020) found 60.4% of surveyed producers in Indiana, Illinois, and Iowa were currently using conservation tillage (including reduced tillage or no-till), while 24.7% were using cover

crops. Adhikari et al. (2023) found 78.2% of surveyed producers in South Dakota adopted conservation tillage while 47.5% adopted cover crops. Singer, Nusser and Alf (2007) found 8% of the farmers in four states in the corn belt (Illinois, Indiana, Iowa, and Minnesota) planted a cover crop in the fall of 2005. At a finer geospatial scale in the Western Lake Erie Basin (covering parts of Ohio, Michigan, and Indiana), Burnett et al., (2018) found 16.2% of corn and soybean farmers planted cover crops after the 2013 fall harvest. In contrast, crop rotation is often studied using geospatial data. For example, Socolar et al. (2021) found that 4.5% of the study area that included the states of Illinois, Indiana, Iowa, Kansas, Minnesota, Missouri, Nebraska, and Ohio was under corn monoculture and half of the study area had a corn-soy rotation.

It is worth noting that although these studies were conducted in the general region of US Midwest or Corn Belt, the adoption rates varied by geospatial boundaries. These studies focused on a snapshot of the conservation practices and lacked studies on adoption rates across years. Survey findings with farmers as units also tend to show higher rates of adoption than the present study using acreage as units (Arbuckle and Roesch-McNally, 2015). Using farmers as the unit of analysis and reporting reflects a disciplinary focus on people. In contrast, agroecosystem and agronomy studies often use acres as units reflecting their disciplinary focus on land. Descriptions provided by federal agencies such as USDA Economic Research Service and National Agricultural Statistics Service use acres as units (e.g., Wallander et al., 2021). These federal statistics are commonly consulted by natural and social scientists in research design and by policy-makers and education professionals such as extension specialists in communication. Such differences in units can potentially impede the wide application of social science study results in interdisciplinary agricultural research and policy conversations.

To bridge the disciplinary gap and bring more visibility to social survey data, we propose connecting self-reported behavior data (e.g., whether a respondent used a practice) with information about scale (e.g., on how many acres the respondent used a practice and for how long), which calls for shifts in conventional survey design, analyses, and presentation. Through our methods and results, we demonstrate how continuous observation of a single farm-field over multiple years helps inform our knowledge of yearly fluctuation in reported practice adoption and, in doing so, generates unique insights for large grain farms. We present our results along with descriptions from the Ag Census and ARMS. Although our analysis is specific in space and time, the method we propose aims to inspire innovative designs and uses of farmer surveys in understanding evolving agricultural systems as well as provide better social and behavioral data for agroecosystem research and policy development.

Our analyses are guided by three questions:

1. What are the prevailing crop rotation, tillage, and cover crop practices for corn and soybean fields across four Midwest states (IL, IN, MI, OH)?
2. How do the four states compare in the adoption of these three practices?
3. To what extent do tillage and cover crop adoption rates change annually?

## Materials and methods

### *Data collection: a panel farmer survey*

We gathered data using a self-administered mail survey that targets corn and soybean farms with over 100 acres (40 ha) in

production in a total of 263 counties in Illinois (95), Indiana (81), Michigan (31), and Ohio (56) where over 15% of the land area is planted to corn and soybean to exclude urban areas from the sampling frame. Soybean and corn farms are predominant in the US Midwest and play critical roles in the region's agricultural production, steering the environmental, economic, and social outcomes of the region's cash grain production system. Farm addresses were purchased from a private vendor, Farm Market iD, Westmont Illinois. Samples were stratified by farm size, with equal numbers of farms operating 100–499 acres (30 to 202 ha) and 500 or more acres (203 or more ha). The oversample of large farms was to ensure adequate coverage of acres in the study region. Based on the sampling design, weights were calculated by the ratio between the percent of farms within a farm size category for a state in the sample frame and the respective percent in the sample.

Although the mail survey method is not new, our multi-year sampling design, the integration of measures, and data analysis procedures are novel and provide practical lessons for reorienting survey data uses to describe prevailing practices and capture changes at the regional scale. The first survey was conducted in spring 2017 measuring farming practices in the 2016 growing season and has been repeated at annual intervals since then. In each survey year, a pre-notice postcard, a survey packet (including cover letter, and questionnaire), a reminder postcard, and one or two follow-up questionnaire(s) were sent to farmers, following a modified Dillman Tailored Design Method (Dillman, Smyth and Christian, 2014). The sample follows a two-part panel design to account for attrition over time in the panel. Compared to Ag Census and ARMS, our survey coverage reveals a more granular resolution with three consecutive years from 2016–2018 at the regional scale instead of single years at five- or six-year intervals at the federal level (Table 1).

One challenge in measuring the same farm/field over years was to anticipate and manage participants moving in and out of the panel. In the first survey year of 2017, 10,582 surveys were mailed, and 3086 surveys were returned, resulting in an initial response rate of 29%. All participants who gave a valid response were invited back for the second-year survey, and 1480 returned a valid survey. In addition, 3520 surveys were mailed to new farm addresses to maintain a yearly sample size target for each state;

of these, 693 valid responses were returned, which comprised the new-sample portion of the panel. Then, participants in the earlier survey waves were invited back to the third-year survey with the continued addition of a new sample. The same sampling strategy was used every year, generating an overall average annual response rate of 43.5%. Each year's sample consisted of a stratified combined sample (both return and new), which was considered representative of farm size at the state level. In this analysis, we used the field-level portion of the 2017, 2018, and 2019 survey data, which correspond to crop years 2016, 2017, and 2018. We named our annual surveys as Michigan State University (MSU)-Panel Farmer Survey (PFS).

### Measures

The survey instrument was developed through consultation with agricultural scientists and stakeholders, including an interdisciplinary team of scientists, and from previous research based on the agricultural practices' literature. The survey instrument was also pretested with a farmer focus group. In the section on field-level farming practices, farmers were asked to identify their largest corn or soybean field on the farm and answer operational and management questions for that field. Although the method was not a random field selection, our strategy ensured consistency of the fields that are measured each year and increased the survey's overall acreage coverage within each farm.

We measured crop rotation, tillage, and cover crop use with specific survey items in the field-based section of the questionnaire. Crop rotation was constructed as three-year cropping histories from the question 'In each of the last three years, what crop did you grow on [your largest] field?' We used the farmers' responses for cropping history to derive crop rotation by categorizing crop rotation into three groups: corn-soybean rotation, continuous corn rotation, and other rotation. Corn-soybean rotation was defined as only corn or soybean planted in the reported years (i.e., 2016, 2017, and 2018). Continuous corn rotation was defined as only corn planted in the reported years. Other rotations included other crops such as wheat and dry beans or two crops planted in a single year. Each field assigned a crop rotation in our analyses had cropping information for at least three consecutive years. A total of 3091 fields had crop rotation information.

**Table 1.** Recent Ag Census, ARMS, and Michigan State University-Panel Farm Survey (MSU-PFS, Authors' survey) coverage from 2010–2018

Practice	2010	2011	2012	2013	2014	2015	2016	2017	2018
Corn			Census					Census	
Soybeans			Census					Census	
Tillage			Census					Census	
Cover crop			Census					Census	
Tillage-corn	ARMS						ARMS		
Cover crop-corn	ARMS						ARMS		
Tillage-soybean			ARMS						ARMS
Cover crop-soybean			ARMS						ARMS
Tillage-corn							PFS	PFS	PFS
Cover crop-corn							PFS	PFS	PFS
Tillage-soybean							PFS	PFS	PFS
Cover crop-soybean							PFS	PFS	PFS

The tillage question was, ‘what kind of tillage did you perform on [your largest corn or soybean] field before the 2016 growing season?’ Respondents were instructed to check all that applied within four tillage categories for both fall and spring preceding the growing season: (1) conventional tillage (such as moldboard plow) with less than 15% residue remaining on the surface, (2) reduced tillage (such as chisel plow) with 15–30% residue remaining on the surface, (3) conservation tillage (such as vertical, ridge, strip, or mulch till) with more than 30% residue remaining on the surface, and (4) no-till. We combined reduced tillage and conventional tillage into the category of conventional tillage to be consistent with residue-based tillage definitions (Wade, Claassen and Wallander, 2015). No-till was defined as fields with no tillage in the fall after the harvest of the previous growing season or during the spring preceding the current growing season. Conservation tillage was defined as fields with only conservation tillage in the fall of the previous growing season and spring of the current growing season. If fields were reported to have used conventional or reduced tillage in spring or fall, they were categorized as conventional tillage. Continuous no-till was defined as no-till in three consecutive years (2016, 2017, and 2018).

Winter cover crops were measured with a single question: ‘During the 2015–2016 winter (years changed according to survey year), did [your largest] field have a cover crop?’. Respondents answered ‘yes’ or ‘no’ and were prompted to specify what cover crop was planted if they selected ‘yes.’ Continuous cover crop was defined as using cover crops in three consecutive winters (2015–2016 winter, 2016–2017 winter, 2017–2018 winter). Cover crops in the study are defined as crops planted not for harvest.

For all three practice measures, we completed detailed data cleaning and validation. Practice use is often more nuanced and context-dependent than the survey question entailed. For example, we entered and checked all the comments that respondents wrote about their crop rotation and individually coded those rotations. For cover crops, some respondents considered winter wheat or corn/soybean residues as ‘cover crops’, suggested by their answers to the follow-up open-ended question ‘which cover crop did you plant.’ If farmers reported wheat, corn stalks, or soybean stubble, their responses were recoded to zero, that is as no cover crop. Allowing respondents to provide more details on their practices turned out to be a valuable source of information to balance the nuanced production system and the need to simplify categories for the analyses. The data cleaning and validation process was time-consuming but necessary in using the survey data to measure adoption of the three practices.

### Data analysis

The adoption rate is defined as the number of acres adopted for a given practice (e.g., corn-soybean rotation) divided by the number

of total acres. To calculate adoption rates, we completed a lengthy data transformation procedure, including multiplying the acres of the field by whether a field is managed by a practice. Such calculation required measurements of the practice and field characteristics including field size. The adoption rates for tillage and cover crops were calculated by crops and for each growing season. For example, the adoption rate of no-till for the pre-2016 growing season for corn fields was calculated by the acres of corn fields reported using no-till divided by the total acres of corn fields in the 2016 growing season. Adoption rates by state and crop were also calculated for state comparisons. Weights were applied to all crop rotation, tillage, and cover crop statistics to account for the oversampling of large farms. All descriptive analyses were performed in SPSS 26, and the adoption rates were calculated in Excel. No-till and cover crop adoption rates were plotted by state and crop to show the changes from the 2017 growing season to the 2018 growing season. The survey for the 2016 growing season (collected in 2017) only included corn fields and was thus not included in the yearly comparison.

We also consulted the Ag Census and the ARMS to compare our survey results. The Ag Census data reported acres of total harvested cropland, land harvested for corn for grain, and soybean for grain (USDA-National Agricultural Statistics Service, 2019a, 2019b), cropland on which no-till practices were used, and cropland planted to a cover crop (excluding Conservation Reserve Program lands) (USDA-National Agricultural Statistics Service, 2019a, 2019b). These statistics were used to calculate the adoption rates with acres of total harvested cropland as the denominator. ARMS no-till estimates were from Wade, Claassen and Wallander (2015) and Claassen et al. (2018), and ARMS cover crop estimates were from Wallander et al. (2021). The earliest ARMS data used in these reports were the 2010 corn field surveys.

## Results

### Sample description

Compared to Ag Census and ARMS, our MSU-PFS survey describes a subsample of farms in four Midwestern states that consists of large grain farms (corn and soybeans) with more than 100 acres (40 ha) of planted areas to corn and/or soy. According to the 2017 Ag Census, corn and soybean fields together accounted for 64% (Michigan) to 96% (Illinois) of the total harvested area in these four Midwestern states that grow more corn and soybeans than the national average (Table 2). The survey sample data used in this analysis included 166,029 acres (67,190 ha) of corn fields for the 2016 growing season, 69,561 acres (28,150 ha) for the 2017 growing season, and 75,992 acres (30,753 ha) for the 2018 growing season. Soybean fields were not sampled in the first year of the survey field section.

**Table 2.** Share of corn and soybean acreage out of total harvest cropland acres from 2017 Ag Census

	US	Illinois	Indiana	Michigan	Ohio
Corn for grain (%)	26	49	44	30	32
Soybean (%)	28	47	48	34	50
	US	Illinois	Indiana	Michigan	Ohio
Total harvested cropland (acres)	320,041,858	22,701,382	12,345,774	7,214,667	10,190,952
Total harvested cropland (ha)	129,516,344	9,186,923	4,996,157	2,919,672	4,124,132

There were 76,218 acres (30,844 ha) of soybean fields sampled for the 2017 growing season and 55,558 acres (22,484 ha) sampled for the 2018 growing season.

The average production size of sampled farms in our regional survey ranged from 584 acres (236 ha, Michigan) to 740 (299 ha, Indiana) (Table 3). In comparison, in the Ag Census more than one-third of the farms were small-holder farms with less than 49 acres (20 ha) that grow grains or other crops. Fewer than one-third of the farms were 50 (20 ha) to 179 acres (72 ha). The average farm sizes from our data by the state were larger than those in the Ag Census due to our stratified sampling design (farms operating 100 acres or more).

### Crop rotation

We found that 66 percent of all sampled acres that had at least three years of cropping information had a corn and soybean rotation (Table 4). Continuous corn accounted for eight percent of all acres, and 18 percent of all acres had 'other' crop rotation, which is a category that encompasses a variety of other cropping practices, such as the inclusion of wheat, hay, alfalfa, or dry beans in the rotation. At the state level, corn and soybean rotation was most common in Indiana (72%), Ohio (71%), and Illinois (68%). Michigan (41%) had the most crop diversity and the lowest percentage of corn and soybean rotation in our sample, which stood in contrast to the 64% of combined percentage of single-year corn and soybean acreage reported by the Ag Census (Table 2). The difference is likely due to our survey's considering multiple years of cropping data. Michigan farmers have been shown to incorporate crops other than corn and soybean in

**Table 4.** Crop rotation acres (percentages) for large (over 100 acres) grain farms by states (weighted) as reported by MSU-PFS (Authors' survey)

	Corn and soy	Continuous corn	Other
Midwest (%)	66	8	18
Illinois IL (%)	68	13	10
Indiana IN (%)	72	6	12
Michigan MI (%)	41	6	44
Ohio OH (%)	71	3	18

their rotation more often than farmers in other Midwest states do (Michigan Department of Agricultural and Rural Development, 2019). Shares of acreage planted to continuous corn in our survey date were lower than anticipated. Illinois had the highest share of continuous corn (13%), followed by Indiana (6%), Michigan (6%), and Ohio (3%).

The Ag Census did not offer estimates of crop rotation, although single-year shares of crop acreage are commonly used to support the dominance of corn and soybean planting in the Midwest. Using ARMS data, Claassen et al. (2018) reported estimates for conservation rotation, which was a more specific crop-rotation concept that included the requirement for high residue crop, low nitrogen crop, and attaining a threshold level of average annual residue. They estimated that roughly 28% of 2016 corn acreage and 12% of soybean acreage was planted as part of a conservation crop rotation (Claassen et al., 2018). Compared to our survey data, ARMS did not report estimations for traditionally defined crop rotations.

**Table 3.** Unweighted farm size and field size statistics

	2017 Census of Agriculture				MSU-PFS			
	IL	IN	MI	OH	IL	IN	MI	OH
Average farm size (acres)	427	296	205	173	738	740	584	673
Average farm size (ha)	173	120	83	70	299	299	236	272
Percent of farms by size								
1 to 9 acres	11	13	11	13	-	-	-	-
10 to 49 acres	25	33	36	34	-	-	-	-
50 to 179 acres	26	27	31	30	-	-	-	-
100 to 179 acres	-	-	-	-	16	19	30	18
180 to 499 acres	17	13	13	14	31	30	23	30
500 to 999 acres	10	6	5	5	29	27	32	33
1000 acres or more	11	7	5	4	24	24	15	20
Total field area (acres)	-	-	-	-	121,247	83,074	56,684	81,337
Total field area (ha)	-	-	-	-	49,067	33,619	22,939	32,916
Number of fields								
2016	-	-	-	-	826	594	375	734
2017	-	-	-	-	634	484	317	598
2018	-	-	-	-	507	456	392	455

Note: Ag Census surveyed all farms including farms with 50 to 179 acres. MSU-PFS (Authors' survey) sampled farms with more than 100 acres. This population difference should be considered when interpreting the comparison.

### No-till

Our survey reported single-year no-till was used on roughly 20% of the corn acres (2016) and 39% of the soybean acres (2017) in the four-state region (Table 5). In comparison, using ARMS, Claassen et al. (2018) reported somewhat higher adoption rates of single-year no-till at the national level, which was 27% for corn fields and 40% for soybean fields. Wade, Claassen and Wallander (2015) combined no-till with strip-till in using the ARMS data and reported 31% of the combined adoption rates on corn fields and 46% on soybean fields. The Ag Census did not differentiate tillage practices by crops. If using the national average no-till adoption rate (33%) to estimate no-till adoption by crops for large grain farms in the Midwest, the average would simultaneously overestimate single-year no-till adoption rates for corn fields yet underestimate single-year no-till adoption rates for soybean fields.

In the sample, 619 corn or soybean fields were observed over three consecutive years, covering 52,592 acres (21,283 ha) across four states. These longitudinal field data were used for the analysis of continuous no-till. Overall, 15 percent of these acres were not tilled in any of three consecutive years. This value is lower than that from Claassen et al. (2018), who reported that 21% of the combined acreage in the surveys of corn, soybean, cotton, and wheat were continuously in no-till or strip-till in all four years. It is likely due to our concentrating on large farms.

For state differences, Ohio was the most likely state to have no-till corn (27% in 2016, 33% in 2017, and 28% in 2018) and no-till soybean (52% in 2017 and 2018) compared to the other three states in most of the years, while Michigan and Illinois had lower adoption of no-till on corn or soy fields as shown in Panels B and C in Figure 1 respectively. Ag Census estimates did not differentiate between corn fields and soybean fields (Panel A in Fig. 1). Ohio had the highest overall no-till adoption rate (42%), followed by Indiana (40%) and Illinois (29%). Michigan had the lowest overall no-till adoption rate (22%). Our findings mirrored Ag Census findings on state differences for single-year no-till adoption. However, the Ag Census overestimated state-level no-till adoption rates for corn fields in large

farms and underestimated state-level no-till adoption rates for soybean fields in large farms for all states. ARMS reports did not report state-level estimates.

For temporal changes, in general, no-till adoption rates for the same crop remained stable from 2017 to 2018 (Fig. 1). Two exceptions were for no-till corn in Ohio, which dropped from 33 to 28%, and no-till soybeans in Michigan, which dropped from 31% in 2017 to 23% in 2018. In comparison, Ag Census and ARMS monitored the long-term changes in no-till use. Both the 2012 and 2017 Ag Census revealed that the overall no-till adoption rates remained stable for Ohio and Michigan, while Indiana saw a slight decrease and Illinois saw a slight increase. Overall, Ag Census showed that no-till adoption rates remained similar from 2012 to 2017.

### Cover crop

Our survey data reported cover crop adoption rates for corn fields (following cover crops, corn was planted) prior to the 2016, 2017, and 2018 growing seasons and for soybean fields (following cover crops, soybeans were planted) prior to the 2017 and 2018 growing seasons (Table 6). For the Midwest, the shares of corn acres planted to cover crop were 9 percent prior to the 2016 growing season, 15 percent prior to the 2017 growing season, and 13 percent prior to the 2018 growing season. The shares of soybean acres planted to cover crops were 13 percent prior to the 2017 growing season and 9 percent prior to the 2018 growing season. Using ARMS data, Wallander et al. (2021) reported that prior to the 2016 growing season, the national cover crops adoption rate on corn fields was 5 percent and the adoption rate on soybean fields was 8 percent, both lower than our estimates for fields in large grain farms in the Midwest.

As shown in Panels B and C of Figure 2, Michigan had the highest cover crop adoption rates prior to corn in all three years: 17% in 2016, 27% in 2017, and 18% in 2018 (Table 6). Illinois had the lowest cover crop adoption rates prior to corn: 4% in 2016, 8% in 2017, 9% in 2018. For soybean fields, Indiana had the highest cover crop adoption rate (18%) in

**Table 5.** Comparison of no-till adoption rates (by acres) between Ag Census, ARMS, and MSU-PFS (Authors' survey) (weighted)

	Ag Census and ARMS					MSU-PFS				
	US	IL	IN	MI	OH	UM	IL	IN	MI	OH
All crops 2017 (%)	33 <sup>a</sup>	29 <sup>a</sup>	40 <sup>a</sup>	22 <sup>a</sup>	42 <sup>a</sup>	–	–	–	–	–
No-till/strip-till corn 2011 (%)	31 <sup>b</sup>	–	–	–	–	–	–	–	–	–
No-till corn 2016 (%)	27 <sup>c</sup>	–	–	–	–	20	12	28	13	27
No-till corn 2017 (%)	–	–	–	–	–	21	13	26	13	33
No-till corn 2018 (%)	–	–	–	–	–	20	14	28	17	28
No-till/strip-till soy 2011 (%)	46 <sup>b</sup>	–	–	–	–	–	–	–	–	–
No-till soy 2012 (%)	40 <sup>c</sup>	–	–	–	–	–	–	–	–	–
No-till soy 2017 (%)	–	–	–	–	–	39	29	43	31	52
No-till soy 2018 (%)	–	–	–	–	–	38	32	42	23	52

UM-upper Midwest, the four studied states combined.

<sup>a</sup>Source: USDA NASS (2019b), USDA NASS (2019a).

<sup>b</sup>Source: Wade, Claassen and Wallander (2015).

<sup>c</sup>Source: Claassen et al. (2018).

Note: Ag Census surveyed all farms including farms with 50 to 179 acres. MSU-PFS (Authors' survey) sampled farms with more than 100 acres. The population difference should be considered when interpreting the comparison.

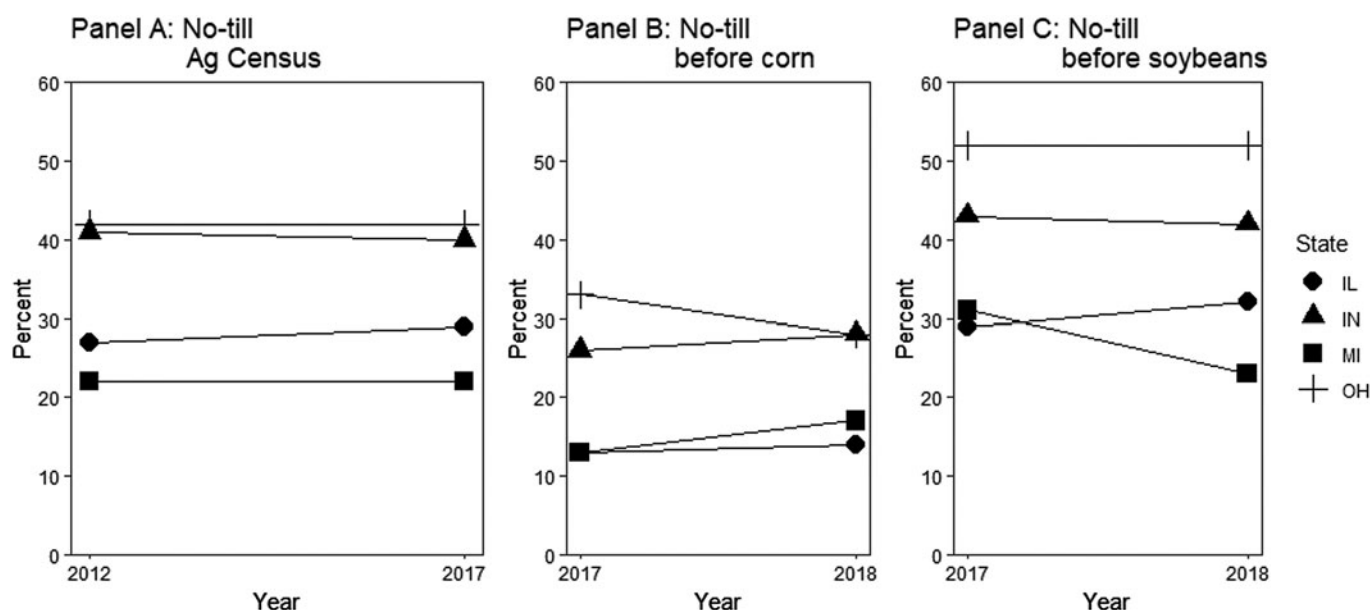


Figure 1. No-till overall (Panel A, Ag Census), no-till corn (Panel B, MSU-PFS), and no-till soybeans (Panel C, MSU-PFS), shares by states and years.

2017. In 2018, Ohio had the highest cover crop adoption rates (15%) prior to soybean. Without differentiating crops, the Ag Census found that Michigan had the highest cover crop adoption rates (9%), followed by Indiana (8%) and Ohio (7%) (Panel A in Fig. 2). Illinois was the lowest (3%). Both Ag Census and ARMS’s national averages and Ag Census’s estimates of state cover crop adoption rates were lower than our state estimates for most states and years.

We found a dip in cover crop adoption rates for most states from 2017 to 2018 except for Illinois corn fields. Cover-crop adoption may have increased slightly from 8 to 9% for Ohio soybean fields, wherein cover crop adoption increased from 12 to 15% (Fig. 2). Cover crops may be more susceptible to harvest season temperature, precipitation, and other environmental factors limiting cover crop planting (Roesch-McNally et al., 2018), and thus show more fluctuation in adoption rates than no-till. In comparison, Ag Census reported an overall increase in cover crop adoption for all four states from 2012 to 2017. Because of the spacing of sampling intervals, the Ag Census misses the yearly

fluctuation of cover crop adoption rates, dampening confidence in the long-term increasing trend in cover crop adoption for individual states.

### Discussion

We used three consecutive years of survey data to describe prevailing crop rotation, cover crop, and tillage practice for large (>100 acre) grain farms in Illinois, Indiana, Michigan, and Ohio. Results from 3914 farmer surveys showed good agreement with Ag Census and ARMS on the dominance of corn-soybean rotations, modest no-till adoption, and little cover crop acreage. However, our more detailed sampling showed yearly fluctuations in conservation practices, especially for the use of cover crops. Our survey also had larger sample sizes for Michigan and Ohio. For these two states, we found lower estimates of the single-year and continuous no-till percentage of acres before corn, and higher estimates of the no-till percentage of acres before soybeans and cover crop uses compared to national estimates. The analysis demonstrates the

Table 6. Comparison of cover crops adoption rates (by acres) between Ag Census, ARMS, and MSU-PFS (Authors’ survey) (weighted)

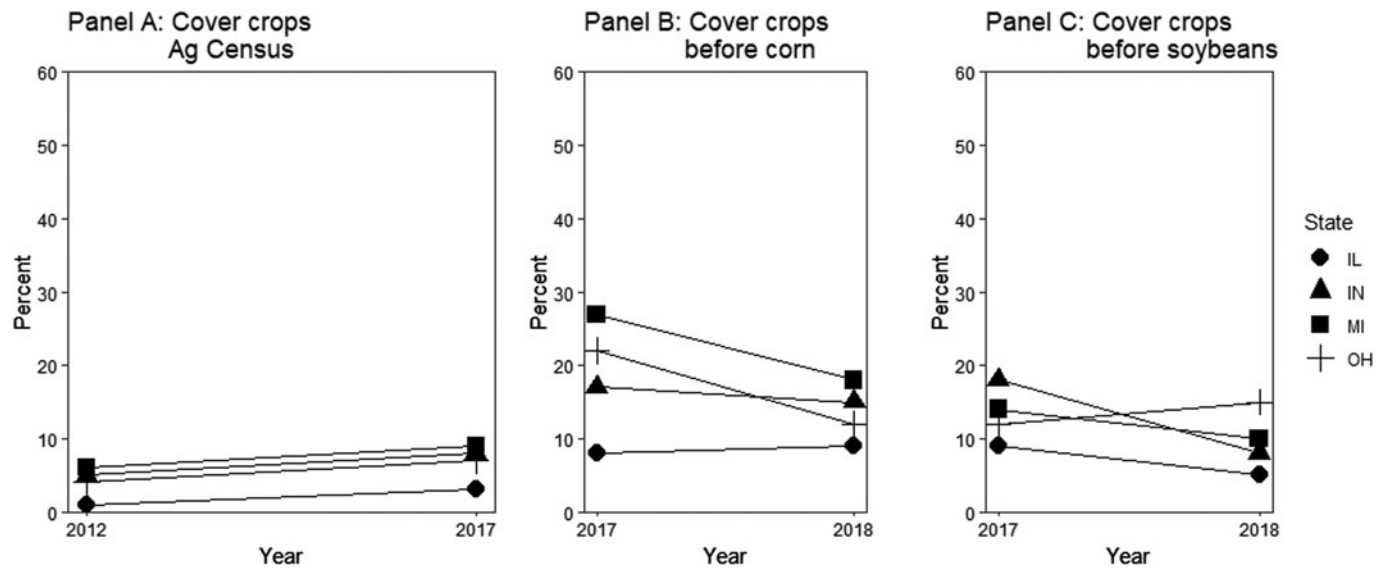
	Ag Census and ARMS					MSU-PFS				
	US	IL	IN	MI	OH	UM	IL	IN	MI	OH
All crops 2017 (%)	5 <sup>a</sup>	3 <sup>a</sup>	8 <sup>a</sup>	9 <sup>a</sup>	7 <sup>a</sup>	–	–	–	–	–
Corn 2016 (%)	5 <sup>b</sup>	–	–	–	–	9	4	13	17	10
Corn 2017 (%)	–	–	–	–	–	15	8	17	27	22
Corn 2018 (%)	–	–	–	–	–	13	9	15	18	12
Soybean 2017 (%)	–	–	–	–	–	13	9	18	14	12
Soybean 2018 (%)	8 <sup>b</sup>	–	–	–	–	9	5	8	10	15

UM-upper Midwest, the four studied states combined.

<sup>a</sup>Source: USDA NASS (2019b), USDA NASS (2019a).

<sup>b</sup>Source: Wallander et al. (2021).

Note: Ag Census surveyed all farms including farms with 50 to 179 acres. MSU-PFS (Authors’ survey) sampled farms with more than 100 acres. This population difference should be considered when interpreting the comparison.



**Figure 2.** Cover crop overall (Panel A, Ag Census), cover crops prior to corn (Panel B MSU-PFS), cover crops prior to soybeans (Panel C MSU-PFS), shares by states and years.

value of complementing national statistics with a survey with a stratified sampling design that covers more field acres and consecutive years, targets large grain farms, and collects data on the same field in consecutive years.

The results show that farm types and data collection years matter for determining prevailing practices for states and sub-national regions. Our annual farmer survey focuses on corn and soybean farms with more than 100 acres and oversampled farms with more than 500 acres, while Ag Census includes all farms, a third of which are less than 50 acres with no differentiation among crop types. Farm size and crop type may well affect the likelihood of a farm operation's use of conservation practices. Large farms may have more resources to experiment with new practices, which might explain why some of our adoption rate estimations were higher than the Ag Census estimation. Likewise, different cash crops have different management needs and constraints, affecting the adoption of conservation practices.

The yearly fluctuation in cover crop adoption rates, compared to the relatively stable albeit comparatively high adoption rates of no-till, suggests some best management practices are more sensitive to changing environmental and economic contexts. For example, harvest timing, fall precipitation, and crop and seed prices all impact cover crop decisions (Roesch-McNally et al., 2018); these factors also tend to change from year to year, leading to the large variability of cover crop adoption rates from year to year. Such variability should be taken into consideration when gauging long-term changes in cover crop adoption and assessing the effectiveness of conservation initiatives. Importantly, multiple years of granular data may be needed to tease out the effects of certain initiatives from the naturally occurring yearly fluctuations.

The spatial coverage and temporal frequency of data collection are critically important, and our inquiry revealed the tradeoff between spatial and temporal frequency: where one is larger, the other is constrained, and the reverse may also be true. On the one hand, national-level datasets provide estimates that reveal considerable detail about specific crops in a specific year across expansive geography. On the other hand, regional datasets provide detailed information about fields and farms that provides

more nuanced detail about specific crops for multiple years or successive crop seasons, more closely approximating a typical crop rotation. Although both strategies are representative, they provide different leverage points for describing the current state of on-farm practice adoption and, by extension, for crafting agricultural policy.

The comparison between our results and federal statistics provided insight on which information can be added by a regional continuous farmer survey. However, there are a few limitations of our survey approach that should be considered when interpreting the difference between the descriptions. First, ARMS randomly selected fields within a farm. In contrast, we asked farmers to report on their largest fields to provide a cognitive reference for our mail survey recipients and help farmers to report on the same field over multiple years. Using the survey question of 'How similar is the management of this field in relation to your farm operation', we found 87.1% of respondents managed the reported fields like all their other fields with similar soil types and field conditions or like all other fields planted in the same crop, which gave us confidence that the results were generally representative for the whole farm. That said, farmers may experiment with conservation practices on smaller or less productive fields. Compared to ARMS and Ag Census, we are likely to miss capturing the acreage under emergent management practices.

Second, measures of practices varied between surveys. We directly asked farmers to report their tillage practices in one of four categories (no-till, conservation tillage, reduced tillage, and conventional tillage) to balance survey complexity, data accuracy, and specificity. Within ARMS, tillage practices were determined using binary field management questions (Was this field no-tilled or strip-tilled?) and field operation and equipment questions (What operation or equipment was used, including all field work using machines for tillage?) (Questions from USDA-ERS NASS ARMS questionnaire). Claassen et al. (2018) converted this information to a Soil Tillage Intensity Rating, which characterizes soil disturbance due to tillage. The self-administered mailed survey method does not allow for the collection of detailed



residue and operation data without sacrificing response rates. Instead, we asked respondents to report on types of tillage in the spring and fall, which kept the temporal details of the practice. The decision of how to measure the adoption of conservation practice and in which level of detail should match the questions and resources.

Third, the average response rate for our annual farmer survey was 43.5%, which was lower than Ag Census' response rate of 72% (USDA-NASS, 2017) and ARMS's response rates of 49% for Illinois, 44% for Indiana, and 53% for Michigan and Ohio (USDA-NASS, 2020), but is higher than other mail surveys on agricultural conservation practices (Arbuckle et al., 2013; Houser et al., 2019). Last, although some comparisons could be performed with access to raw federal data (e.g., cover crop adoption rates by crops); the raw federal data are not publicly available. Like other human subjects' data, ARMS and Ag Census must be strictly managed to protect participants' privacy, preventing most researchers and local policymakers from accessing data for tailored analyses. Lack of data access is a procedural source of potential errors in comparing data sources. Dedicated resources will be needed to build data-sharing infrastructures including personnel along with developing privacy protection protocols in data-sharing. A grant program could be developed for researchers and local policymakers to request controlled data access.

*Implications for an Agriculture Information System.* Agricultural policies and industry heavily depend on accurate and timely information that reflects spatial and temporal dynamics of human and natural conditions. Our analyses revealed a need to build an agricultural information exchange and workforce that integrates diverse data sources with differing strengths and weaknesses to provide a greater understanding of agricultural management practices that provide baseline data for 'business-as-usual' or prevailing practices. The variance in adoption rates due to sampling years, farm types, farm sizes, measurement differences, and responses vs non-responses should be quantified further as we seek to combine and interpret different results.

Toward such an integrated system, researchers collecting farm practice data should also consider important methodological questions, such as how frequently researchers should survey producers, and at what spatial scale we should sample them. Should researchers collect more data at the regional scale at a greater frequency to complement existing federal datasets? Our research suggests annual frequency may be an appropriate time step for data gathering to consider growing operational complexity as farmer decision-making can operate simultaneously on a within-season and between-season basis, especially as climate variability increases throughout the Midwest. Capturing multiple facets of decision-making related to practice adoption is important for understanding agricultural transitions from 'business-as-usual' to aspirational systems. However, faced with resource constraints, annual sampling that considers the combination of crop rotation and management practices may not be realistic. Researchers must ensure data quality concerns are balanced with representativeness to enable inference for empirical models.

Other types of data may help with the dilemma of respondent burden and decreasing response rates, highlighting the importance of cross-disciplinary collaborations. The focus of our study is on producer-reported behavior although there are limitations associated with behavior surveys, such as non-response bias, self-selection bias, and memory bias. Integrating geospatial data, including remote sensing data, is likely to add precision in determining farming practices without burdening the same population groups repeatedly. With

advances in satellite techniques and spatial sciences, datasets can vary widely with respect to spatial and geospatial resolutions. These data can benefit from validation with behavior surveys. Future studies might determine prevailing conservation practices combined with spatial and behavior data to critically assess the advantages and disadvantages of each data type. With diverse data sources and more temporal and spatial details, we are more likely to approach the 'ground truthing' of prevailing farming practices and promote the timeliness and relevance of agricultural policies.

In summary, using three consecutive years of survey data, we found a similar farming pattern (dominant corn-soybean rotation, limited use of cover crop and no-till corn, moderate use of no-till soybean) in four Midwestern US states, yet different estimates for cover crop and no-till adoption rates as compared to federal data. Portraying the intersection of practices was not as easily realized across the different data levels. Our findings show the value of combining regional and national surveys to provide greater coverage and details for improved predicting and promoting conservation policies at multiple administrative and geospatial levels. Through multiple years of data collected by different entities at varied levels, researchers and policymakers will be closer to reaching a more comprehensive picture of US conservation practices adoption rates.

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## References

- Adhikari, R.K., Wang, T., Jin, H., Ulrich-Schad, J.D., Sieverding, H.L. and Clay, D. (2023) 'Farmer perceived challenges toward conservation practice usage in the margins of the Corn Belt, USA', *Renewable Agriculture and Food Systems*, **38**, 1–14.
- Arbuckle, J.G., Prokopy, L.S., Haigh, T., Hobbs, J., Knoop, T., Knutson, C., Loy, A., Mase, A.S., McGuire, J., Morton, L.W., Tyndall, J. and Widhalm, M. (2013) Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. *Climatic Change* **117**(4), 943–950.
- Arbuckle, J.G. and Roesch-McNally, G. (2015) 'Cover crop adoption in Iowa: the role of perceived practice characteristics', *Journal of Soil and Water Conservation*, **70**(6), pp. 418–29.
- Burnett, E., Wilson, R.S., Heeren, A. and Martin, J. (2018) 'Farmer adoption of cover crops in the western Lake Erie basin', *Journal of Soil and Water Conservation*, **73**(2), pp. 143–55.
- Claassen, R., Bowman, M., Mcfadden, J., Smith, D. and Wallander, S. (2018) *Tillage intensity and conservation cropping in the United States*. United States Department of Agriculture.
- Cusser, S., Bahlai, C., Swinton, S.M., Robertson, G.P. and Haddad, N.M. (2020) 'Long-term research avoids spurious and misleading trends in sustainability attributes of no-till', *Global Change Biology*, **26**(6), pp. 3715–25.
- Davis, A.S., Hill, J.D., Chase, C.A., Johanns, A.M. and Liebman, M. (2012) 'Increasing cropping system diversity balances productivity, profitability and environmental health', *PLoS One*, **7**(10), 1–8.

- Dillman, D.A., Smyth, J.D. and Christian, L.M. (2014) *Internet, phone, mail, and mixed-mode surveys: the tailored design method*. 4th edn. Hoboken, NJ: John Wiley & Sons, Inc.
- Fleckenstein, M., Lythgoe, A., Lu, J., Thompson, N., Doering, O., Harden, S., Getson, J.M. and Prokopy, L. (2020) 'Crop insurance: a barrier to conservation adoption?', *Journal of Environmental Management*, **276**, 1–7.
- Houser, M., Marquart-Pyatt, S.T., Denny, R.C.H., Reimer, A. and Stuart, D. (2019) Farmers, information, and nutrient management in the US Midwest. *Journal of Soil and Water Conservation* **74**(3), 269–280.
- Hunt, N.D., Hill, J.D. and Liebman, M. (2017) 'Reducing freshwater toxicity while maintaining weed control, profits, and productivity: effects of increased crop rotation diversity and reduced herbicide usage', *Environmental Science and Technology*, **51**(3), pp. 1707–17.
- Kaspar, T.C. and Singer, J.W. (2011) 'The use of cover crops to manage soil' in Hatfield, J. and Sauer, T.J. (eds.) *Soil management: building a stable base for agriculture*. Madison, WI: American Society of Agronomy and Soil Science Society of America, pp. 321–37.
- Matson, P.A. (1997) 'Agricultural intensification and ecosystem properties', *Science*, **277**(5325), p. 504.
- Mcfadden, J.R., Smith, D.J. and Wallander, S. (2022) *Weather, climate, and technology adoption: an application to Drought-Tolerant corn in the United States*. Cambridge, MA: National Bureau of Economic Research.
- Meredith, G., Bean, A., Brymer, A.B., Friedrichsen, C. and Hurst, Z. (2022) 'Integrating human dimensions within the LTAR Network to achieve agroecological system transformation', *Rangelands*, **44**(5), pp. 368–76.
- Michigan Department of Agricultural and Rural Development. (2019) *Michigan agriculture facts & figures*. Lansing, Michigan: Michigan Department of Agricultural and Rural Development.
- Prokopy, L.S., Gramig, B.M., Bower, A., Church, S.P., Ellison, B., Gassman, P.W., Genskow, K., Gucker, D., Hallett, S.G., Hill, J., Hunt, N., Johnson, K.A., Kaplan, I., Kelleher, J.P., Kok, H., Komp, M., Lammers, P., LaRose, S., Liebman, M., Margenot, A., Mulla, D., O'Donnell, M.J., Peimer, A.W., Reaves, E., Salazar, K., Schelly, C., Schilling, K., Secchi, S., Spaulding, A.D., Swenson, D., Thompson, A.W. and Ulrich-Schad, J.D. (2020) 'The urgency of transforming the Midwestern U.S. landscape into more than corn and soybean', *Agriculture and Human Values*, **37**(3), pp. 537–39.
- Robertson, G.P. (2015) 'A sustainable agriculture?', *Daedalus*, **144**(4), pp. 76–89.
- Robertson, G.P., Allen, V.G., Boody, G., Boose, E.R., Creamer, N.G., Drinkwater, L.E., Gosz, J.R., Lynch, L., Havlin, J.L., Jackson, L.E., Pickett, S.T.A., Pitelka, L., Randall, A., Reed, A.S., Seastedt, T.R., Waide, R.R. and Wall, D.H. (2008) 'Long-term agricultural research a research education and extension imperative', *BioScience*, **58**(7), pp. 640–45.
- Robertson, G.P., Gross, K.L., Hamilton, S.K., Landis, D.A., Schmidt, T.M., Snapp, S.S. and Swinton, S.M. (2014) 'Farming for ecosystem services: an ecological approach to production agriculture', *American Institute of Biological Sciences* **64**, 404–415.
- Robertson, G.P., Hamilton, S.K., Paustian, K. and Smith, P. (2022) 'Land-based climate solutions for the United States', *Global Change Biology*, **28**(16), pp. 4912–19.
- Roesch-McNally, G.E., Basche, A.D., Arbuckle, J.G., Tyndall, J.C., Miguez, F.E., Bowman, T. and Clay, R. (2018) 'The trouble with cover crops: farmers' experiences with overcoming barriers to adoption', *Renewable Agriculture and Food Systems*, **33**(4), pp. 322–33.
- Singer, J.W., Nusser, S.M. and Alf, C.J. (2007) 'Are cover crops being used in the US corn belt?', *Journal of Soil and Water Conservation*, **62**(5), pp. 353–58.
- Socular, Y., Goldstein, B.R., De Valpine, P. and Bowles, T.M. (2021) 'Biophysical and policy factors predict simplified crop rotations in the US Midwest', *Environmental Research Letters*, **16**(5), 1–12.
- Spiegel, S., Bestelmeyer, B.T., Archer, D.W., Augustine, D.J., Boughton, E.H., Boughton, R.K., Cavigelli, M.A., Clark, P.E., Derner, J.D., Duncan, E.W., Hapeman, C.J., Harmel, R.D., Heilman, P., Holly, M.A., Huggins, D.R., King, K., Kleinman, P.J.A., Liebig, M.A., Locke, M.A., McCarty, G.W., Millar, N., Mirsky, S.B., Moorman, T.B., Pierson, F.B., Rigby, J.R., Robertson, G.P., Steiner, J.L., Strickland, T.C., Swain, H.M., Wienhold, B.J., Wulffhorst, J.D., Yost, M.A. and Walthall, C.L. (2018) 'Evaluating strategies for sustainable intensification of US agriculture through the Long-Term Agroecosystem Research network', *Environmental Research Letters*, **13**(3), 1–16.
- Syswerda, S.P. and Robertson, G.P. (2014) 'Ecosystem services along a management gradient in Michigan (USA) cropping systems', *Agriculture, Ecosystems and Environment*, **189**, pp. 28–35.
- Tilman, D., Balzer, C., Hill, J. and Befort, B.L. (2011) 'Global food demand and the sustainable intensification of agriculture', *Proceedings of the National Academy of Sciences of the United States of America*, **108**(50), pp. 20260–64.
- USDA-National Agricultural Statistics Service. (2017) Census of Agriculture Appendix A. Census of Agriculture Methodology. Retrieved from [https://www.nass.usda.gov/Publications/AgCensus/2017/Full\\_Report/Volume\\_1,\\_Chapter\\_1\\_US/usappxa.pdf](https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usappxa.pdf).
- USDA-National Agricultural Statistics Service. (2019a) *2017 census of agriculture-table 1. State summary highlights: 2017*. USDA-National Agricultural Statistics Service.
- USDA-National Agricultural Statistics Service. (2019b) *2017 census of agriculture-table 41. Land use practices: 2017 and 2012*. USDA-National Agricultural Statistics Service.
- United States Department of Agriculture (USDA) Agricultural Statistics Board, National Agricultural Statistics Service (NASS) (2020) Farm production expenditures methodology and quality measures. Retrieved from NASS website [https://www.nass.usda.gov/Publications/Methodology\\_and\\_Data\\_Quality/Farm\\_Production\\_Expenditures/07\\_2021/fpxq0721.pdf](https://www.nass.usda.gov/Publications/Methodology_and_Data_Quality/Farm_Production_Expenditures/07_2021/fpxq0721.pdf).
- Wade, T., Claassen, R. and Wallander, S. (2015) *Conservation-practice adoption rates vary widely by crop and region*.
- Walbridge, M.R. and Shafer, S.R. (2011) A long-term agro-ecosystem research (LTAR) network for agriculture. The Fourth Interagency Conference in the Watersheds, pp. 1–7.
- Wallander, S., Smith, D., Bowman, M. and Claassen, R. (2021) *Cover crop trends, programs, and practices in the United States*.
- Wezel, A., Casagrande, M., Celette, F., Vian, J.F., Ferrer, A. and Peigné, J. (2014) *Agroecological practices for sustainable agriculture: a review*. EDP Sciences.