UNDERSTANDING PRODUCTION RISK OF CONSERVATION TILLAGE PRACTICES

by

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Abstract

This study examines the effects of different degrees of conservation tillage methods on agricultural production losses. To accomplish this objective, we employ a unique county-level panel dataset containing data on conservation tillage acreage, crop insurance losses, and weather variables. The data encompasses corn and soybean production in the states of Iowa and Illinois spanning from 2005 to 2019. We employ the traditional fixed effect econometric model and conducted several robustness tests in the empirical research utilizing disaggregated monthly weather variables and extended duration aggregated weather variables. Evidence indicates that counties with elevated no-till practices tend to have greater overall farm losses, whereas counties with increased reduced till practices are likely to incur lower overall farm losses. Overall, our findings indicate that reduced tillage may mitigate agricultural output risk and serve as an effective climate change adaptation strategy in US agriculture. These results provide insights for policymakers aiming to consider integrating conservation tillage into risk management programs or subsidies more effectively by differentiating subsidies by tillage types.

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Introduction

As the global population continues to grow, agriculture faces the dual challenge of ensuring food security while maintaining environmental sustainability (Robertson and Swinton, 2005). This can be achieved by mitigating production risk using conservation practices. This duality is critical because agricultural systems lie at the intersection of environmental stewardship and food security. Soils play a critical role as the primary medium for food production (Shukle et al., 2019; Kopittke et al., 2019). However, agricultural practices such as intensive tillage have increasingly threatened soil health, putting agricultural productivity and environmental integrity at risk (Stevens, 2018). This has made soil conservation and sustainable farming practices a pressing concern for farmers, policymakers, and the agricultural sector at large.

Conservation tillage practices, minimizing or eliminating soil disturbance by planting directly in the soil with little to no prior soil preparation, emerge as a potential approach to improve soil health and reduce soil erosion (Bolliger et al., 2006; Christoffoleti et al., 2007). While traditional intensive tillage compacts the soil, diminishing pore space, and limiting water infiltration and root development, conservation tillage practices promote the formation of stable soil aggregates and ample pore spaces. This creates an environment where roots can penetrate deeply, facilitating better nutrient and water absorption and allowing for improved air and water movement within the soil. The environmental and economic advantages of implementing soil conservation methods such as no-till farming are likely reflected in increased land values for farms (Chen et al., 2023) and reduced soil erosion (Kwang et. al., 2023). Hence, this might help preserve productivity and supply chain of agricultural products over the years by reducing farmers' risk of crop loss due to soil degradation.

Crop insurance is an agricultural insurance policy that protects farmers from crop losses due to weather and other unprecedented events by paying indemnities as compensation to farmers. Crop insurance is a safety net for farmers in the event of a disaster and it protects farmers from both yield loss and revenue loss depending on the coverage. It is primarily implemented in United States by the Federal Crop Insurance Corporation (FCIC), a division of the United States Department of Agriculture (USDA).

As stated by the USDA's crop insurance at a glance report, crop insurance policies covered 494 million acres of farmland in 2022 crop year. Furthermore, the comprehensive liability of Federal Crop Insurance Program (FCIP) surpasses $193 billion, with the predominant portion of the liabilities attributable to row crops, accounting for 74 percent of insured liability in 2022. Notably, FCIP indemnities by cause of loss in 2022 exceeded 19 billion dollars, a massive surge from the $2.96 billion in 2001. Annual indemnity payments have risen by an average 19.6 percent each year since 2000, demonstrating a growing production risk.

Farmers received more than $143.5 billion in federal crop insurance indemnities from 1995 through 2020, with just under two-thirds paid out for crop damage from drought and excess moisture exacerbated by the climate crisis, according to USDA Risk Management Agency, cause of loss historical data. As climate change causes extreme weather, insurance payment and premium subsidies have increased. As documented in the 2019 USDA report, it is projected that the expenses associated with crop insurance (the portion of total insurance premiums that is subsidized by the Federal Government) could rise by 3.5% to 22% by the year 2080 due to the effects of climate change, regardless of farmers adapting their crop choices and planting locations (Crane-Droesch et al., 2024).

Specifically, Crane-Droesch et al. (2024) determined that the anticipated impact of climate change on crop yields will result in increased costs for insuring corn and soybean. Perry et al. (2020) suggested that rising temperature due to climate change will increase the cost of crop insurance for farmers because the perceived risk of crop failure rises. Given this, it is crucial to gather further evidence regarding the relationship between conservation tillage practice and production risk among corn and soybean farmers. This evidence would play a significant role in bolstering the resilience of US agriculture in the face of climate change and as a result, reducing crop insurance indemnity payments.

Due to the fact that agriculture relies heavily on favorable weather conditions for successful crop yields, the agricultural sector in the United States is highly susceptible to the detrimental effect of climate change. Increasing evidence suggests that climate change has led to a rise in the frequency and intensity of extreme weather events, including floods and droughts, which have had a detrimental impact on crop production in the US (Karl et al., 2009; Walthall et al., 2013). Given the escalating occurrence and intensity of extreme weather events due to climate change, the adoption of sustainable agricultural practices like conservation tillage becomes crucial in preserving and augmenting agricultural productivity in the United States. Research highlights this necessity; for instance, Chen et al., (2021) illustrates that conservation helps in mitigating drought-induced yield losses, leading to improved resilience. Also, Haddaway et al., (2017) indicates that reduced tillage improves soil organic carbon, vital for soil health and productivity, especially during extreme weather events. However, Ogle et al. (2012) assert that no-till methods may reduce agricultural yield especially in areas with elevated precipitation and cooler climates.

As weather extremes and climate variability increase, sustainable farming practices that balance high yields with resilience to extreme weather conditions are becoming increasingly vital for sustainable agricultural production. Notably, the adoption of conservation tillage practices has gained traction over the past decade, according to the USDA Census of Agriculture data. Specifically, the no-till adoption rate increased from 35% in 2012 to 38% in 2022, while other conservation tillage methods (reduced tillage practices) expanded from 27% to 35%. Correspondingly, conventional tillage has seen a notable decline, dropping from 38% in 2012 to 27% in 2022, reflecting a positive shift toward more sustainable agricultural practice, particularly reduced tillage practice. The increasing adoption of these practices reflects growing awareness of their potential benefits for resilience. Evidence indicates that implementation of no-till practices on farms has been shown to enhance resilience against drought, thereby mitigating the risk of low crop yields (Classen et al., 2018).

Research has consistently demonstrated that crop yields are responsive to the impact of climate change (Rosenzweig et al., 2014; Wang et al., 2021, Urban et al., 2015; Zhao et al., 2017; Ortiz-Bobea et al., 2018; Tack et al., 2015; Lobell et al., 2013, D'Agostino & Schlenker, 2016). Skees et al. (2008) indicates that droughts and extreme heat have contributed to around 31% of crop yield losses in the United States. According to Perry et al., (2020), a 1°C increase in temperature is associated with approximately 32% and 11% increase in yield risk for corn and soybeans respectively. Therefore, efficient adaptation of crop production to climate change is essential to mitigate the threats to global food security posed by a growing world population (Wheeler & Von Braun 2013; Ray et al., 2013; Burke & Emerick, 2016).

While numerous studies have demonstrated the benefits of no-till farming for soil health and productivity, there is ongoing debate about its effectiveness in all environmental conditions (Pittelkow et al., 2015; Ogle et al., 2012; Cusser et al., 2020). According to Cusser et al. (2020), the inconsistent results in previous no-till research may be due to differences in soil types, climate conditions, and land management practices that affect how no-till systems function. However, rigorous quantitative evidence on the effect of different degrees of conservation tillage (no-till and reduced till) on overall risk is scarce. Hence, the need for this study. This study assesses the effects of varying degrees of conservation tillage, specifically no-till and reduced tillage, rather than combining them as conservation tillage, as done by Chen et al. (2024). Also, it employs the loss cost ratio (LCR) obtained from crop insurance data as an indicator of production losses, in contrast to the crop yield utilized by Cooray et al. (2021).

This study aims to investigate the extent to which different degrees of conservation tillage practices contribute to mitigating overall risks in corn and soybean production. The empirical setting for this study is agricultural production in Illinois and Iowa states. Based on the 2017 US AgCensus, Iowa and Illinois are the first and second-ranked state in terms of reduced tillage acreage with 10.1 million acres and 9.5 million acres respectively. According to 2022 AgCensus data, these states are prominent agricultural producers, making substantial contributions to U.S. agricultural output and ranking highly in maize and soybean production, accounting for 34.7% and 29.6% of the combined total production, respectively. Additionally, Iowa and Illinois possess a substantial percentage of their agricultural land participating in conservation practices such as adoption of conservation tillage, rendering it a crucial region for assessing the effects of various tillage practices. AgCensus data 2022 indicates that reduced tillage comprises 31% of farmland in Iowa and 33.8% in Illinois, whereas no-till constitutes 28.2% of farmland in Iowa and 24.5% in Illinois.

Furthermore, climate change has significantly affected Illinois and Iowa, resulting in elevated temperatures and precipitation, frequent flooding, and the exacerbation of extreme weather events (Giesting et. al., 2022; Frankson et. al., 2022). The environmental conditions in

Illinois and Iowa render it a pivotal location for investigating the impacts of conservation tillage, as its farmers are at the forefront of adjusting to evolving weather patterns. The specific focus is to examine whether counties that employ higher levels of the various conservation tillage practices (such as no-till and reduced till) are associated with lower crop insurance indemnity payments. In order to accomplish this objective, we create a distinctive panel dataset at the county level, incorporating comprehensive data on planting losses, tillage practices, and weather conditions. Planting loss data is primarily sourced from the Risk Management Agency's (RMA) "cause-of-loss" (COL) data, while information on tillage practices is gathered using satellite-based remote sensing dataset called OpTIS. Also, data on weather variables is obtained from the Parameter-Elevation Regression on Independent Slopes Model (PRISM) climate dataset. The panel data covers 200 counties in Illinois and Iowa state from 2005 to 2019.

We employed a traditional linear panel fixed effect model. This approach allows us to address two key concerns: endogeneity arising from time-invariant unobserved county-specific factors which are accounted for by the county fixed effect, and endogeneity stemming from time-varying unobserved factors that affect all counties in a given year, which are accounted for by the time fixed effect.

Our contribution lies in utilizing a novel longitudinal county-level dataset, enabling a quantitative analysis of the relationship between different degrees of conservation tillage and crop insurance losses across a broader geographical region (Iowa and Illinois) and over an extended time frame (2005 - 2019). Unlike many agronomic studies that typically focus on specific locations and shorter time periods when examining the resilience effects of conservation tillage, our research extends the scope and duration of analysis. This study provides a novel contribution to literature by being the first to include both no-till and reduced-till practices as independent variables in estimating the loss cost ratio (LCR). Previous research focuses on a single conservation tillage type overlooking the potential distinct and combined effects of these practices on production risk (such as Chen et al., 2021). By incorporating both tillage types, this study offers a more comprehensive understanding of how different conservation tillage strategies influence agricultural risk and insurance outcomes. Thus, this approach provides in-depth insights for policymakers and farmers aiming to balance soil health with risk mitigation strategies.

Findings from our study show that that no-till adoption has a positive and statistically significant effect on the magnitude of indemnity payments at the county level while reduced tillage adoption has a negative and statistically significant effect on the magnitude of county-level indemnity payments. Given that annual conservation spending in the United States alone has surpassed 6 billion dollars in recent years (United States Department of Agriculture, 2019), this knowledge enables farmers and governments to optimize conservation strategies, minimizing risk and maximizing benefits.

Literature Review

Conservation tillage, which includes no-till and reduced tillage practices, has garnered global interest in agricultural systems for its capacity to enhance soil health, augment water retention, and lower production costs. Although the advantages of conservation tillage for environmental sustainability are well-established, its effects on agricultural production losses continue to be a prominent focus of research.

The mechanism underlying the positive effects of conservation tillage on soil health involves several interconnected processes. Firstly, the crop residues left on the soil surface create a protective layer that shields the soil from the erosive forces of rain and wind. Secondly, these crop residues decompose, thereby enriching the soil with organic matter. This increase in organic matter enhances the soil structure, leading to improved water retention and greater capacity to hold essential nutrients. This fosters higher microbial activities which facilitate efficient nutrient cycling.

Conservation tillage can enhance water quality by curtailing sediment and nutrient runoff into nearby water sources. It has the potential of improving organic matter, water quality, carbon sequestration and reducing soil erosion, hence, its numerous environmental and economic benefits to farmers, the environment, and the society at large (Stavi et al., 2012; Islam and Reeder, 2014). Conservation tillage increases the soil's ability to retain organic matter for extended periods (Aziz et al., 2013; Helgason et al., 2010). In addition, continued use can make soil have more stable internal structure (Blanco-Canqui & Ruis, 2018), reducing harmful environmental impact and enhancing agricultural productivity (Cusser et al., 2020; Ogle et al., 2012).

The improvement of soil health through conservation tillage has a direct impact on crop yield, productivity, and climate resilience, which include the ability to withstand droughts, floods, and extreme temperatures. As a result, there is a potential for reduced risk and a decreased need for indemnity claims in agriculture through the use of conservation tillage.

A vital component of conservation tillage is its function in maintaining agricultural production in arid climates, especially in areas susceptible to drought Recent study acknowledges the resilience benefits of conservation tillage in the context of climate change. Chen et al. (2021) found no data indicating that conservation tillage adversely impacts corn or soybean yields. The study employing county-level observational data demonstrates that conservation tillage may partially mitigate the anticipated effects of climate change on drought-related soybean yield reductions within the U.S. Corn Belt. This highlights conservation tillage as a strategic method for farmers to reduce climate risk while maintaining productivity in changing climatic conditions.

Deng et al. (2023) performed a five-year investigation in the arid regions of northern China, analyzing various tillage strategies and their impact on soil moisture retention and maize productivity. The research indicated that subsoiling with straw mulch (SUS) was the most efficacious method, markedly enhancing soil water retention and maintaining crop yields amid variable rainfall conditions. Significantly, average yearly maize yields rose by 9.59% with conservation tillage in contrast to conventional tillage. This substantiates the concept that conservation tillage mitigates crop production losses during drought and may even augment yields in moisture-restricted settings.

Pearsons et al. (2023) conducted a thorough study examining the long-term profitability of organic and conventional field crop systems utilizing reduced tillage methods in the Farming Systems Trial (FST) at the Rodale Institute. Their research indicates that minimizing tillage does not substantially influence long-term profitability in either organic or conventional systems. Although gross revenues decreased under reduced tillage, with a 10% decline in conventional systems and a 13% decline in low-input organic systems, diminished input costs offset the revenue shortfall. Consequently, net returns remained consistent. This indicates that conservation tillage can be financially sustainable without increasing crop yield deficits. The manure-based organic system exhibited superior profitability compared to conventional systems, irrespective of tillage methods, suggesting that elements like continuous living cover and manure inputs are more influential on profitability than tillage intensity alone.

Che et al. (2023) corroborate a similar conclusion by assessing the long-term economic effects of no-till adoption over a 23-year dataset. Although yields from no-till farming did not exhibit statistically significant differences from conventional tillage, the diminished operational costs linked to no-till resulted in increased net returns, especially when the method was implemented over extended durations. This suggests that no-till methods, although potentially diminishing short-term yields, enhance long-term financial sustainability by reducing production costs, hence alleviating crop production losses. The advantages of conservation tillage also encompass the enhancement of soil health, which subsequently influences the sustainability of crop production. Piccoli et al. (2023) evaluated the impact of varying tillage intensities on soil physical characteristics in northern Italy. Reduced tillage and no-till methods enhanced soil porosity, hydraulic conductivity, and water penetration capacity, resulting in greater soil moisture retention. These findings corroborate Deng et al. (2023), indicating that better soils resulting from conservation tillage methods mitigate the likelihood of crop production losses, especially in areas vulnerable to water stress.

The implementation of conservation tillage is determined by farmers' opinions of its effects on soil health, risk, and profitability. Ogieriakhi and Woodward (2022) performed a thorough assessment of the motivations behind farmers' adoption or rejection of conservation tillage practices. Their findings indicated that although farmers acknowledge the long-term advantages of conservation tillage for soil health, apprehensions regarding short-term yield fluctuations and upfront expenses impede widespread implementation. This review highlights the necessity of mitigating perceived hazards and offering financial incentives to promote the adoption of conservation tillage practices.

The effects of conservation tillage on production risk have been investigated. Cooray et al. (2023) examined the impact of different tillage intensities on production and yield risk, concluding that conservation tillage typically produced greater average yields than conventional tillage.

Nonetheless, they observed that conservation tillage did not uniformly diminish yield risk, as assessed by variance, skewness, and kurtosis of the yield distribution. This indicates that although conservation tillage can improve average yields, its efficacy in reducing production losses may be contingent upon specific factors, including soil type and climatic circumstances.

The ecological advantages of conservation tillage enhance its significance in mitigating agricultural production losses. Sadiq et al. (2024) established that conservation tillage markedly decreases greenhouse gas emissions in wheat production systems, aiding in climate change mitigation. Conservation tillage enhances soil organic carbon content and improves water retention, so fostering resistance to climate variability, stabilizing crop yields, and mitigating production risks under global climate problems.

Nonetheless, these findings have limits. Numerous studies have demonstrated that conservation tillage functions as a climate-resilient practice, allowing farmers to improve their resilience to extreme weather events (Madarasz et al., 2021; Awada et al., 2014; Ogieriakhi and Woodward, 2022; Rahman et al., 2021; Babu et al., 2023; Alhassan et al., 2021; Dong et al., 2021; Nouri et al., 2021). However, a substantial segment of the current literature on conservation tillage predominantly emphasizes its agronomic benefits, rather than investigating the particular effects of various conservation tillage methods on planting risk and, consequently, crop insurance indemnity payments in the United States. To our knowledge, no research has been undertaken to investigate the direct impact of different levels of conservation tillage methods on insurance indemnity payments, given their acknowledged role in bolstering resistance to catastrophic weather events.

Consequently, our principal contribution is the provision of empirical evidence concerning the correlation between various levels of conservation tillage and the degree of reduced agricultural losses at the county level. This discovery is significant as it enables the quantitative validation of assertions that farmers employing conservation tillage encounter reduced rates of planting loss. The study seeks to examine the extent of the impact that different forms of conservation tillage have on production losses. This research, by showing this advantage, holds significant policy implications for justifying government support of conservation measures, such as conservation tillage. This may result in enhanced adoption of appropriate conservation tillage methods, a decrease in insurance expenditures, and support initiatives aimed at mitigating climate change. This study will augment previous agronomic research that emphasizes conservation tillage as a climate-smart approach.

Data Description

The county level panel dataset used in this study covers 2005 to 2019 and is built from multiple sources. The main dependent variable in our analysis is derived from the county-level crop insurance data made publicly available through the Risk Management Agency (RMA) Summary of Business database. This data has the potential to offer valuable understanding of the magnitude of losses and their causes. Unlike Schlenker and Roberts (2009), we utilized the indemnity-based measure, which is the Loss cost ratio (LCR), given by the ratio of total indemnities over total liabilities. The LCR variable offers a significant benefit over relying on average yields, as it provides a direct assessment of yield risk, rather than just the average performance.

Subsequent to the collection of RMA data, we employ satellite-derived county-level data on conservation tillage adoption rates sourced from the Operational Tillage Information System (OpTIS) database, established by Dagan Inc. and Applied Geosolutions (AGS), now known as Regrow Ag.OpTIS offers satellite-derived data on the use patterns of agricultural conservation measures, such as no-till and reduced till methods, across extensive agricultural regions. OpTIS generates precise, prompt, and spatially extensive annual data on no-till adoption utilizing information from various earth-observing satellites. This data is utilized to evaluate residue levels in the field, with the OpTIS system categorizing them into four classifications: Conventional tillage (0–15% residue cover), reduced tillage with low residue cover (15–30% residue cover), reduced tillage with high residue cover (30–50% residue cover for corn only), and no-till (50% or more residue cover with 30 – 50% non-corn residue cover). No-till practices are typically associated with fields categorized as high residue, reduced till practices with low and moderate residue, and traditional till practices with very low residue. This implies that in this study, reduced tillage adoption rate (RedTill) is the percentage of planted crop acres with 15% to 50% of corn residue cover and 15 to 30% of soybean residue cover and no-till adoption rate (NoTill) (percentage of planted crop acres with 51% or more corn residue and 30 to 50% of soybean residue cover) are obtained from OpTIS database. The OpTIS data are computed and verified at the farm-field level, while ensuring the confidentiality of individual farmers by disseminating only spatially aggregated results at significantly larger sizes (Hagen et al., 2020).

Furthermore, the validation of the OpTIS no-till adoption data was primarily conducted by comparing it with photographic and roadside survey data gathered at the field level across many representative counties (Refer to Hagen et al., (2020) for additional details on the validation methodology). The field-estimated residue cover and OpTIS-estimated residue cover have a 0.683 Pearson correlation coefficient (Hagen et al., 2020). Hagen et al. (2020) illustrate that the OpTIS data exhibit a robust link with the conservation tillage statistics from the agricultural census, evidenced by an 80% correlation coefficient. The reliability of the OpTIS data is further validated by its utilization in recent scholarly works within the field of agricultural economics (e.g., Won et al., 2023, Chen et al., 2021; Chen et al., 2023). The county-level OpTIS data about no-till adoption rates are accessible for all counties in Illinois and Iowa, ensuring comprehensive statewide coverage. The OpTIS conservation tillage data employed spans from 2005 to 2019.

Also, the county level corn and soybean total acres planted, utilized to calculate the conservation tillage adoption rates is sourced from the US Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). Conservation tillage adoption rates are calculated by dividing the acres where conservation tillage is practiced by the total acres planted in each county and used in percentage terms. This is done for both No tillage adoption rate and reduced tillage adoption rate.

Alongside crop insurance, conservation tillage adoption rates and NASS data, we also incorporate weather indicators to serve as control variables in our analysis. The weather data are sourced from the PRISM climate dataset. The PRISM data set is globally acknowledged as one of the finest quality spatial climate data sets available and serves as the official climatological data for the USDA. The pertinent weather variables employed in the investigation comprise: the count of heating degree days (below 10°C, HDD), growing degree days (10–29°C, GDD), cooling degree days (above 29°C, CDD), precipitation (PPT), and the square of precipitation (PPTSQ) (Schlenker & Roberts, 2009). All degree days and precipitation included in this analysis are aggregated across the growth season from May to July. The county-level OpTIS conservation adoption data utilized here covers 200 counties in Illinois and Iowa. The descriptive statistics for the data are summarized in Table 1.

TABLE 1: Descriptive statistics of variables used in the baseline empirical model, 2005 -2019 (n = 5,518)

Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
LCR (%)	18.713	12.886	0.328	112.571
NoTill (%)	22.365	12.130	0.564	67.782
RedTill (%)	50.680	14.484	3.129	88.873
GDD May-July	1004.266	133.794	618.973	1447.708
CDD May-July	6.465	7.961	0	42.901
HDD May-July	1.413	4.368	0	38.931
PPT May-July	353.793	133.522	93.496	755.496
PPTSQ May-July	7092.63	4256.038	339.546	28857.870

Abbreviations: LCR, loss cost ratio; NoTill, No-till adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days

Empirical Estimation

We utilized a fixed effect traditional panel data model for our empirical estimation. We estimate the county-level effect of various conservation tillage adoption, Specifically, no-till (NoTill) and reduced till (RedTill), on loss cost ratio using the following empirical specification:

$$LCR_{it} = \beta 1 Till_{it} + \beta 2 W_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \qquad (1)$$

Where LCR_{it} is the planting loss measure (in %-terms) for county i and year t; $Till_{it}$ is indicator of conservation tillage at i county in t year which are $NoTill_{it}$ and $RedTill_{it}$. Reduced tillage adoption rate is the percentage of planted crop acres with 16% to 50% of residue and No-till adoption rate (percentage of planted crop acres with 51% to 100% residue) are obtained from OpTIS database.

W_{it} is the weather indicator that includes GDD, CDD, HDD, precipitation and precipitation squared — aggregated over the main growing period from May to July in the main model ; $\beta 1$ and $\beta 2$ are parameters to be estimated; α_i is the county fixed effect (FE) to capture unobservable time-invariant variables such as soil characteristics; γ_t is the year fixed effects (FE) to capture time-varying unobservables that affect all counties, such as macroeconomic shocks.

Given the panel nature of the county-level dataset, we utilized the traditional linear panel FE model to estimate the equation. This addresses endogeneity due to time-invariant unobservables (unobservable endogeneity across counties such as soil types) and are absorbed by the county fixed effect (α_i). Furthermore, the time-varying unobservables (such as unobserved macroeconomic shock) that affects all counties in the same way in a particular year are controlled for, by utilizing the time fixed effect (γ_t).

Results

Main Empirical Specification Result

This model estimates how various factors, such as conservation tillage practices, temperature (growing, cooling and heating degree days) and precipitation, affect the Loss Cost Ratio (LCR) in percentage term, which is being used here as a measure of yield risk in agricultural production.

TABLE 2: Impact of conservation tillage practices on production losses: Main regression results from the linear fixed effect (FE) model

Independent variables	**Dependent Variable: LCR (%)**
NoTill (%)	0.052 ** (0.024)
RedTill (%)	-0.082 *** (0.022)
GDD May-July	0.024*** (0.006)
CDD May-July	0.106 *** (0.034)
HDD May-July	0.726 *** (0.049)
PPT May-July	0.009 ** (0.004)
PPTSQ. May-July	0.00003 (0.0001)
Number of Observations	5518
Adj. R^2	0.4113

Note: All columns include county and year fixed effects; standard errors are shown in parentheses; Abbreviations: LCR, loss cost ratio; NoTill, No-till, adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days
$^*p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$

Table 2 reveals that no-till adoption has a positive and statistically significant effect on the magnitude of indemnity payments at the county level while reduced tillage adoption has a negative and statistically significant effect on the magnitude of county-level indemnity payments. This implies that counties with higher levels of no-till are likely to have higher levels of overall farm losses while counties with higher level of reduced till are likely to have lower levels of overall farm losses. This is consistent with Ogle et al. (2012), which stated that no-till can reduce agricultural productivity, particularly in wetter climatic conditions. Furthermore, the result estimated that one percentage point increase in no-tillage adoption will result in approximately a 0.05 percentage point increase in loss cost ratio and one percentage point increase in reduced tillage adoption will result in approximately a 0.08 percentage point reduction in loss cost ratio.

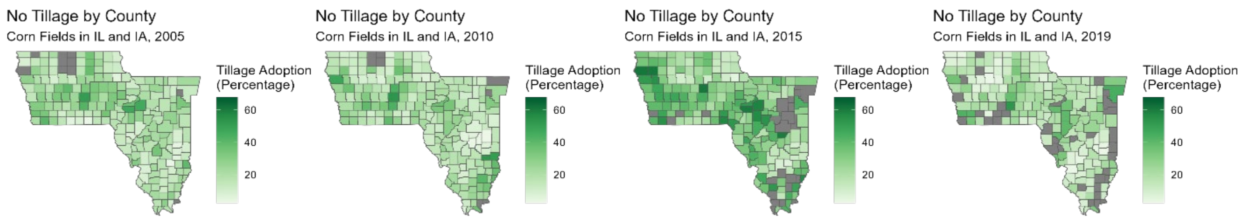
This outcome can primarily be ascribed to the distinctive moisture dynamics in these regions, which no-till techniques tend to exacerbate. No-till agriculture minimizes soil disturbance and preserves crop leftovers on the soil surface, thereby retaining soil moisture, which can postpone essential warming and drying during the early season. In areas such as Iowa and Illinois, elevated moisture levels can impede planting schedules and foster circumstances favorable for diseases and pests, thus diminishing crop yields. The findings align with Ogle et al. (2012), who observed that no-till techniques can diminish agricultural output, especially in wetter climates, hence elucidating the association between no-till and heightened farm losses in this study area.

Conversely, reduced tillage seems to confer a protective benefit against crop loss, as indicated by diminished indemnity payments in counties where it is more prevalent. Reduced tillage entails minimal soil disturbance, enhancing soil aeration and water infiltration, hence facilitating quicker drying and warming of soils in early spring while preserving moisture retention. This balance is especially beneficial in areas such as Iowa and Illinois, where surplus moisture may normally lead to agricultural loss. Reduced tillage enhances soil structure, promotes root development, and mitigates erosion, so fortifying crop resistance against severe weather conditions and resulting in fewer insurance claims.

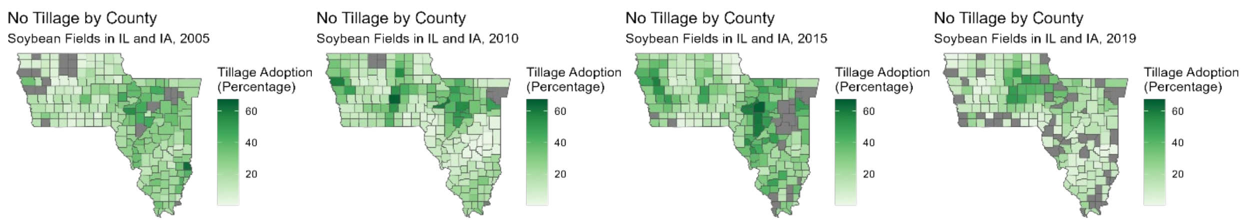
Furthermore, temperature variables also play an important role. Growing Degree Days (GDD) is revealed to be associated with a slight increase in LCR, increasing it by 0.024% for each degree day increment. This might be because warmer temperatures during planting expedite crop growth which affects synchronization with ideal planting condition, increasing susceptibility to pests and diseases. For example, elevated temperatures promote fungal proliferation, heightening disease susceptibility. Cooling Degree Days (CDD) substantially increases LCR by 0.106% for each degree day increase. This signifies elevated summer temperatures detrimental to crops and exacerbating losses. Increased cooling requirements may result in crops becoming stressed from sustained exposure to high temperature, diminishing agricultural yield.

Additionally, Heating Degree Days (HDD) increases LCR by 0.726% for each degree day increase. Lower temperatures during the growing period hinder growth, rendering crops vulnerable to damage. Precipitation slightly increases LCR by 0.009% for each degree day increase. Although water is essential for plant growth, excessive precipitation can foster conditions that promote fungal and bacterial growth, hence increasing disease risks and adversely affecting crop health. Also soil saturation may restrict root oxygenation and nutrient absorption, leading to decreased production.

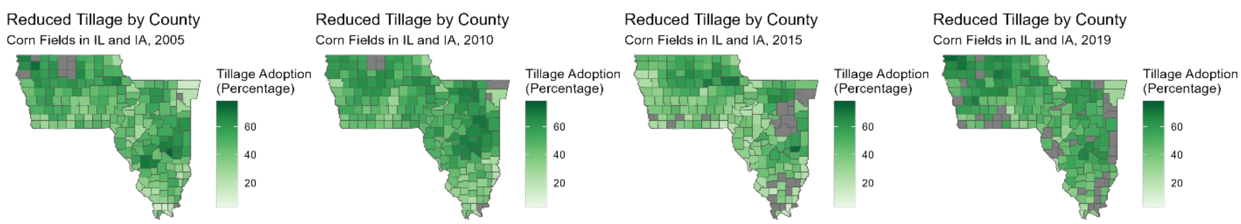
In general, we find evidence that reduced tillage reduces county-level crop insurance losses. However, our result indicates that no-tillage increases county-level crop insurance losses. These results are robust across alternative model specifications. Notably, Figure 1 depicts a significant trend in farmers' preferences for conservation tillage, indicating that the adoption of reduced tillage exceeds that of no-till practices in the study area. This suggests that farmers in the study area prefer reduced tillage over no-till practices. This preference is consistent with our main result, indicating that reduced tillage is associated with lower county level production losses. The fact that reduced tillage is so prevalent in our study areas lends credence to our findings, indicating that the farmers' decisions are influenced by risk management techniques. This underscores the effectiveness of reduced tillage in mitigating production risks.



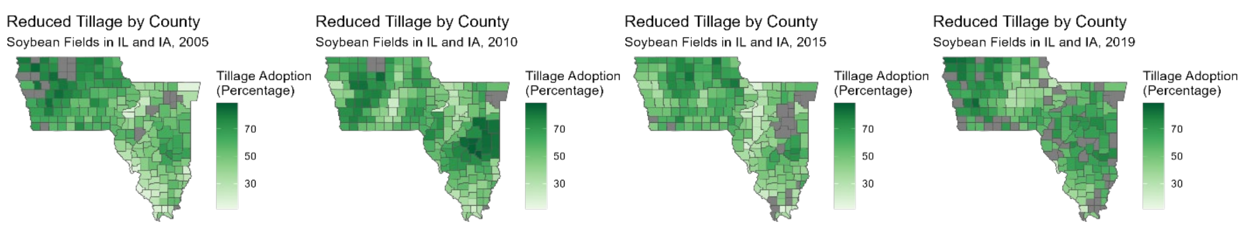
(a) No-till in corn Illinois and Iowa fields



(b) No-till in soybean Illinois and Iowa fields



(c) Reduced Tillage in soybean Illinois and Iowa fields



(d) Reduced Tillage in soybeans Illinois and Iowa fields

Figure 1. Time trend of conservation tillage practice adoption in study region

Monthly Weather Variable Model

This model disaggregates the weather variables by month, specifically for May, June, and July, to capture more precise month-to-month impacts. Utilizing monthly data rather than aggregated data, captures subtle variation in weather patterns, mitigating aggregation bias and enhancing precision. Table 3 indicates that no-till farming has a statistically significant positive impact on county-level indemnity payments, suggesting higher overall farm losses. Conversely, reduced tillage adoption has a statistically significant negative effect, indicating lower losses. These findings align with our main model. The analysis reveals that counties with higher no-till adoption rates tend to experience greater farm losses, while those with higher reduced tillage adoption rates tend to have lower losses.

Specifically, a one-percentage-point increase in no-till adoption leads to approximately a 0.04 percentage-point increase in loss cost ratio and a one-percentage-point increase in reduced tillage adoption leads to approximately a 0.08 percentage-point reduction in loss cost ratio. Additionally, the estimated parameters for weather control variables in our model are largely consistent with expected outcomes.

Additionally, Growing Degree Days (GDD) from May to July positively influence LCR, with May and July exerting very significant effects, indicating that heat during the early and late seasons exacerbates crop losses. In May, elevated temperatures may expedite early growth, increasing vulnerability to pests and illnesses, but in July, thermal stress during reproductive phases likely leads to greater losses. Conversely, Cooling Degree Days (CDD) indicate a protective influence in June, as lower temperatures diminish LCR, likely by fostering robust root and vegetative growth. The beneficial influence of Heating Degree Days (HDD) in June and July further suggests that residual cold conditions hinder crop development, notwithstanding the advancement of the season.

Precipitation (PPT) affects LCR in various ways throughout the months. May precipitation exerts a marginally adverse influence on LCR, indicating that early rainfall facilitates crop establishment, hence reducing losses. Nonetheless, rainfall in June and July exhibits positive correlations with LCR, especially in July, probably because of increased disease risks and soil saturation resulting from moisture accumulation. The squared precipitation term (PPTSQ) for May demonstrates a declining effect, signifying that modest rainfall increases are beneficial until saturation, whereas minor positive impacts in June and July imply that excessive rainfall may worsen production losses. These cumulative monthly effects highlight that climatic circumstances during particular phases of crop development substantially influence resilience.

TABLE 3: Impact of conservation tillage practices on production losses: Regression results from linear fixed effect (FE) model with disaggregated monthly weather variables.

Variable	**Dependent Variable: LCR (%)**
NoTill (%)	0.044 * (0.024)
RedTill (%)	-0.077 *** (0.022)
GDD May	0.038 *** (0.012)
GDD June	0.021 * (0.011)
GDD July	0.064 *** (0.013)
CDD May	0.098 *** (0.035)
CDD June	- 6.735 *** (2.340)
HDD May	13.505 (30.284)
HDD June	4.747 *** (0.512)
HDD July	0.138 * (0.081)

PPT May	- 0.015 * (0.009)
PPT June	0.012 * (0.006)
PPT July	0.026 *** (0.007)
PPTSQ May	-0.0002 (0.0002)
PPTSQ June	0.0001 (0.0001)
PPTSQ July	0.00004 (0.0001)
Number of Observations	5518
Adj. R^2	0.4285

Note: All columns include county and year fixed effects; standard errors are shown in parentheses; Abbreviations: LCR, loss cost ratio; NoTill, No-till adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days
*p < 0.1.**p < 0.05.***p < 0.01

Extended Period Weather Variable Model

This model utilizes weather variables aggregated over an extended period from May to August to assess the effects of broader weather periods. This is because August weather conditions can affect final yield results, especially when corn and soybean reach late reproductive and maturity stages. By integrating August in the model, we aim to capture the comprehensive seasonal impacts of weather on LCR under no-till and reduced tillage practices. Incorporating this period allows the model to ascertain whether no-till or reduced till methods provide resilience or vulnerability in late season climatic conditions. This late-stage impact is especially pertinent for conservation tillage practices, as the cumulative effects of no-till or reduced tillage on soil moisture, nutrient availability, and disease susceptibility may become more pronounced in August, affecting the LCR in ways not pronounced in earlier months.

Table 4 demonstrates that no-till agriculture exerts a statistically significant positive effect on county-level indemnity payments, implying increased overall agricultural losses. In contrast, the adoption of reduced tillage has a statistically significant adverse effect, signifying diminished losses. These results correspond with our primary model. The data indicates that counties with elevated no-till adoption rates generally incur bigger farm losses, whereas those with increased reduced tillage adoption rates usually experience reduced losses.

A one-percentage-point rise in no-tillage adoption results in a about 0.05 percentage-point increase in the loss cost ratio, while a one-percentage-point increase in reduced tillage adoption corresponds to an approximate 0.07 percentage-point decrease in the loss cost ratio. The calculated parameters for weather control factors in our model align with anticipated results. These findings are consistent with our main model, hence, confirming the robustness of our main model. The squared term for precipitation suggests that, in addition to the linear effect, further precipitation does not substantially influence LCR. The value approaches zero, indicating a negligible effect when accounting for increased precipitation levels. Additional extended weather period variable models are included in the appendices.

TABLE 4: Impact of conservation tillage practices on production losses: Regression results from linear fixed effect (FE) model with extended period weather variables

Variable	**Dependent Variable: LCR (%)**
NoTill (%)	0.051 ** (0.024)
RedTill (%)	-0.072 *** (0.022)
GDD May-August	0.018 *** (0.005)
CDD May-August	0.122 *** (0.034)

HDD May-August	0.565 ***
	(0.047)
PPT May-August	0.017 ***
	(0.004)
PPTSQ. May-August	- 0.00007
	(0.0001)
Number of Observations	5518
Adj. R^2	0.4051

Note: All columns include county and year fixed effects; standard errors are shown in parentheses; Abbreviations: LCR, loss cost ratio; NoTill, No-till adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days
*p < 0.1.**p < 0.05.***p < 0.01

Policy Implications

This study's findings have significant implications for agricultural policy, especially for the promotion of tillage practices that combine conservation objectives with economic resiliency. The correlation between elevated no-till practices and heightened overall farm losses, contrasted with reduced losses in counties that adopt greater reduced tillage, offers valuable guidance for policymakers aiming to mitigate agricultural production losses in Iowa and Illinois. This pattern corresponds with previous studies, including Ogle et al. (2012), which emphasize the possible disadvantages of no-till techniques in humid regions, where the advantages of soil conservation may be offset by heightened production risks.

No-till, although crucial for minimizing erosion and enhancing long-term soil health, may unavoidably lead to agricultural losses by increasing fields' susceptibility to moisture retention concerns and diseases, particularly in the high-rainfall environments characteristic of Iowa and Illinois. Considering that a one percentage point rise in no-till adoption corresponds to an estimated 0.05 percentage point increase in the Loss Cost Ratio (LCR), policymakers ought to explore balanced strategies that promote soil conservation while mitigating production risks. This may entail motivating farmers who embrace no-till methods to also implement supplementary strategies, such as enhanced drainage systems, disease-resistant crop types, and cover cropping. Such techniques can mitigate moisture retention and insect problems linked to no-till, ensuring that the soil health advantages of this method are achieved without increasing production risk.

The correlation between reduced tillage and diminished farm losses suggests its viability as a more robust technique in the study area climatic conditions. A one percentage point rise in reduced tillage adoption correlates with an approximate 0.08 percentage point decrease in LCR, so providing a compelling rationale for advocating this tillage practice in policies designed to mitigate output losses. Reduced tillage preserves certain soil structure advantages of no-till while providing greater adaptability to field circumstances, hence enhancing crop resilience to fluctuating weather and moisture levels. Agricultural policy can promote a sustainable approach that links conservation goals with loss reduction by incentivizing reduced tillage through subsidies, technical assistance, or cost-sharing initiatives. Policymakers ought to consider providing training on reduced tillage strategies customized to local soil and climate variables, ensuring farmers comprehend how to optimize the advantages of this strategy specific to their farms.

This comprehensive understanding of tillage effects on LCR also emphasizes the significance of region-specific policy formulation. In regions with persistent high rainfall or dense soil types susceptible to waterlogging, no-till practices may require supplementary soil management techniques to mitigate the severity of moisture-related crop losses. Conversely, counties characterized by well-drained soils or less average precipitation may derive greater advantages from no-till practices with diminished risk, facilitating customized strategies that align with regional conditions.

The results endorse comprehensive conservation and climate resilience programs that emphasize adaptability and farmer flexibility. By acknowledging that reduced tillage provides an effective balance between soil protection and productivity, governments can prioritize the promotion of sustainable and economically viable tillage techniques amidst climate variability. This strategy will ultimately enable farmers to make informed and resilient decisions, enhancing both agricultural productivity and environmental stewardship in Iowa and Illinois.

Conclusions and Limitations

This study analyzed the effects of conservation tillage on crop production losses, specifically assessing the influence of no-tillage and reduced tillage adoption on production losses at the county level. The analysis, utilizing county-level data, estimated that a one percentage point rise in no-tillage adoption is associated with a 0.05 percentage point increase in the loss cost ratio. Also, a one percentage point increase in reduced tillage adoption is associated with a 0.08 percentage point decrease in the loss cost ratio. These findings indicate a complex link between conservation tillage methods and production losses, with consequences for both policy and sustainable agricultural practices.

The positive correlation between no-tillage adoption and farm losses indicates that, under specific circumstances, no-tillage measures may not entirely alleviate production risks at the county level. This result may arise from regional environmental conditions or management techniques that interact variably with no-tillage. In areas with poorly drained soils or excessive rainfall during planting, no-tillage may hinder soil warming and postpone planting, which could adversely affect early crop establishment and yield. This research indicates that, although no-tillage has acknowledged advantages, especially for soil conservation and carbon sequestration, its effect on short-term production losses may differ markedly depending on local conditions.

In contrast, the adoption of reduced tillage demonstrates a favorable correlation with diminished production losses, as seen by the reduction in the loss cost ratio. Reduced tillage retains a greater amount of crop residue compared to conventional tillage, while permitting limited soil disturbance, hence enhancing soil health, moisture retention, and resilience to unfavorable climatic conditions. These advantages likely lead to diminished farm losses, underscoring reduced tillage as an effective method for reconciling soil health enhancement with consistent productivity results.

The research indicates that both no-tillage and reduced tillage approaches promote sustainable agriculture management, however they affect crop insurance losses in distinct ways. Reduced tillage consistently yields advantages in minimizing production losses at the county level, rendering it a favorable choice for farmers aiming to improve productivity resilience. The heightened losses linked to no-tillage emphasize the necessity of customizing conservation strategies to local circumstances to optimize both environmental and economic advantages.

These insights can guide future agriculture policy and crop insurance initiatives. Policymakers and insurers might contemplate incentives that emphasize the adoption of reduced tillage, according to its proven capacity to diminish crop insurance losses. Furthermore, extension programs should concentrate on instructing farmers regarding the exact conditions in which no-tillage is most likely to be effective. This comprehensive understanding of tillage effects underpins the advocacy for specific conservation strategies that enhance sustainable production while adeptly mitigating risk.

This study provides empirical insights; nonetheless, it is crucial to acknowledge its limits and provide directions for future research. The analysis primarily examines the correlation between crop production losses and one specific soil conservation practice—conservation tillage. To provide a better comprehension, it might be necessary to capture the simultaneous impacts of supplementary conservation practices such as cover cropping and crop rotation. Furthermore, the study utilizes county-level data and is confined to a certain region in the United States, specifically Iowa and Illinois. Despite these states being significant agricultural regions, integrating farm-level panel data from a wider geographic scope could yield more universally applicable insight.

Future study could improve comprehension by examining the influence of various climate zones on the efficacy of conservation tillage, providing a more customized analysis for distinct agricultural regions. As our analysis is also focused on short-term outcomes, future research should explore longer timeframes to capture the full risk management potential of conservation tillage.

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Appendices

More Extended Period Weather Variable Models

These models utilize weather variables aggregated over an extended period to assess the effects of broader weather periods

TABLE 5: Impact of conservation tillage practices on production losses: Regression results from linear fixed effect (FE) model (April - July)

Variable	**Dependent Variable: LCR (%)**
NoTill (%)	0.056 **
	(0.024)
RedTill (%)	-0.077 ***
	(0.022)
GDD April-July	0.006
	(0.005)
CDD April-July	0.026 ***
	(0.009)
HDD April-July	0.706 ***
	(0.049)
PPT April-July	0.009 ***
	(0.003)
PPTSQ. April-July	- 0.0001
	(0.0001)
Number of Observations	5518
Adj. R^2	0.4082

Note: All columns include county and year fixed effects; standard errors are shown in parentheses; Abbreviations: LCR, loss cost ratio; NoTill, No-till adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days
*p < 0.1.**p < 0.05.***p < 0.01

TABLE 6: Impact of conservation tillage practices on production losses: Regression results from linear fixed effect (FE) model (April - August)

Variable	**Dependent Variable: LCR (%)**
NoTill (%)	0.054 **
	(0.024)
RedTill (%)	-0.070 ***
	(0.022)

GDD April-August	0.002 (0.005)
CDD April-August	0.026 *** (0.010)
HDD April-August	0.552 *** (0.048)
PPT April-August	0.014 *** (0.003)
PPTSQ. April-August	- 0.0002 ** (0.0001)
Number of Observations Adj. R^2	5518 0.4016

Note: All columns include county and year fixed effects; standard errors are shown in parentheses; Abbreviations: LCR, loss cost ratio; NoTill, No-till adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days
*p < 0.1.**p < 0.05.***p < 0.01

TABLE 7: Impact of conservation tillage practices on production losses: Regression results from linear fixed effect (FE) model (April – September)

Variable	**Dependent Variable: LCR (%)**
NoTill (%)	0.056 ** (0.024)
RedTill (%)	-0.071 *** (0.022)
GDD April-September	0.004 (0.004)
CDD April-September	0.029 *** (0.009)
HDD April-September	0.501 *** (0.046)
PPT April-September	0.013 *** (0.003)
PPTSQ. April-September	- 0.0001 (0.0001)
Number of Observations Adj. R^2	5518 0.4042

Note: All columns include county and year fixed effects; standard errors are shown in parentheses; Abbreviations: LCR, loss cost ratio; NoTill, No-till adoption rate; RedTill, Reduced tillage adoption rate; PPT, Precipitation; PPTSQ, Precipitation square; GDD; Growing degree days, CDD; Cooling degree days; HDD; Heating degree days
*p < 0.1.**p < 0.05.***p < 0.01