

Research article

Cover crops as climate insurance: Exploring the role of crop insurance discounts to promote climate adaptation and mitigate risk

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ABSTRACT

Climate adaptation is vital for agriculture to manage the growing risks from more frequent droughts, floods, and extreme heat. Yet, adaptation measures remain underused in some of the most agriculturally productive regions, such as the U.S. Cornbelt. Cover crops represent a growing but still underutilized adaptation measure that offers co-benefits to farmers and society. In this study we examine farmers' perceptions of cover crops as a climate adaptation tool and explore the potential for integrating cover crops into existing crop insurance. We surveyed 1023 farmers in Illinois, Indiana, and Iowa to examine what factors shape cover crop acreage, intensity (percent of farm with cover crops), and farmers' future cover crop plans through negative binomial and ordered logit regression models. In addition, we explored farmers' views on policy changes to incorporate the use of cover crops into crop insurance decisions. We found that farmers largely do not perceive extreme weather as a factor in their cover crop decisions, but they do see cover crops as effective in mitigating some impacts of extreme weather. Nearly twice as many farmers reported neutral or improving cash crop yields following cover crops as those who reported declining cash crop yields. Perceptions of negative cash crop yield responses correlated to fewer acres, lower intensities, and plans for fewer cover crops, while positive yield responses only predicted plans to increase cover crops. Program enrollment, self-efficacy, and reduced tillage were all associated with higher cover crop intensities, acres, and plans. Farm size was positively correlated with more acres of cover crops but also lower intensities. Farmers were interested in crop insurance discounts and carbon markets as policy instruments but ranked cost-share programs as their top option overall. Future research should further explore the link between training, experience, and financial costs to inform what policy instruments will most effectively support scaling up cover crop adoption.

1. Introduction

Climate adaptation—changes in response to warming temperatures—is vital for agriculture as the risks from increased droughts, floods, and extreme heat become more prevalent each year (Angel et al., 2018; Rodell and Li, 2023). A pressing concern is how farmers will adapt to these changing conditions. Climate adaptation has long-term implications for the stability of the world's food supply (Gaudin et al., 2015), and many adaptation measures offer important co-benefits for farmers and society through carbon sequestration (Jian et al., 2020), ecosystem regulating services (Van Eerd et al., 2023), and greater resilience of cash crops to extreme weather (Aglasan et al., 2023; Won et al., 2023).

Crop insurance (also called weather insurance or agricultural insurance) is a prominent risk mitigation approach to protect farmers against extreme weather. Because crop insurance is widely used, an interesting question is whether crop insurance can be leveraged to also encourage farmers to adapt to extreme weather, in addition to the traditional application, recovering from damages (Loreau et al., 2021). In the U.S. Cornbelt, which generally refers to 12 Midwest states known for extensive corn production historically (Green et al., 2018), more than 85% of farmers use crop insurance (Fleckenstein et al., 2020; Rorsch, 2021). Research on cover crops—noncash crops, such as grasses or legumes, typically planted after harvest and terminated before the following cash crop is planted—have found promising risk-mitigation

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benefits (Aglasan et al., 2021; Basche et al., 2016; Kaye and Quemada, 2017), which led to recommendations that linking cover crop adoption to discounts on farmers' crop insurance premiums could be a valuable policy tool to encourage higher use of cover crops (Claassen et al., 2017; Bryant & O'Connor, 2017; CTIC, 2015). During 2018–2022, three Cornbelt states (Illinois, Indiana, and Iowa) piloted a novel policy approach to link climate adaptation to crop insurance by offering a \$5 discount on crop insurance premiums for each acre farmers planted with cover crops (UIUC, 2021; Indiana State Department of Agriculture; Sawadgo, 2020). A temporary national program modeled on the state versions, the Pandemic Cover Crop Program, was also piloted during this period (Turner et al., 2023).

In this paper, we examine whether farmers' risk perceptions are salient for cover crop adoption and a crop insurance discount policy tool. We further explore farmers' preferences around the crop insurance discount approach alongside more common approaches, such as cost-share subsidies. We pose two research questions:

1. Does the risk of extreme weather, alone and alongside other factors, influence farmers' adoption or future use of cover crops?
2. To what extent do farmers' responses indicate that crop insurance discounts could be an effective policy tool to promote climate adaptation by scaling up cover crop adoption?

To answer our research questions, we administered a survey that was returned by 1,023 farmers across Illinois, Indiana, and Iowa in February–April 2023. We construct ordered logit and negative binomial regression models to answer the first question and use descriptive statistics to answer our second question. In the remainder of the introduction, we review the literature on why farmers adopt, avoid, or discontinue cover crops, and the role of crop insurance in encouraging or discouraging management practices that support climate adaptation.

1.1. Drivers of cover crop adoption and abandonment

Cover crops fit within a broader set of conservation practices that have long been recommended to reduce negative externalities from agriculture (U.S. Department of Agriculture Federal Crop Insurance Corporation, 2020). These same practices—reduced tillage, nutrient management best practices, crop diversification, and cover crops, among others—are also adaptations to the risks of extreme weather (Francaviglia et al., 2023). Despite these important co-benefits, conservation practice adoption has remained relatively low among large-scale conventional farmers in the U.S. Cornbelt. For example, less than one-third of farmers adopt nutrient best management practices, aimed at reducing fertilizer losses that cause water pollution (Ribaudo et al., 2011). Cover crops are used on 6% of harvested U.S. croplands nationally (USDA, 2024). No-till (also called zero tillage) and reduced tillage, which minimizes soil erosion and disturbances to soil ecosystems, have been a success story of conservation practice adoption, as no-till became the most common tillage practice in the United States in the past decade, with reduced tillage as the second most common (USDA, 2019).

Research has found that risk perceptions of negative on-farm impacts of climate change, especially the frequency and recency of events, motivates conservation practice adoption generally (Howden et al., 2007; Haden et al., 2012; Arbuckle, 2013; Houser et al., 2017; Mase et al., 2017). Because cover crops have become a more recent interest among conservation practices, less is known about the link between climate risk perceptions and cover crop adoption. Wilson et al. (2023) found that only increased tile drainage was driven by climate risk perceptions, while cover crop adoption was driven by farmer identity. Several other studies have looked at cover crop adoption and risk perceptions, finding no correlation with adoption (Campbell et al., 2021), negative relationship due to perceptions that cover crops increased risks (Arbuckle and Roesch-McNally, 2015), and positive correlation with adoption for

farmers that were less risk averse (Burnett et al., 2018). Other factors motivating cover crops adoption include perceptions of how effective it is for management goals, called response efficacy (Guo et al., 2023; Burnett et al., 2018; Arbuckle and Roesch-McNally, 2015), as well as perceptions of profitability (Wang et al., 2021; Guo et al., 2023). Farmers with higher environmental concerns are more likely to plant cover crops, while farmers interested in maximizing cash crop yields are less likely to plant them (Upadhaya and Arbuckle, 2021; Walpole and Wilson, 2022; Lang and Rabotyagov, 2022). Farmers' perceived self-efficacy, or perceived behavioral control, has also been found to correspond to cover crops adoption (Burnett et al., 2018). The influence of social networks and public agencies promoting cover crops correlates to greater adoption (Nowatzke and Arbuckle, 2023). Farmers using no-till are more likely to adopt cover crops than farmers using conventional tillage (Lee and McCann, 2019). One explanation, from protection motivation theory, for why these variables influence farmers' management decisions is that people take protective actions when: first, they perceive a given risk to be high enough that the benefits of acting outweigh the costs of maintaining the status quo; and second, they perceive themselves capable of taking effective action (Floyd et al., 2000; Witte and Allen, 2000). Thus, if farmers are perceiving risk from extreme weather, it can explain why they are adopting cover crops as a response.

At the same time, there is a range of management circumstances that constrain cover crop adoption. The time pressure for planting and terminating cover crops, upfront costs, and slowly accruing benefits are some of the most common challenges (Van Eerd et al., 2023; Dunn et al., 2016). Because cover crops help soils retain moisture, soils can be wetter and cooler in the spring, which delays when farmers can plant their cash crops. Some farmers have responded by increasing their tillage in the spring after terminating cover crops to plant cash crops sooner (Roesch-McNally et al., 2017) and experience with saturated soil has been correlated with less use of cover crops (Morton et al., 2015). Studies have also reported the difficulties for farmers to break even on cover crops (Campbell et al., 2021; Bergtold et al., 2017). Other studies have contended that cover crops can contribute to profitability within three years (Myers et al., 2019) or are closer to breaking even if farmers graze livestock on their cover crops (Skevas et al., 2022; Popovici et al., 2023; Wang et al., 2021). Land tenure is a challenge when farmers rent cropland because they are reluctant to invest the upfront money in cover crops since they may lose the long-term benefits if the landlord would decide to rent to another farmer (Doran et al., 2022; Lang and Rabotyagov, 2022; Gong et al., 2021; Sawadgo and Plastina, 2021). Farmers with larger farms have been found to be more likely to plant cover crops (Walpole and Wilson, 2022; Lo et al., 2021; Dunn et al., 2016). However, this comes with an important caveat that larger farms may plant at lower intensities (i.e., lower percentages of their farm; Thompson et al., 2021; Guo et al., 2023).

How cover crops contribute to overall cash crop yields (and thus profitability) remains a question mark for many, if not most, farmers. Research suggests that the type of cover crop and the practice's longevity are two of the most consequential factors. A meta-analysis found that cover crops comprised of legumes and species mixes were correlated with higher corn yields, while grasses were not statistically significant (Marciello and Miguez, 2017). This is notable because grasses, particularly cereal rye, are the most common type of cover crop because it established late in the year as temperatures are cooler (ibid.) but has also been correlated with declining corn yields (Nichols and MacKenzie, 2023). A study using satellite imagery to analyze 90,000 fields in 2019–2020 reported corn yield losses of 5.5% on average and soybean yield losses of 3.5% (Deines et al., 2023). Another meta-analysis, with 60% of studies based in North America and for fewer than five years, found a mean increase in soil organic carbon of 15.3%, but with a substantial range from –15% to 65% (Jian et al., 2020). The analysis showed that croplands with cover crops had greater soil carbon stocks than croplands with without cover crops. Cash crop systems were

similar, though corn-soybean-wheat rotations had the largest stocks. Regression results showed that the largest gains in soil carbon stocks occurred on temperate croplands, fine-grain soils, and mixes of more than two types of cover crop species. A 30-year study of diverse rotations in Canada that included cover crops found increased and stabilized cash crop yields, while 40% of long-term cover crop users in South Dakota, USA, reported increased profits (Wang et al., 2021).

1.2. Crop insurance and conservation practice adoption

Because crop insurance reduces farmers' financial risks, it is unclear whether crop insurance discounts will be an effective approach to encourage climate adaptation. Existing studies are mixed between mostly neutral or negative effects on conservation practice adoption. Upadhaya and Arbuckle, 2021 find that farmers who are more oriented towards conservation practices are more likely to take adaptive measures, such as cover cropping. At the same time, confidence in crop insurance was more likely to correlate with mal-adaptive behaviors, such as conventional tillage and increased tile drainage. Similarly, Annan and Schlenker (2015) find that crop insurance reduces the negative economic impacts of extreme heat conditions for corn growers and could function as a disincentive for greater use of conservation practices. Connor et al. (2022) found that crop insurance has a disincentivizing effect on cover crop adoption but cautioned that the effect sizes were very small and likely not an important factor. Other studies have similarly found that crop insurance has only minimal effects if any on conservation practices, such as a drainage water recycling system (Sellars et al., 2022) or chemical use (Regmi et al., 2022).

One reason conservation practice adoption may remain limited to a minority of farmers is that farmers see conservation practices as a type of supplementary insurance. Fleckenstein et al. (2020) found support for this view, in that cover crops and conservation tillage were positively correlated with crop insurance use. In this study, Fleckenstein and colleagues found that 43% of their sample reported crop insurance as the most valued risk management strategy, while 26% reported either cover crops or conservation tillage. Mase et al. (2017) similarly found that 64% of U.S. Midwest farmers used in-field conservation practices, while 59% purchased additional crop insurance and 43% use new technologies. At the time of publication, only one other study had looked at the crop insurance discount approach, similarly finding support that conservation practices and crop insurance can be complementary. In Iowa, the pilot program increased the area planted in cover crops by 11% for farmers enrolled in the program (Sawadgo, 2024). This also means that as a tool of "additionality" for cover crops that 89% of the cover crops that were supported through the discount program would have been planted regardless (ibid.).

1.3. Linking risk mitigation, crop insurance, and conservation adoption

The interplay between conservation practices and crop insurance presents an important opportunity for shaping climate adaptation strategies. Conservation practice adoption can help to protect farmers from catastrophic losses, but it can also help reduce the costs of subsidizing crop insurance. Policy changes in the 1990s dramatically increased federal support of crop insurance (O'Donoghue, 2014), and subsidies accounted for 62% of insurance premiums on average in 2022 (GAO, 2023a), which led to substantial growth in enrollment. Increased claims represent a potentially expensive increase in taxpayer funds as extreme events increase (Tack et al., 2017), since farmers may choose to rely heavily on crop insurance to mitigate risks, rather than the potential added expense of cover crops or other conservation practices. This matters because corn is predicted to face declining yields from rising temperatures (Bowling et al., 2018), while simplified cropping systems face higher risks from catastrophic disturbances than diversified systems (Müller et al., 2017). Over the past several decades, crop insurance claims have grown substantially as crop losses have increased due to

climate change (Gowda et al., 2018; Raza et al., 2019; Dhaliwal and Williams, 2022). Crop insurance indemnities are expected to increase by as much as 60% in the coming decades (Tack et al., 2017). The prevalence of corn-and-soybean rotations in the U.S. Cornbelt supports this concern that crop insurance policy encourages monocropping and the associated environmental harms and climate risks.

Internationally, research on crop insurance has also looked at the potential for negative environmental externalities based on the use of crop insurance. Multiple studies show that crop insurance tends to have similar problematic effects for the environment, where insurance increases agricultural productivity through increase inputs and specialization and expanding cultivation of land, including environmentally sensitive areas (Müller et al., 2017; Kurdyś-Kujawska et al., 2021; Hou & Wang, 2022). Recent research points to the development of different types of crop insurance policies that may have implications for future environmental consequences. Many insurance policies have traditionally relied on areas or yields to estimate indemnity payments, index-based instruments are a recent alternative where payments are triggered when certain climatic conditions are met (e.g., monthly precipitation) (Bucheli et al., 2023). There are also differences in approaches as to whether crop insurance is subsidized or bundled with other incentives, such as access to credit (Müller et al., 2017), can be connected with cross-compliance mechanisms to require conservation practices (De Laporte et al., 2024), or differences between private insurance versus state support (Bucheli et al., 2023). More research is needed on how these variations might alter the environmental impacts of crop insurance, in addition to the focus on whether these approaches encourage farmers to use crop insurance.

2. Methods

2.1. Data collection

To examine farmers' risk perceptions of cover crops, we distributed mailed and online surveys across the three states (Illinois, Indiana, and Iowa) with pilot programs offering a crop insurance premium discount for acres planted in cover crops (Fig. 1). We used both random and convenience sampling strategies to maximize response. For the random sampling, we worked with a private company, DataForce, to distribute an informational postcard with a link to take the survey online, followed by two rounds of mailed paper surveys to 8,000 farmers split evenly across the three states in our study area from February to April 2023. Farmers returned 669 surveys (484 mailed copies and 185 completed online). The low response rate of 8.4% of the random sample may reflect both the ongoing declining trends of farmers being over-surveyed (Johansson et al., 2017; Glas et al., 2019), as well as the specific



Fig. 1. Study area in the U.S. Cornbelt.

Table 1
Dependent and explanatory variables used in the negative binomial (adoption) and ordered logit (intensity, plans) regression models, along with the hypothesized effects on the dependent variables.

Dependent Variables	Operationalized	Hypothesis
Cover Crop Intensity	Percent of acres with cover crops categorized into none, low (less than 1/3), medium (1/3 to 2/3), and high (greater than 2/3)	N/A
Cover Crop Acres	Count of acres planted in cover crops	N/A
Cover Crop Plans	Likert scale from discontinuing use to whole farm use	N/A
Explanatory Variables	Operationalized	Hypothesis
Cash Crop Yield Response	Categorical variables (lower, same, higher) to show perceptions of corn and soybean yields responses following cover crops.	+
Crop Insurance	Binary response on whether farmers had crop insurance or not.	-
Risk Perception	Likert scale index on farmers perceptions of the frequency, concern, likelihood, and severity of extreme weather on their farm.	?
Program Enrollment	Binary variable: past participation in financial assistance program and interest in participating again.	+
Self-Efficacy	Likert scale on how difficult it is to use cover crops.	+
Response Efficacy	Likert scale on how effective farmers felt cover crops are for mitigating the effects of extreme weather.	+
Farm Size (Log)	Number of acres farmed converted to natural log to deal with sigmoidal distribution of farm sizes.	-/+/?
Income	Ordinal scale of small, medium, and large farms based on USDA's gross cash farm income scale.	+
Percent Rented	Number of acres rented out of the total number of acres farmed.	-
Reduced Tillage	Ordinal scale of soil disturbance based on the most frequently used form of tillage, from conventional to zero tillage.	+
Age	Continuous variable of farmers' ages.	-
Gender	Binary variable of male or not male.	?
Education	Ordinal variable of increasing years of education from some high school to graduate school.	+
Convenience Sample	Dummy variable to indicate whether the respondent was part of the convenience sample.	+

challenge of farmers also completing the mandatory Census of Agriculture during this timeframe, which occurs only once every five years. In addition, we recruited through an online convenience sample, working with the state departments of agriculture to email their constituents. The convenience samples, distributed over the same February to April window, returned 354 completed surveys (215 from Illinois, 67 from Iowa, and 52 from Indiana). Overall, our sample includes 1,023 completed surveys. In the results and supplementary materials, we provide a breakdown of key differences between random and convenience samples. In looking at our two samples, there is a substantial difference in cover crop use. Both samples are skewed in favor of cover crop users. Nearly two-thirds of respondents in the random sample use cover crops, while in the convenience sample more than 90% of respondents use cover crops. We account for these differences by including the sample type as a dummy variable in each model.

2.2. Variable measurement

Table 1 summarizes variables and how they were operationalized. To analyze farmers' risk perceptions, we included a set of four questions regarding farmers' prior experiences with extreme weather, expectations of experiencing extreme weather in the coming year, concerns with

negative impacts on their farm, and how severe they expect extreme weather to be (tailored from Arbuckle, 2013). We created one risk perception variable by taking the mean value of these four items (Cronbach's alpha of 0.75). We also asked respondents how helpful they thought cover crops were in mitigating the effects of extreme weather on a 5-point Likert scale (response efficacy). We asked about a series of items that may influence farmers' use of cover crops. We asked farmers if their corn or soybean yields following cover crops were higher or lower. We used a five-point Likert scale that included: always lower, often lower, about the same, often higher, and always higher. For the respondents that used cover crops before both cash crops, we took the average value from both responses. Farmers that did not plant cover crops marked not applicable for this question. We operationalized these responses as a categorical variable, collapsing always lower and often lower into a single lower yields response and the same for higher yields. Additional variables that influenced farmers perceptions of cover crops included: whether or not farmers' use crop insurance, measured as a binary yes or no; how difficult it is for farmers to use cover crops in their operation, based on a 5-point Likert scale; and whether farmers were interested in participating in a financial assistance program, such as EQIP, operationalized as a binary one or zero to represent interested or not interested. We also asked about a set of farm characteristics, including: farm size, operationalized as the number of tillable acres in 2022; farm income, operationalized as an ordinal variable based on USDA categories of small, medium, or large gross cash farm income; whether they conventional, reduced, or no-till was their most widely used tillage practice, which was operationalized as an ordinal variable from one to three with higher values representing less soil disturbance (reduced tillage); and how much land farmers rented of the total that they farmed in 2022, operationalized as a percentage between zero and one (percent rented). Lastly, we included several demographic questions, including: age, as a continuous variable; gender, operationalized as a binary one for not male and zero for male, given the overwhelming number of responses marked as male; the most recent level of education completed, ranging from some high school to postgraduate and operationalized as an ordinal variable.

2.3. Outcome measures

We constructed statistical models with three different dependent variables that capture different aspects of cover crop use. First, we used a negative binomial regression model to predict Cover Crop Adoption, which represents the overall number of acres planted in cover crops. Because cover crops are not normally distributed, we use a Poisson model that is intended to deal with overdispersion for cover crop adoption; in this case, cover crop adoption is highly skewed towards farms with zero acres because of the non-adopters in our sample. Second, we created an ordered logit model for Cover Crop Intensity, which represents the percentage of a farm's acres that were planted in cover crops in 2022. Here again, the percentages of cover crop adoption are not normally distributed, so we constructed four categories to represent different levels of intensity: none (0%), low (1-33%), medium (34-66%), and high (67-100%). Third, we constructed another ordered logit model to predict farmers' Cover Crop Plans, which represents farmers' intentions to adopt cover crops in the coming three years, ranging from plans to stop using cover crops, maintaining a similar level, trending towards more acres, trending towards more acres and whole farm adoption, or already at whole farm adoption of cover crops. In combination, these models help to reveal information about adoption versus non-adoption, challenges with scaling up adoption, and ongoing use of cover cropping as a practice.

2.4. Statistical analyses

Comparing across the adoption, intensity, and plan models allows us to gain a fuller picture on the difficulties in measuring farm management decisions. For example, looking only at the number of acres would favor

larger farms, while intensity may reveal that there are limitations to the extent of adoption rather than treating it as an all-or-nothing binary variable. Further, plans can help to show how perceptions of cover crops impact farmers' intentions, while also allowing a comparison with actual behavior, both of which are important dimensions in conservation practice adoption research. In all three models we imputed data to deal with missing responses. In the negative binomial regression (Cover Crop Adoption model) we imputed 137 responses as part of a total of 877 observations, accounting for 16% of the total. In the ordered logit regression (Cover Crop Intensity), we again imputed 137 responses as part of a total of 791 observation, accounting for 17% of the total. In the second ordered logit regression (Cover Crop Plans model) we also imputed 137 responses as part of a total of 901 observations, accounting for 15% of the total. We ran the models in Stata, using the `how_many_imputation` package (von Hippel, 2018; Statistical Software Components S458452). We report the coefficients, standard errors, and statistical significance in the Results section. The full model results can be found in Appendix A.

We hypothesized that the following explanatory variables would be positively correlated with the three dependent variables: *increased cash crop yield response*, *program enrollment*, *self-efficacy*, *response efficacy*, *income*, *reduced tillage*, *gender*, *education*, and *convenience sample* (see Table 1). We hypothesized that the following variables would be negatively correlated with our three dependent variables: *negative cash crop yield response*, *crop insurance*, *percent rented*, and *age*. We hypothesized that *farm size* would be positively correlated with cover crop acres but negatively correlated with cover crop intensity. We do not have a theoretical expectation for whether *farm size* would be positively or negatively correlated with future cover crop plans. Similarly, given the mixed findings in the existing literature, we do not have a hypothesis for whether *risk perception* will be positively or negatively correlated with any of the three dependent variables.

2.5. Limitations

The main limitation of our study is the low response rate from the random sample of farmers, which limits the generalizability of our study. Moreover, our sample is skewed in terms of the number of farmers that currently use cover crops compared with the general population of farmers. Non-response bias in the random sample may mean that our random sample is also skewed towards farmers who use cover crops over farmers that do not. However, we are interested in understanding whether farmers that use cover crops see them as a risk-mitigation strategy. The large proportion of cover crops adopters in this study is highly relevant to our research questions. In addition, our survey is also cross-sectional and thus cannot measure adoption over time, only self-reported adoption and intentions to adopt. Lastly, the scope of our study is limited to farmers in the U.S. Cornbelt and does not address international agricultural contexts with varying climate hazards and policy approaches that influence farmers' climate risk perceptions.

3. Results

3.1. Summary of survey sample

The median age of farmers responding to our survey is 64 years old and 95% are male, which is older than the average age of farmers in our study area (56–58.6 years; USDA, 2024). Nearly half of the farmers in our sample completed a bachelor's degree or higher (45%), while the next largest group had earned a two-year college degree or taken some college courses (31%). The smallest group had earned a high school degree (23%) or taken some high school (1%). The median farm size in our study is 575 acres, while sizes range from as small as 20 acres (our minimum size for inclusion) to as large as 20,000 acres. The median farm size in Illinois, Indiana, and Iowa was 100, 56, and 130 acres respectively (USDA, 2024). More than 50% of our sample are farms

between 500 and 5,000 acres, while another one-third of our sample was from farms between 100 and 500 acres. Most farmers in our sample rent at least some farmland. Only 19% own all of the land they farm, while 30% rent some farmland but less than half of their farm. Another 39% rented more than half of their farmland and 12% rented all of their farmland. Farm income is nearly equally split between farms making less than \$350,000 (38%) and farms making between \$350,000 and \$1 million (42%). The remaining 20% earned more than \$1 million. Farmers were asked to list their most common tillage practice. Reduced tillage was the most commonly listed (38%), while zero tillage was second (35%). Conventional tillage was least common (20%). Some farmers marked more than one option on the paper survey, while a few farmers selected "other" for their tillage practices (7%).

More than two-thirds of the farmers who responded to our survey (718 of 1,023) had planted at least some cover crops over the previous five years (2018–2022). Of these, 411 planted cover crops every year, while the remainder had roughly equal numbers of farmers: four years (74 farmers), three years (76 farmers), two years (76 farmers), and one year (80 farmers). In 2022 (the last year of data on cover crops), of 823 complete responses, 35% planted no cover crops, 26% planted at low intensities (less than 1/3 of their farm), 16% planted at medium intensities (between 1/3 and 2/3), and 23% planted at high intensities (>2/3). The mean proportion of farm acres planted in cover crops was 50% of a farm, while median levels were similar at 47% of the farm. Farmers reported cereal rye as the most common type of cover crop by farm (43%). The next largest category was multiple types of cover crops (28%), within which cereal rye was also frequently listed, followed by mixes (14%), legumes (7%), other grasses (6%), and brassicas (2%). The most common response overall, and for the random sample, are plans to increase the amount of cover crops. However, there are substantial differences in the goals among farmers in the different samples. Farmers in the random sample are much more likely to want to *stay the same or decrease* than farmers in the convenience sample, who are much more likely to have a goal of *whole farm* adoption than farmers in the random sample (Fig. 2).

A majority of farmers reported that corn and soybean yields were mostly the same following cover crops (Fig. 3). Nearly three times as many farmers reported soybean yields were often higher than were often lower, while nearly twice as many reported the same for corn yield. A small number of farmers reported that yields for either crop were either always lower or always higher. The main difference between the convenience and random samples was the much higher percentage of farmers in the random sample that answer *Not Applicable* for corn yield responses than did in the convenience sample (61% compared to just 14%). Otherwise, both samples had similar bell curves from *Always Lower* to *Always Higher*, with *About the Same* as the modal response (see Appendix A).

3.2. Cover crops' role in risk mitigation

Based on our three models, *risk perceptions of extreme weather* are not an important factor shaping farmers' decisions on cover crops. This is notable considering the over-representation of farmers using cover crops in both of our samples. In the Cover Crop Intensity model, *risk perception* is statistically significant at the 0.1 level and negatively correlated with cover crop intensity categories. The odds that a farmer would have a one-unit decrease (e.g., medium to low, etc.) in cover crops intensity was 16% greater for farmers with lower *risk perception*. *Risk perception* is not statistically significant in the other two models for the number of Cover Crops Acres planted or future Cover Crop Plans (see Table 2 for all model results). Overall, this indicates that *risk perception* is not a major factor in cover crop decisions.

Response efficacy is a related concept that asked farmers whether they believe that cover crops would be effective in response to extreme weather. Across all three models, *response efficacy* is statistically significant and positively correlated with the dependent variables. It has the

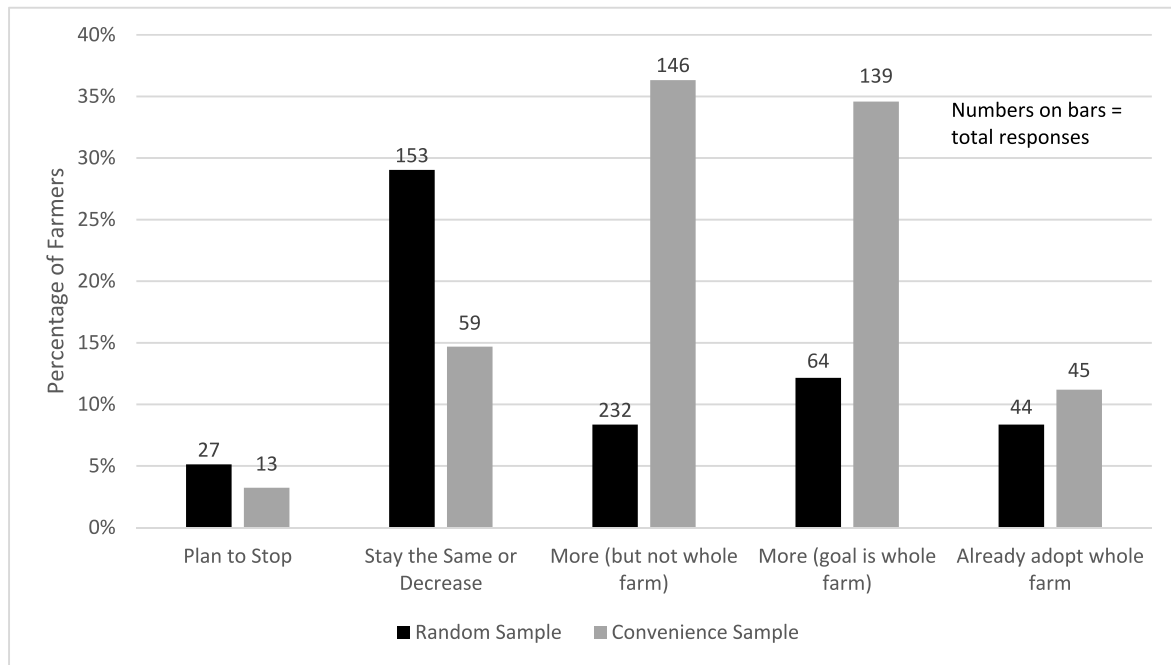


Fig. 2. Farmers' intentions for future cover crop use, comparing random and convenience samples.

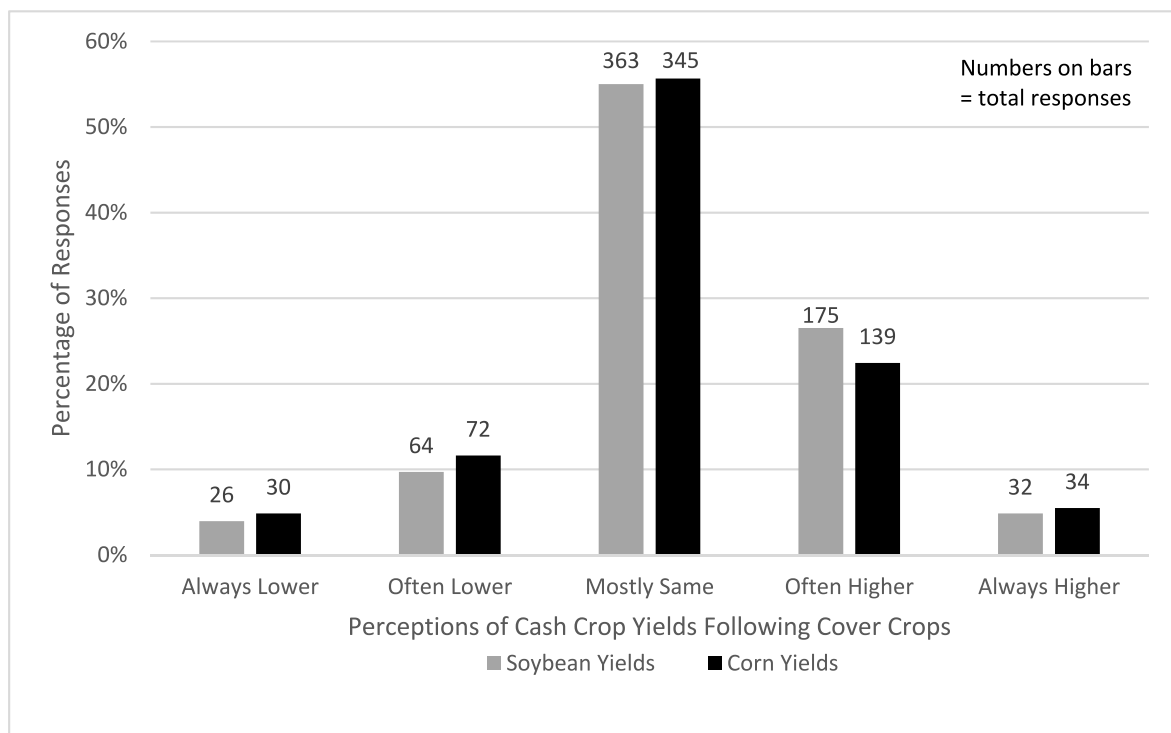


Fig. 3. Farmers' perceptions of corn and soybean yields following cover crops. In our sample, 201 farmers did not plant cover crop before soybeans, while 258 did not plant cover crops before corn. Not applicable responses are excluded from the figure.

biggest effect on predicting future plans, with farmers being 66% more likely to increase cover crops for each one-unit increase in their *response efficacy* beliefs. Farmers are likely to have one-quarter acre more of cover crops as their perceptions of *response efficacy* increase and are 37% more likely to have a higher intensity level.

Self-efficacy and *program enrollment* are statistically significant positive predictors of more cover crops in all three models. *Program enrollment* had the strongest effect, where farmers were more than twice as

likely to have a one-unit increase in intensity category as a farmer that did not participate in a USDA, watershed-based, or commodity-run financial assistance program. For the Cover Crop Acres model, farmers that enrolled in a program are likely to have 1.9 acres of cover crops for each cover crop acre planted by farmers that have not enrolled in a program. *Reduced tillage* was also statistically significant in all three models, indicating that farmers using no-till are nearly 50% more likely to increase their use of cover crops than farmers using reduced tillage. It

Table 2

Statistical models predicting cover crop adoption, intensity, and plans. Variables that are statistically significant across all three models are bolded. For variables that are statistically significant in one or two models, only the coefficient and standard error are bolded.

Dependent Variables (Models)	Cover Crop Intensity (Ordered Logit)		Cover Crop Acres (Negative Binomial)		Cover Crop Plans (Ordered Logit)		
	Explanatory Variables	Odds Ratio (SE)	P-Value	Incidence Rate Ratio (SE)	P-Value	Odds Ratio (SE)	P-Value
Yield Response ^a	–	–	–	–	–	–	–
Lower Yield	0.39 (0.14)	0.000***	0.40 (0.08)	0.000***	0.21 (0.06)	0.000***	
Higher Yield	1.25 (0.22)	0.006	0.99 (0.18)	0.905	1.48 (0.24)	0.017**	
Crop Insurance	1.15 (0.35)	0.642	0.25 (0.18)	0.055*	0.97 (0.24)	0.904	
Risk Perception	0.84 (0.08)	0.089*	0.93 (0.08)	0.356	0.90 (0.08)	0.215	
Program Enrollment	2.08 (0.40)	0.000***	1.90 (0.27)	0.000***	1.52 (0.24)	0.009***	
Self-Efficacy	1.48 (0.11)	0.000***	1.72 (0.17)	0.000***	1.37 (0.12)	0.000***	
Response Efficacy	1.37 (0.11)	0.000***	1.27 (0.08)	0.000***	1.66 (0.12)	0.000***	
Farm Size (Log)	0.69 (0.06)	0.000***	1.55 (0.13)	0.000***	0.95 (0.08)	0.743	
Income	1.13 (0.16)	0.368	1.37 (0.16)	0.007***	0.78 (0.10)	0.045**	
Percent Rented	1.22 (0.33)	0.451	1.04 (0.26)	0.874	1.18 (0.30)	0.523	
Reduced Tillage	1.22 (0.14)	0.087*	1.30 (0.13)	0.007***	1.49 (0.16)	0.000***	
Age	0.99 (0.01)	0.023**	1.00 (0.01)	0.846	0.99 (0.01)	0.102	
Gender	1.27 (0.46)	0.513	1.11 (0.33)	0.721	1.07 (0.36)	0.842	
Education	0.94 (0.05)	0.236	0.89 (0.08)	0.185	0.95 (0.05)	0.290	
Convenience Sample	1.81 (0.33)	0.001***	1.52 (0.22)	0.003***	1.69 (0.29)	0.003***	

^aAbout the same yield response was used as the reference condition.

* Statistical significance at the p = 0.1 level.

** Statistical significance at the p = 0.05 level.

*** Statistical significance at the p = 0.01 level.

also increases the odds by 22% that they will increase their level of intensity and they are likelier to have 1.3 acres for each acre planted by a farmer that uses reduced tillage.

Cash crop yield responses are also important factors for all three models. We used about the same as the reference condition for comparing farmers' experiences with yields. Lower yield response is an important predictor in each model, indicating that farmers are 61% less likely to have higher intensity levels if they have lower cash crop yield responses, while also being likely to have less than one-half acre of cover crops relative to each acre of cover crops planted by farmers whose cash crop yields stay about the same. The odds are also 79% lower that farmers with lower yield responses will plan to increase their cover crop use in the future. Higher yield response was statistically significant only in the Cover Crop Plans model, which indicates that it is distinct from about the same in this last model but is not different for farmers when it comes to the relationship in what farmers actually do on their farms.

A number of variables were statistically significant in one or two of the models. Crop insurance, which some studies have found to conflict with cover crop adoption, was statistically significant and negatively correlated to Cover Crop Acres but not Intensity categories or Plans. Farmers with crop insurance plant 0.25 acres of cover crops for each acre of cover crops planted by farmers that do not have crop insurance. Farm size has a positive effect on the number of overall acres, but has a negative effect on intensity, indicating that while large farms have more acres in cover crops, the intensity of those acres decreases with farm size. Income is statistically significant and positively correlated to increasing the number of acres planted but is negatively related to future plans to increase cover crops. Demographic variables are not statistically significant in any of our models. Age is an exception in the Intensity model. However, its coefficient is so small as to be practically meaningless. Lastly, and notably, the convenience sample was statistically significant and positively correlated with the dependent variables in all three models, indicating that farmers that are connected with state agricultural agencies are more likely to have higher intensities of cover crops, more acres, and plans to increase cover crops in the future. This is consistent with the high coefficients for Program Enrollment in the models.

3.3. Policy preferences for cover crops

Here, we explore the potential for promoting the adoption of cover

crops by linking them to crop insurance through discounted premiums. We asked about farmers' use of and receptivity to this alternative mechanism to promote cover crop adoption. We report descriptive statistics on enrollment in the pilot programs and preferences on program enrollment.

Of the 715 farmers that planted cover crops at least once in the past five years, 543 (76%) received some type of financial assistance, excluding the state and federal crop insurance discount programs. USDA programs were the most common (446 farmers), followed by funding through a commodity organization (228 farmers), watershed grants (210 farmers), and carbon payments (177 farmers). Most of the farmers that received financial assistance had received at least two types (339 farmers). Participation in the state crop insurance discount programs (425 farmers) was almost as common as participation in USDA programs. Farmers enrolling in the state discount programs had mostly participated in another program, but for 77 farmers, the state discount program was the only financial assistance program they enrolled in. We asked farmers to report their cover crop acres for their most recent year of enrollment in the state discount programs. Overall, these 425 farmers reported planting 402 acres on average for their most recent year of enrollment. Of the 77 farmers that had only enrolled in the state discount program, they enrolled on average 353 acres of cover crops in their most recent year of participation. We did not ask farmers to indicate whether they would have planted cover crops in the absence of the discount and so we do not make claims as to whether the discount created any additionality.

Two-hundred and fifty-nine farmers participated in the national PCCP, which also permitted farmers to stack payments by allowing farmers to enroll acres that were already receiving financial assistance payments through another program. There were 151 farmers enrolling all of their PCCP acres in another program, 70 enrolling some of their acres in another program, and 38 enrolling their cover crop acres only in the PCCP. While it is difficult to assess additionally, when we look at the 2018–2022 cover crop levels these farmers reported, there were only 10 farmers who appeared to increase or try out cover crops over 1–2 years, averaging just 44 acres per farm. The remaining farmers appear to maintain steady cover crop levels every year. Of the farmers that enrolled in the PCCP, 61% also enrolled in a state program; this includes 28 of the 38 farmers that reported not enrolling their PCCP acres in any other program. It is possible they interpreted the question to mean other financial assistance programs, excluding crop insurance discounts. For

the farmers that only enrolled acres in the PCCP, they reported an average of 288 acres of cover crops. When we compare the number of acres for farmers participating only in the state or federal crop insurance discount program, those enrollments are higher than the acres planted in 2022 by the 150 farmers that did not use any financial assistance (87 acres on average). Farmers that used only USDA programs for financial assistance planted an average of 317 acres of cover crops in 2022.

Farmers largely report being willing to participate in the state discount programs again (38% of 890 responses) or are interested in participating (31%), while only 2% report that they would not participate again; 20% are not interested in participating and 9% are unsure. For the PCCP, we offered additional response options to collect enrollment data. Of 896 responses, 26% participated and another 12% were interested, while 41% were unaware of the program, 14% were not interested, and 7% marked not applicable, likely due to not having crop insurance.

We also asked farmers about their experiences with USDA cost-share programs, watershed grants (similar to USDA cost-share programs), farm organization programs, and carbon markets. Of the farmers that participated in each of these programs, 5–6 times as many farmers indicated they would participate again versus those who would not participate again. However, a majority of farmers have not participated in a watershed grant, farm organization, or carbon market program. Of those who had not participated, about half to twice as many were interested in participation as were not interested (Table 3).

We also asked farmers to rank their preferences when it came to using these different policy options for promoting cover crops, in which included traditional cost-share programs, crop insurance discounts, stacking program payments, carbon payments, and conservation compliance. This last option is part of the Farm Bill and is quasi-regulatory in that it connects subsidy eligibility, including crop insurance, to maintain certain practices, such as limiting soil erosion and protecting wetlands. USDA cost-share programs were the top choice for 53% of respondents. Crop insurance discount received the most votes for second place. Third place votes were equally split across all of the non-cost-share options, while carbon payments received the largest share of fourth-place votes and conservation compliance received the largest share of fifth-place votes.

4. Discussion: cover crops’ climate adaptation potential

Overall, our findings indicate that farmers do not link extreme weather with their decisions to use cover crops. While *risk perception* plays a small, negative role on cover crop intensity, farmers with *crop insurance* are likely to have far fewer acres in cover crops compared to farmers that do not carry crop insurance. This is an interesting mismatch for the crop insurance discount approach, since farmers who do not use crop insurance are likely to plant more acres of cover crops. At the same time, farmers are generally receptive to the crop insurance discount approach and there is support for the view that cover crops are effective for mitigating extreme weather given the importance of *response efficacy*. The bigger issue may be that farmers do not perceive extreme weather to

be a serious problem for themselves. Haden et al. (2012) found that climate adaptation among California farmers was driven by psychological proximate concerns for local impacts driven by climate change. Since farmers in our sample did not perceive extreme weather events to be a major concern, it is unlikely that this is a strong motivator for cover crops currently.

The importance of *program engagement*, *self-efficacy*, and *response efficacy* indicates that training and positive experiences with cover crops are crucial differences in generating greater adoption. While this finding does not present an obvious solution for dealing with farmers that are not connected with state agencies, or agricultural extension more broadly, it does suggest that expanded technical assistance, more peer-learning networks, and more on-farm research, especially on working farms, could be a worthwhile approach (Jackson-Smith and Veisi, 2023; Sutherland and Marchand, 2021). Our findings that reduced tillage also corresponds with cover crops adoption, intensity, and future plans suggests that farmers may perceive it as part of a set of practices that work well together (Church et al., 2020), which further supports the need for training as a key aspect of scaling up cover crop use. Given the widespread use of crop insurance, providing an opportunity to gain a discount for cover crops would create an opportunity to reach a wider audience on the practice’s risk mitigation benefits.

While some studies have argued that farmers may see cover crops as a type of additional insurance (e.g., Mase et al., 2017), our results suggest that cover crops are not strongly connected to risk mitigation beliefs and are not likely competing or complementing crop insurance at present (e.g., Connor et al., 2022). However, there is some support for the view that farmers who do not use cover crops may see crop insurance as their main risk mitigation tool, given the finding that Cover Crop Acres is negatively related to crop insurance. We would argue that the negative relationship between *farm size* and Cover Crop Intensity also indicates that operators of larger farms are less likely to view cover crops as a risk mitigation tool. For reasons identified in other studies, large farm sizes make it more complicated to manage cover crops given shortcomings in time and labor (Roesch-McNally et al., 2017). Other studies have found farm size to be a predictor of cover crop adoption. However, like Thompson et al. (2021) and Guo et al. (2023), we show the importance of a more nuanced approach to adoption. It is important to note that our study over-represents large farms compared to the median farm sizes in the study area. From a policy perspective, the majority of crop insurance indemnity payments are paid to larger farms (GAO, 2023b). This means larger farms may not be incentivized to adopt measures to mitigate extreme weather.

We also find that farmers who perceive cover crops to harm their cash crop yields are more likely to plant cover crops at lower intensities, on fewer acres, and reduce their cover crop use in the future than those who perceive positive yield outcomes. It is important to note that even among samples over-represented with adopters, negative yield experiences are likely to reduce farmers’ willingness to plant cover crops (Yoder et al., 2021). Another important finding is that the most common response in the descriptive data among both the random and convenience samples was that yields are *about the same*, which we used as the reference condition when comparing *lower* and *higher yield responses*. This may reflect one of the often-cited benefits of using cover crops, which is that they can contribute to improved interannual yield stability (Bowles et al., 2020), by mediating yield drags in dry (Leuthold et al., 2021) and wet (Aglasan et al., 2023; Won et al., 2023) years. In the models, this indicates that farmers who see *higher yield responses* are similar to those that see no effect on cash crop yields. Given that relatively few farmers are using cover crops yet, this suggests there is potential for farmers to have positive experiences with cover crops, which could be supported by more technical assistance and messaging, especially from trusted messengers, that contextualizes how cover crops benefit yields over time to deal with extreme weather. An additional aspect is that we collapsed yield responses for both soybean and corn because many farmers only planted cover crops before one type of cash

Table 3
Farmers’ preferences regarding financial assistance programs and carbon markets.

Program Enrollment	USDA Cost-Share	Watershed Grant	Farm Organization	Carbon Market
Yes (Would Again)	48%	24%	26%	20%
Yes (Not Again)	7%	4%	4%	4%
No (Interested)	22%	37%	42%	42%
No (Not Interested)	17%	22%	19%	27%
Unsure	6%	13%	9%	7%
Total Responses	N = 920	N = 877	N = 869	N = 874

crop rather than for both. Future research should explore how these management differences may affect farmers' perceptions of cover crops. Additionally, quantifying changes in yield responses would add valuable insights as to potential thresholds that farmers see as critical to maintain the practice.

Our descriptive findings that most cover crop adopters perceive neutral or better cash crop responses complicate the picture from previous studies that farmers planting cover crops are routinely experiencing economic losses, even with cost-share subsidies (Thompson et al., 2020; Plastina et al., 2020; Bergtold et al., 2017). Only in situations where farmers used cover crops for livestock grazing, have they experienced positive returns, and then, only in combination with subsidies (Plastina et al., 2018). We did not gauge whether livestock grazing was a factor in this study. Given our over-representation of cover crop adopters, we think it is likely that farmers in our study were either more successful at managing cover crops to not negatively impact yields or they were less sensitive to real or potential financial losses. Future research should continue to explore the extent to which management and training can influence these outcomes, particularly for farmers with either limited experience planting cover crops or based on what goals they want cover crops to help accomplish.

Farm size, income, and reduced tillage all had expected relationships with cover crop outcomes. Our findings support previous research that farmers who used more reduced tillage practices, particularly No-Till, are more likely to plant cover crops (Guo et al., 2023). Similarly, while larger farms are likely to have more acres, they are less likely to have higher percentages of cover crops on their farm, indicating real barriers to scaling up adoption. One policy implication is whether future efforts should focus on increasing intensities of cover crops and particular management challenges that come with larger farms. *Income* also indicates that farmers are more likely to plant cover crops when they have greater financial resources, but that this does not translate into higher intensity and is also negatively related to future plans. In combination, this suggests that larger farms—in both acres and dollars—do not incorporate cover crops into their operations consistently. Given the importance of *reduced tillage*, it seems plausible that environmental values, which we did not measure, or *response efficacy* beliefs are driving farmers' adoption decisions.

4.1. Policy implications of crop insurance discount programs

Our exploratory findings on the crop insurance discount program indicate that farmers are receptive to this policy instrument. However, a limitation in our findings is the large number of farmers that did not know about the PCCP; over time, opinions on the instrument could become more positive or negative as more farmers learn about it. There are two potential benefits for policymakers to consider the ongoing use of a crop insurance discount instrument. The main potential benefit is that because crop insurance is widely used, programmatic decisions will reach a much larger audience. This may provide the best opportunity to reach more farmers with information about cover crops. Even our overrepresented sample of cover crop adopters did not rate carbon markets very highly. While this may not indicate actual opposition, other studies indicate that farmers are skeptical of carbon markets (Strong and Barbato, 2023; Houser et al., 2023). However, a plurality of farmers in our survey indicated they were interested in carbon markets. If policymakers want to pursue an option beyond traditional cost-share programs, linking cover crops to crop insurance offers a viable option, particularly for messaging and exposure to ideas that may not be sought by most farmers. Because crop insurance agents are often also farmers, this approach may be able to leverage peer influence through this policy approach as well, though more research would be needed to know if crop insurance agents are influential, as well as what kind of training would be needed to promote the value of the discount effectively. The second benefit is the potential to increase the number of acres of cover crops that are planted. Sawadgo (2024) found that the Iowa discount

program resulted in an 11% increase in cover crops that would not have existed otherwise. While there is limited evidence so far that discount programs could attract new farmers, farmers' receptivity to discounts could allow the program to be partnered with more educational and technical assistance that might alter these dimensions.

In practice, the pilot programs extended the subsidies that already exist in crop insurance. While this was not a concern for the pilot programs, if the discount programs would become popular, the level of subsidies could become a challenge, requiring caps that cost-share programs currently have. It would be beneficial for researchers, practitioners, and policymakers to consider a mix of policy options to scale up cover crop adoption. The U.S. Government Accountability Office (2023a,b) recommends capping Federal Crop Insurance Program subsidies for farms whose average annual gross income exceeds \$900,000, which would affect fewer than 1% of crop insurance holders but would result in big savings for the program. This could provide an incentive for those large farms to increase their cover crops if a crop insurance discount program were available as an alternative. The most promising finding in this study is that a majority of farmers who plant cover crops reported neutral or beneficial cash crop yields following cover crops. If greater experience and knowledge can lead to these positive outcomes, it is possible that a stronger set of arguments for cover crops can be made on business grounds. Since the biggest difference between our convenience and random samples was the much higher proportion of farmers who had not tried cover crops, finding ways to get farmers started should be a high priority.

5. Conclusions and future research

Our study analyzed whether farmers viewed cover crops as a risk mitigation strategy to deal with extreme weather. We found that farmers did not perceive there to be significant risks of extreme weather but that they did view cover crops as effective in mitigating the consequences of extreme weather. However, we also found that the farmers in our study, which over-represents those using cover crops, largely perceive cover crops as having neutral or beneficial effects on cash crop yields. Farmers' confidence in their ability to adopt cover crops, participation in financial assistance programs, and low intensities of adoption for larger farms, suggest that a focus on technical assistance is a critical aspect for scaling up cover crop adoption. We also find support for the argument that farmers who do not use cover crops may see crop insurance as their main risk mitigation tool. An important challenge for policymakers and practitioners is to emphasize the connection between cover crops and risk mitigation. Crop insurance discounts were ranked favorably by farmers, suggesting that it can be a potentially valuable policy tool for promoting cover crops.

Future research should dig deeper into whether and why perceptions of cover crops' effectiveness change with greater experience, and particularly if there are threshold effects after a certain number of years. Drawing on a framework, such as the transtheoretical model that looks at stages of change in a decision-making process, could shed valuable light on how farmers' observations of their management before and after cover crop adoption, as well as the information they consider in this process, influences both their climate risk perceptions and their perceived self-efficacy (e.g., Doran et al., 2022). Research looking at what role farm management may play in financial gains and losses would also be incredibly valuable to help provide assistance to farmers as they gain experience planting cover crops, but also help to evaluate the financial assistance levels that are necessary or whether cover crops may be financially viable without subsidies. Analyzing differences among farm size, income, and other management practices across different regions would also be important to show how these factors influence climate risk perceptions. This study also provided a glimpse at issues of policy design, findings that farmers in this study are more supportive of cost-share and insurance discount instruments than carbon markets or conservation compliance. Linking crop insurance to cover

crops could provide a valuable opportunity for education and outreach to a larger audience considering that 85% of farmers in the Cornbelt use cover crops. However, a challenge of relying on heavily subsidized crop insurance to promote cover crops is that the discounts represent an expanded subsidy. While the pilot program versions of the discounted premiums did not have any acreage limitations, it is difficult to imagine this remaining were the program to become widely popular. For example, the state of Wisconsin is implementing their own pilot discount program (Wisconsin Department of Agriculture Trade and Consumer Protection, 2024) and national legislation has been introduced as well (NALC, 2024). If the goal is to scale up cover crop use for risk mitigation, future research will need to consider the potential tradeoffs or synergies with other policy approaches.

CRedit authorship contribution statement

Landon Yoder: Writing – original draft, Visualization, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Chloe Wardropper:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Rachel Irvine:** Writing – review & editing, Methodology, Investigation, Data curation, Conceptualization. **Seth Harden:** Writing – review & editing, Funding acquisition, Conceptualization.

Declaration of generative AI in scientific writing

We declare that we did not use any generative AI writing in the creation of this paper.

Declaration of competing interest

The authors have no competing interests to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jenvman.2024.123506>.

Data availability

Data will be made available on request.

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