Understanding Farmers' Perception of Extreme Weather Events and Adaptive Measures

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Chinonso Ezenwa Etumnu
Kentucky State University

Tong Wang
South Dakota State University

Hailong Jin
South Dakota State University

Heidi Sieverding
South Dakota School of Mines and Technology

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Understanding farmers' perception of extreme weather events and adaptive measures

Chinonso Etumnu [a], Tong Wang [e,*], Hailong Jin [e], Heidi L. Sieverding [b], Jessica D. Ulrich-Schad [c], David Clay [d]

[a] School of Agriculture, Communities, and the Environment at Kentucky State University, Frankfort, KY, United States
[b] Department of Civil and Environmental Engineering at South Dakota School of Mines and Technology, Rapid City, United States
[c] Department of Sociology & Anthropology at Utah State University, Logan, UT, United States
[d] Department of Agronomy, Horticulture and Plant Science at South Dakota State University, Brookings, SD, United States
[e] Ness School of Economics and Management at South Dakota State University, Brookings, SD, United States

A R T I C L E I N F O

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A B S T R A C T

Extreme weather events have cost lives and financial losses across the United States. Moreover, they are expected to increase in frequency, and this will exacerbate their impact on vulnerable sectors such as agriculture. But how farmers could adapt to extreme weather events by adopting different conservation practices has received slight attention in the literature. This study examines how farmers' perceptions of drought and flooding influence their decisions to implement conservation practices in their conventional crop fields. Out of the 350 farmer responses we received, fewer than half indicated a likelihood to adopt no-tillage/reduced tillage (43%), cover crops (40%), crop diversification (37%), and integrated crop-livestock grazing (29%). Using this data and a multivariate probit modeling framework, we show that farmers' decisions can be partly explained by their perception of drought but not by their perception of flooding. Specifically, the perceived number of drought years significantly increases the likelihood of adopting no-tillage/reduced tillage and diversified cropping in the future. However, the number of drought years is not significantly associated with the use of cover crops and integrated crop-livestock grazing. These results suggest that the effects of extreme weather events on adoption of conservation practices as adaptive measures vary across different practices. Therefore, adaptation policies that make use of conservation practices must be tailored to farmers' needs and priorities to be effective.

1. Introduction

From 2016 to 2020, droughts, floods, freezes, storms, tropical cyclones, and wildfires, cost 3,969 lives and resulted in financial losses of over $630 billion in the United States (U.S.) (NOAA-NCEI, 2021). Moreover, these events are expected to increase in frequency, which will exacerbate their impact on vulnerable sectors such as agriculture. For example, crop and rangeland losses in the U. S. resulting from extreme weather events were estimated at $6.5 billion in 2020 (Market Intel, 2021a). This estimate does not even include losses to livestock, horticulture, timber, and damage to farm infrastructure (Market Intel, 2021a).

* Corresponding author at: Ness School of Management & Economics, Harding Hall 201, Box 2220, Brookings, SD 57007, United States.
E-mail address: tong.wang@sdstate.edu (T. Wang).

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Several studies have raised awareness about the increased frequency and prevalence of extreme weather events across the U.S. (Duffy and Tebaldi, 2012; Wang et al., 2019). For example, about 96 percent of farming land in Arizona, California, Idaho, Montana, Nevada, Oregon, and Washington was experiencing some form of drought as of September 2021 (Frank, 2021; Pappas, 2021). In addition, 2021 marked the second year of a regional drought in the Midwest (Woloszyn et al., 2021). Besides drought, flooding has impacted farmers across the U.S. For example, in 2019, the Mississippi River, Midwest, and Southern flooding resulted in losses of $6.2 billion, and millions of acres were not planted (NOAA-NCEI, 2021), and in 2021, Hurricane Ida led to $700 million in crop losses in the Northeast and mid-Atlantic regions (Market Intel, 2021b). These exmples illustrate the challenges posed by drought and flooding to the U.S. agricultural sector and the need for government policies to help farmers adapt to such challenges.

A strand of literature attempts to precisely estimate the impacts of drought and flooding in the U.S. (Motha, 2011; Wang et al., 2019; Kuwayama et al., 2018; McCarl and Hertel, 2018; Deschênes and Greenstone, 2007; Troy et al., 2015; Aragon et al., 2021; Wang et al., 2017; Powell and Reinhard, 2016). For example, Kuwayama et al. (2018) found that drought has an overall negative impact on the yield of corn and soybeans while Hodge (2021) found that flooding reduced land prices in the Fargo-Moorhead area. The projected increase in frequency of extreme weather events and associated economic losses necessitate adaptive responses that enable farmers to prevent and mitigate the losses (Rose, 2015; Walsh et al., 2014; Wang et al., 2019). Such adaptive measures include the implementation of conservation practices (such as no-till/reduced tillage, cover crops, diversified cropping, integrated crop-livestock grazing, and conversion from cropland to grassland) on conventional crop fields (Huang et al., 2015; Ding et al., 2009). By affecting nutrient and water cycling, the adoption of conservation practices can increase soil resilience to both drought and flooding (Clay et al 2015; Clay et al, 2012). For example, Clay et al. (2015) showed that reductions in tillage intensity resulted in higher soil organic matter which increased water storage in soil and higher yields during the 2012 drought in South Dakota (SD).

Farmers' decision to adopt conservation practices may depend on their benefits in mitigating the impacts of drought and flooding. For example, no-till/reduced tillage and cover crops conserve the appropriate amount of water in the soil, thereby maintaining soil health and enhancing crop productivity (Arbuckle, Morton, and Hobbs, 2015; Hoorman and Sundermeier, 2017; Jasa, 2013). This benefit of conservation practices has also been showcased in studies such as Ding et al. (2009). Using county data from Iowa, Nebraska, and South Dakota, Ding et al. (2009) estimated the impact of drought and flooding on the adoption of conservation tillage. They found that recent drought increased the adoption of conservation tillage systems whereas spring floods reduced their adoption. However, because Ding et al. (2009) was based on the adoption of conservation practices at the county scale, they could not provide site-specific details on where, what, and why conservation practices were or were not adopted. Therefore, the purpose of this study was to overcome these barriers. Compared to Ding et al. (2009), our study provides a broader view of the influence of extreme weather events by focusing not only on conservation tillage but also on a range of other conservation practices.

Because South Dakota is in a transitional climatic region and experiences high variability in both temperature and precipitation, the state is ideal for assessing the potential effects of extreme weather events on farmers' adaptive measures (NOAA, 2016). Drought and flooding are the major extreme weather events affecting SD, an intercontinental region where short- and long-term weather patterns historically have alternated between drought and flood, yet climate change has amplified these cycles (Van Aalst, 2006; Drought.gov, 2021). For example, the most recent drought situation in SD shows that as of September 16, 2021, 72 percent of the state was in at least moderate drought, 42 percent was in drought, and 11 percent was in extreme drought (Rippey, 2021). Farmers' ability to respond to drought is confounded by intermittent flooding, such as the most recent 2019 Midwestern flood, which affected 20 million acres of farmland (Higgins, 2019).

In this study, our objective is to examine how farmers' perceived frequency of drought and flooding influence the adoption of conservation practices. We hypothesize that SD farmers' likelihood of using conservation practices in the future will be influenced by their perceptions of drought and flooding. Previous studies have attempted to establish this association. For example, Wallander et al. (2013) associated participation in conservation programs (Conservation Reserve Program and the Environmental Quality Incentives Program) with drought. They found that farmers who are most affected by drought are more likely to participate in conservation programs. We build our hypothesis on this finding and examine whether drought and flooding could influence the future use of conservation practices in SD. Using survey data from 350 farmers in SD and a multivariate probit modeling framework, our results indicate that the number of drought years influence the adoption of conservation practices, but the number of flooding years does not influence the adoption of conservation practices. These results suggest that flooding and drought may have different impacts on conservation practice adoption. Thus, extreme weather adaptation policies that focus on conservation practices need to acknowledge the disparity in farmers' responses to flooding and drought.

2. Materials and methods

2.1. Empirical model

We assumed that a farmer's adoption decision hinges on whether the utility he/she receives from adopting (A) the conservation practice (U_i^A) exceeds the utility he/she receives from not adopting (N) the conservation practice (U_i^N). Farmer i is likely to use the practice in the next five years if $\Delta U_i = U_i^A - U_i^N > 0$ and is unlikely to use the practice in the next five years if $\Delta U_i < 0$. Farmer i is "not sure" whether he is likely or unlikely to use the conservation practice if $\Delta U_i = 0$. For each conservation practice, we grouped the farmers into 0 = unlikely, 1 = not sure, and 2 = likely, and estimated a multivariate probit model of the following structure:

Table 1
Likelihood of Making Changes to Conventional Crop Fields affected by Drought/Flooding.

	Very Unlikely	Unlikely	Not Sure	Likely	Very Likely
No-till/reduced tillage	19%	13%	25%	30%	13%
Use cover crops	15%	12%	33%	33%	7%
Diversify cropping	13%	15%	34%	28%	9%
Integrate grazing	33%	17%	21%	21%	8%

Table 2
Variable Description.

Variables	Description	N	Mean	Std	Min	Max
Dependent Variables						
No-till/reduced tillage	Future use of no-till/reduced tillage, 0 = Unlikely, 1 = Not Sure, 2 = Likely	318	1.104	0.862	0	2
Cover crops	Future use of cover crops, 0 = Unlikely, 1 = Not Sure, 2 = Likely	315	1.133	0.811	0	2
Diversified cropping	Future use of diversified cropping, 0 = Unlikely, 1 = Not Sure, 2 = Likely	314	1.096	0.806	0	2
Integrated grazing	Future use of integrated grazing, 0 = Unlikely, 1 = Not Sure, 2 = Likely	313	0.802	0.866	0	2
Independent Variables						
Experience with Extreme Weather Events						
Drought prevalence	Years of extreme weather events, 1 = None, 2 = 1, 3 = 2–3, 4 = 4–5, 5 = 5+	332	2.370	0.772	1	4
Flooding prevalence	Years of extreme weather events, 1 = None, 2 = 1, 3 = 2–3, 4 = 4–5, 5 = 5+	335	3.161	0.795	1	5
Farmers' Perceptions						
Online decision support tools	Use online support tools that integrate weather/climate information, 0 = No, 1 = Yes	341	0.510	0.501	0	1
Soil health concern	Importance of improved soil health, 1 = Not Important, 2 = Slightly Important, 3 = Somewhat Important, 4 = Quite Important, 5 = Very Important	336	4.164	0.908	1	5
Farm staying in the family	It is important to me that the land I farm stay in the family, Strongly Disagree = 1, Somewhat Disagree, Somewhat Agree = 3, Strongly Agree = 4	339	3.555	0.733	1	4
My watershed	How beneficial are conservation practices are on the natural environment, 1 = Not Beneficial, 2 = Slightly Beneficial, 3 = Moderately beneficial, 4 = Very Beneficial	333	3.207	0.738	1	4
Farm and Farmers' Characteristics						
Farm management decisions	Years making farm management decisions, 1 = <5 years, 2 = 5–10 years, 3 = 11–20 years, 4 = 21–30 years, 5 = More than 30 years	291	4.137	1.169	1	5
Primary operation in 2020	Do you consider farming as your primary occupation in 2020?	290	0.762	0.427	0	1
Gross operation sales	Level of gross operation sales in recent typical years, 1 = Less than \$50,000, 2 = From \$50,000 up to \$99,999, 3 = From \$100,000 up to \$249,999, 4 = From \$250,000 up to \$499,999, From \$500,000 up to \$999,999, and 6=\$1 million or more	283	3.265	1.550	1	6
Weather and Soil Characteristics						
Temperature	Average temperature for a 30-year period in Celsius (May-September)	350	18.905	0.737	17.909	20.247
Precipitation	Average precipitation for 30 years in illimetres (May-September)	350	419.707	38.217	337.291	491.724
Slope	Slope of the field (degrees)	350	2.96	1.494	1.004	9.853

$$Y_i = \begin{cases} 0, if -\infty < Y_i^* \le \alpha_{i,1} \\ 1, if \alpha_{i,1} < Y_i^* \le \alpha_{i,2} \\ 2, if \alpha_{i,2} < Y_i^* \le +\infty \end{cases} \quad (1)$$

where Y_i is the observed variable and Y_i^* is the latent variable, with $i \in \{1,2,3,4\}$ and denotes the four respective conservation practices: no-tillage/reduced tillage, cover crops, diversified cropping, and integrated crop-livestock grazing.

To investigate the factors that potentially explain farmers' likelihood to use conservation practices, we modeled the latent variable Y_i^* as below:

$$Y_i^* = X\beta_i + \mu_i \quad (2)$$

where X denotes a vector of explanatory variables that can explain farmers' likelihood to use the management strategies, β_i denotes a vector of coefficients corresponding to the independent variables, and μ_i is the error term. The explanatory variables, selected based on our hypotheses and the literature, are listed in Table 3. They include frequency of extreme weather events (drought and flooding), farmers' characteristics (experience and primary operation), farm characteristics (gross sales), farmer perceptions (soil health, benefits to watershed and succession), and weather and soil characteristics (precipitation, temperature, and slope). The coefficients and standard errors of each of these variables were estimated using multivariate probit models. We also estimated the marginal effects of the explanatory variables because of the difficulty in interpreting the probit estimates directly. The error term μ_i are assumed to be

Table 3
Correlation Matrix of Conservation Practices and Perceptions about Drought and Flooding.

	No-till/reduced tillage	Use cover crops	Diversify cropping	Integrate grazing	Drought	Flooding
No-till/reduced tillage	1					
Use cover crops	0.431***	1				
Diversify cropping	0.308***	0.499***	1			
Integrate grazing	0.162***	0.406***	0.394***	1		
Drought	0.166***	0.101*	0.112**	0.111*	1	
Flooding	0.084	0.049	0.067	0.010	0.064	1

Note: *, **, and *** represent $p < 0.10$, $p < 0.05$, and $p < 0.01$, respectively.

correlated across the conservation practice equations.

2.2. Survey and data description

In 2018, we surveyed 3000 representative SD farmers who participated in the Farm Service Agency program of the U.S. Department of Agriculture. The farmers were sent a web link to complete the survey, and those who did not respond online were then mailed questionnaires. Out of these 3000 farmers, we received 708 responses—a 30 percent response rate. In 2021, we resurveyed 687 producers (we were not able to resurvey 21 respondents, as they did not return with the unique codes we provided) and 94 were either undeliverable or farmers that indicated that they were no longer farming. Out of 593 eligible producers, we received 350 responses from the 2021 survey, achieving a 59 percent response rate. The 2021 survey was carried out shortly after the 2019 flooding when approximately 40% of the state was not planted due to high rainfall and cool conditions.

The 2021 survey contains questions on farm characteristics, conservation practices, farmer demographics, drought and flooding, and their impacts. Specifically, the survey elicited the perceptions of farmers about the prevalence of drought and flooding in their county. It also asked the farmers about the perceived impacts of these extreme weather events on crop yields and acreage planted. Another set of questions delves into the likelihood of using different conservation practices in the future as a response to the prevalence of drought and flooding in previous years. These survey questions allow for an analysis that associates the adoption of conservation practices with the perceived prevalence of extreme weather events.

We merged publicly available information with farmers' survey responses, which include temperature, precipitation, land slope, and other factors that could also affect the adoption of conservation practices (Wang et al., 2021a). Average annual precipitation and temperature for the growing season were collected at the county level from 1988 to 2017. The data on temperature and precipitation were collected from the Parameter-elevation Regressions on Independent Slopes Model. We also collected farm slopes by matching farmers' addresses with information from the gridded Soil Survey Geographic database (Wang et al., 2021a).

To assess farmers' likelihood of using conservation practices in the next five years, we asked them to rate their likelihood of adopting no-till/reduced tillage, cover crops, diversified cropping, and integrated crop-livestock grazing. Five rating categories were available to the farmers: "Very Unlikely", "Unlikely", "Not Sure", "Likely", and "Very Likely". Although the five categories provide useful information, some of them ended up with few observations (Table 1). Therefore, we regrouped the categories from five to three, merging "Very Unlikely" and "Unlikely and "Very Likely" and "Likely". We then summarized farmers' responses using the three resulting categories: "Unlikely", "Not Sure", and "Likely". For example, Table 1 reports that 43 percent of the farmers are "Likely" to use no-till/reduced tillage in the next five years as a response to extreme weather events. Similarly, 40 percent and 37 percent of the farmers are "Likely" to use cover crops and diversified cropping, respectively. Finally, 29 percent of the farmers are "Likely" to integrate crop-livestock grazing in their farms. Table 1 also provides information on the percentage of farmers who are "Not Sure" and those who are "Unlikely" to use the conservation practices.

Table 2 presents a summary of the dependent and explanatory variables. The dependent variables, which indicate farmers' likelihood of adopting different conservation practices, are grouped into three levels: 0 = unlikely, 1 = not sure, and 2 = likely. We first hypothesize that an increase in the frequency of severe drought and severe flooding will increase the likelihood of farmers to adopt conservation practices.[1] This is because we believe that farmers are responsive to extreme weather events and will adopt conservation practices as one strategy to curtail their impacts. We also hypothesize the effects of other explanatory variables on the adoption of conservation practices. For example, we included the number of farm decision years, which ranges from 1=" Less than 5 years" to 5="More than 30 years", as a control variable. The expected role of this variable in the adoption of conservation practices is ambiguous. This is because experienced farmers may be more likely to use conservation practices, but older and more experienced farmers may also be hesitant in experimenting with new practices (Bergtold et al., 2012). The respondents were also asked whether farming was their primary occupation in 2020. This question captures the dedication and time commitment of the farmers, as this could affect the level of investment they would be willing to make on their farms. Thus, we hypothesize that farmers whose primary occupation is farming would be more likely to use conservation practices in the future. Previous research has shown that bigger farms have more leverage to invest in conservation practices (Prokopy et al., 2019). Therefore, to control the effect of economies of scale on farmers' decisions, we include the gross operation sales variable, which ranges from 1 = Less than \$50,000 to 6=\$1 million or more.

[1] The exact survey question asks farmers "In the county you primarily operate in, please check the number of years in which a severe drought or severe wet conditions occurred between 2011 and 2020.".

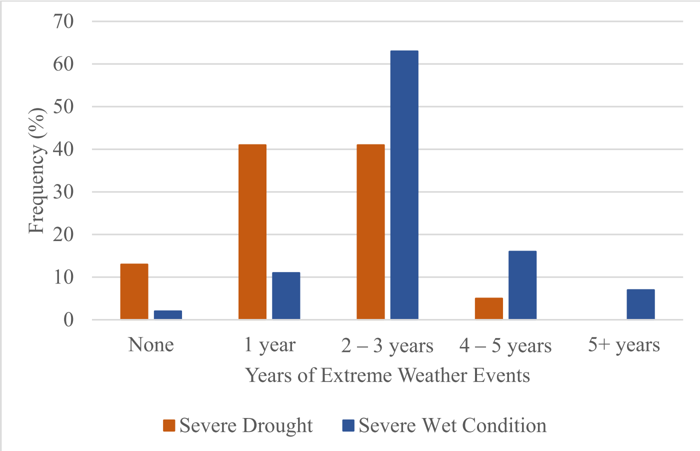

Fig. 1. Perceived Prevalence of Drought and Flooding from 2011 to 2020.

We also controlled for the potential effects of climate on farmers' decisions to adopt conservation practices. To do this, we included 30 years of growing season (May-September) average temperature and precipitation. Additionally, we included the slope of the field to capture the terrain variability, which is an indicator of soil erosion. A steeper field is more likely to erode, thus we controlled for the possible effect of steeper fields on the adoption of conservation practices.

We asked farmers whether they use online tools that integrate weather/climate information in their decision-making. Because online decision tools provide guidance and advice that can help improve farm productivity, farmers who use such tools are hypothesized to be more likely to use conservation practices in the future. Farmers' concerns about soil health were also included as an explanatory variable. When farmers treat soil health seriously when making farm management decisions, we expect them to be more likely to adopt conservation practices. Therefore, we asked respondents to rate the importance of soil health on their soil conservation practice adoption decisions from 1="Not Important" to 5="Very Important". In addition, farmers were asked whether the land they farm will stay with their families. They can choose from four levels of agreement: "Strongly Disagree", "Somewhat Disagree", "Somewhat Agree", and "Strongly Agree". We hypothesize that farmers who are willing to leave a legacy of healthy land for their children are more likely to adopt conservation practices. Respondents were also asked to state how beneficial they believed adopting conservation practices on their land is to their watershed. The options for the farmers to choose ranged from 1="Not Beneficial" to 4="Very Beneficial". Farmers who view conservation practices as more beneficial to their watershed are hypothesized to be more likely to use conservation practices in the future.

3. Results and discussion

Of the dependent variables presented in Table 2, the mean values are 1.104 for no-till/reduced tillage, 1.133 for cover crops, 1.096 for diversified cropping, and 0.802 for integrated crop-livestock grazing. As the mean values for no-till/reduced tillage, cover crops, and diversified cropping are more than one, this implies farmers are inclined to use the conservation practices in the next five years.

Among the explanatory variables used in the study, the mean values of drought and flooding are 2.370 and 3.161, respectively (Table 2). This indicates that on average, farmers perceived more flooding than drought during the 2011–2020 period. Fig. 1 shows farmers' perceived prevalence of drought and flooding in their counties from 2011 to 2020. Farmers' responses for the 10-year interval were grouped into five categories: "none", "1 year", "2–3 years", "4–5 years", and "5 + years". Most farmers reported drought in their counties for "1 year" (41%) and "2–3 years" (41%), while the remaining farmers reported drought for "4–5 years" (5%). In addition, 63% of the farmers reported flooding for "2–3 years", while 16%, 11%, and 7% of the farmers reported flooding for "4–5 years", "1 year", and 5 + years", respectively. These values indicate a cyclical variability in drought and flooding in SD from 2011 to 2020, which is confirmed by Drought.gov (2021). Within the ten-year interval, there were about 4 to 6 documented dry and wet cycles in SD and some of these cycles were more than others (see appendix).

In terms of farmer characteristics, the mean value of years of experience making farm management decisions is 4.137. This indicates that the farmers on average had 21–30 years of farm management experience. On average, three-quarters of the farmers (76%) consider farming as their primary operation in 2020. A mean value of the gross operation sales at 3.265 indicates a gross operation sales level slightly above the "$100,000 - $250,000" range. Table 2 also presents a summary of the weather and soil characteristics. The average annual precipitation is 420 mm with a minimum of 337 mm and a maximum of 492 mm, and the average temperature is 19 degrees Celsius. The average slope of the field is 2.96 degrees, which indicates most of the surveyed farms are suitable for cultivation and less susceptible to soil erosion (Wang et al., 2021c).

Other explanatory variables in Table 2 include the use of online weather/climate decision tools, concern about soil health, farm succession, and benefits to the watershed. A mean value of 0.510 for the use of decision support tools indicates that slightly more than half of the farmers use online tools that integrate weather/climate information. The mean value for the importance of improved soil

Table 4
Factors Influencing the Use of Conservation Practices.

	(1) Use no-till or reduced tillage	(2) Use cover crops	(3) Diversify cropping	(4) Integrate grazing
Extreme Weather Events				
Drought Prevalence	0.248**	0.126	0.236**	−0.025
	(0.114)	(0.108)	(0.109)	(0.113)
Flooding Prevalence	0.067	−0.028	−0.009	−0.075
	(0.107)	(0.106)	(0.104)	(0.111)
Farmers' Perceptions				
Online Decision Support Tools	0.314*	0.244	−0.035*	0.003
	(0.164)	(0.160)	(0.097)	(0.167)
Soil Health Concern	0.176*	0.061	−0.035	−0.201**
	(0.097)	(0.094)	(0.097)	(0.098)
Farm Staying in the Family	0.058	0.197*	0.192*	0.085
	(0.107)	(0.105)	(0.105)	(0.111)
Benefits my watershed	0.295**	0.341***	0.189	0.298**
	(0.117)	(0.114)	(0.113)	(0.118)
Farm and Farmer Characteristics				
Farm Management Decisions	−0.000	−0.059	−0.025	−0.011
	(0.073)	(0.070)	(0.069)	(0.071)
Primary Occupation	−0.459*	−0.259	0.421*	−0.063
	(0.238)	(0.225)	(0.223)	(0.229)
Gross Sales	0.189***	0.112*	−0.067	−0.014
	(0.062)	(0.060)	(0.059)	(0.062)
Weather and Soil Characteristics				
Average Temperature	0.092	0.046	−0.115	0.090
	(0.113)	(0.109)	(0.109)	(0.113)
Average Precipitation	−0.005**	0.001	0.002	−0.004
	(0.002)	(0.002)	(0.002)	(0.002)
Slope	−0.012	−0.099*	−0.022	−0.027
	(0.056)	(0.053)	(0.052)	(0.057)
ρ_{12}	0.434***			
ρ_{13}	0.294***			
ρ_{14}	0.089			
ρ_{23}	0.482***			
ρ_{24}	0.455***			
ρ_{34}	0.444***			
Log-Likelihood	−812.4	LR $\mathscr{X}^2(48) = 92.74$		
Number of Observations	223	Prob> $\mathscr{X}^2(48) < 0.001$		

Standard errors in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5
Marginal Effects for the Use of No-Tillage/Reduced Tillage.

	(1) Unlikely	(2) Not Sure	(3) Likely
Extreme Weather Events			
Drought Prevalence	−0.078**	−0.009*	0.086**
Flooding Prevalence	−0.021	−0.002	0.023
Farmers' Perceptions			
Online Decision Support Tools	−0.098*	−0.011	0.109*
Soil Health Concern	−0.055*	−0.006	0.061*
Farm Staying in the Family	−0.018	0.002	0.020
Benefits my watershed	−0.092**	−0.010*	0.102***
Farm and Farmers' Characteristics			
Farm Management Decisions	0.000	0.000	−0.000
Primary Occupation in 2020	0.143*	0.016	−0.159*
Gross Operation Sales	−0.059**	−0.007**	0.065***
Weather and Soil Characteristics			
Average Temperature	−0.029	−0.003	0.003
Average Precipitation	0.002**	0.000*	−0.002**
Slope	0.004	0.000	−0.004

Standard errors in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Marginal Effects for the Use of Cover Crops.

	(1) Unlikely	(2) Not Sure	(3) Likely
Extreme Weather Events			
Drought Prevalence	−0.039	−0.006	0.044
Flooding Prevalence	0.009	0.001	−0.010
Farmers' Perceptions			
Online Decision Support Tools	−0.075	−0.011	0.086
Soil Health Concern	−0.019	−0.003	0.021
Farm Staying in the Family	−0.060*	−0.009	0.069*
Benefits my watershed	−0.105**	−0.016	0.120***
Farm and Farmers' Characteristics			
Farm Management Decisions	0.018	0.003	−0.021
Primary Occupation in 2020	0.079	0.012	−0.091
Gross Operation Sales	−0.035	−0.005	0.040*
Weather and Soil Characteristics			
Average Temperature	−0.014	−0.002	0.016
Average Precipitation	−0.000	−0.000	0.000
Slope	0.030	0.005	−0.035

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7
Marginal Effects for the Use of Diversified Cropping.

	(1) Unlikely	(2) Not Sure	(3) Likely
Extreme Weather Events			
Drought Prevalence	−0.075**	−0.011	0.085**
Flooding Prevalence	0.003	0.000	−0.003
Farmers' Perceptions			
Online Decision Support Tools	−0.098**	−0.014	0.112
Soil Health Concern	0.011	0.002	−0.013**
Farm Staying in the Family	−0.061*	−0.009	−0.013*
Benefits my watershed	−0.060*	−0.008	0.069*
Farm and Farmers' Characteristics			
Farm Management Decisions	0.008	0.001	−0.010
Primary Occupation in 2020	−0.133*	−0.019	0.152*
Gross Operation Sales	0.021	0.003	−0.024
Weather and Soil Characteristics			
Average Temperature	0.036	0.005	−0.042
Average Precipitation	−0.001	−0.000	0.001
Slope	0.007	0.001	−0.008

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8
Marginal Effects for the Use of Integrated Crop-Livestock Grazing.

	(1) Unlikely	(2) Not Sure	(3) Likely
Extreme Weather Events			
Drought Prevalence	0.009	−0.001	−0.008
Flooding Prevalence	0.029	−0.003	−0.025
Farmers Perceptions			
Online Decision Support Tools	−0.001	0.000	0.001
Soil Health Concern	0.077**	−0.009*	−0.068**
Farm Staying in the Family	−0.033	0.004	0.029
Benefits my watershed	−0.114***	0.014**	0.101**
Farm and Farmers' Characteristics			
Farm Management Decisions	0.004	−0.001	−0.004
Primary Occupation in 2020	0.024	−0.003	−0.021
Gross Operation Sales	0.005	−0.001	−0.005
Weather and Soil Characteristics			
Average Temperature	−0.035	0.004	0.030
Average Precipitation	0.001	−0.000	−0.001
Slope	−0.010	0.001	0.009

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

health is 4.164, which indicates that farmers on average perceived improved soil health as a “quite important” factor that affects conservation practice adoption decisions. A mean value of 3.555 for the farm succession question implies that, on average, farmers are between “somewhat agree” and “strongly agree” with the statement that the land they farm should stay in their family. Furthermore, a mean value of 3.207 for the watershed benefit question shows that respondents generally consider conservation practices to be slightly more than “moderately beneficial” to their watershed.

Table 3 shows that conservation practices and farmers’ perceptions of drought and flooding are positively correlated. For example, farmers’ perception of drought is positively correlated with the use of no-till/reduced tillage, and this relationship has a 99% chance of being true. This indicates that as the number of perceived drought years increases, so does the likelihood that the farmers report using no-till/reduced tillage. This is also the case for the relationship between drought and the other conservation practices. For flooding, the correlation coefficients are positive but not statistically significant. This indicates that an increase in flooding seems to increase the likelihood of using conservation practices, although the strength of that relationship is much lower than the correlation between drought and conservation practices. This reinforces our interest in establishing the relationship between drought and flooding and farmers’ adoption of conservation practices.

Table 4 reports the effects of different explanatory variables on farmers’ likelihood of using conservation practices in the future. At the bottom of Table 4 are the correlation coefficients of individual groups of conservation practices. The reported correlation coefficients indicate that the practices are significantly correlated with each other at the $p < 0.01$ level. For example, ρ_{12} is the correlation coefficient of no-till/reduced tillage and cover crops and has a value of 0.434. Tables 5-8 present the marginal effects of the explanatory variables on the likelihood of using the conservation practices.

Drought prevalence significantly boosts the likelihood of the future use of no-tillage/reduced tillage and diversified cropping on conventional fields. Specifically, a unit increase in the number of drought years increases the likelihood of farmers choosing “likely” in using no-tillage/reduced tillage and diversified cropping by 8.6 percent and 8.5 percent, respectively (Table 5 and Table 7). Furthermore, a unit increase in the number of drought years reduces the likelihood of farmers choosing “unlikely” by 7.8 percent for no-till/reduced tillage and 7.5 percent for diversified cropping (Table 5 and Table 7). This result is in line with our expectation that an increase in the number of perceived drought years would increase the likelihood of using the conservation practices. This result is also consistent with Ding et al. (2009), who found that drought prevalence positively affects the adoption of conservation tillage practices. Other studies such as Saak et al. (2021) and Wang et al. (2021a) provide additional support. For example, Saak et al. (2021) found that respondents whose farms receive less precipitation were more likely to report that conservation tillage led to yield increase and cost reduction. They noted that this effect is because conservation tillage reduces water evaporation and increases water infiltration. Similarly, Wang et al. (2021a) found that less precipitation makes farmers more likely to adopt diversified crop rotation. They suggest that having diverse crops can increase crop yields, especially in extreme weather conditions and this could have led to the adoption of the adaptive measure.

Besides, the effect of perceived drought prevalence on the likelihood of using cover crops and integrated crops-livestock grazing is not significant. Although adopting cover crops and integrated crops-livestock grazing improves soil health and reduces erosion, there may be barriers against their adoption. While cover crops increase soil infiltration and enhance soil water storage capacity, farmers are concerned that cover crops may compete for water with cash crops in drought areas (Kaspar and Singer, 2011). Likewise, because the government tends to favor cash crops such as corn, soybeans, and wheat, adopting crops-livestock grazing in response to extreme weather events may not be financially feasible (Herzberger, 2019).

The prevalence of flooding is not significantly associated with the likelihood of using any of the conservation practices (Tables 5-8). This finding is also in line with Ding et al. (2009), who found that the effect of flooding on the adoption of tillage systems is not significant. The difference in the effect of drought and flooding on the use of conservation practices can be attributed to how farmers respond to extreme weather events. Farmers’ response to drought appears to be individualistic—that is, the effectiveness of their drought response could be achieved alone. However, a flood seems better managed as a community, which takes collective management efforts from all the farmers in the affected community (Tyler et al., 2021). Conversely, some studies have shown that the use of conservation practices by individual farmers could reduce flood-related losses (Antolini et al., 2020; Schilling et al., 2014; Dakhlalla and Parajuli, 2016). For example, cover crops play a more effective role in curtailing flooding than no-tillage, fertilizer management, grassed waterways, and afforestation (Antolini et al., 2020). This is because cover crops moderate the impact of raindrops on the soil surface and reduce the flow of water and its run-off (Jasa, 2015; Murtada, 2019).

We also found other sets of factors that affect farmers’ likelihood of using conservation practices in response to drought and flooding. For example, a unit increase in the perception of watershed benefits increases the likelihood of choosing “likely” by 10.2% for no-tillage/reduced tillage, 12% for cover crops, 6.9% for diversified cropping, and 10.1% for integrated grazing (Tables 5-8). This finding suggests that farmers who perceive that conservation practices are beneficial to their watershed are more likely to use conservation practices in the future. In addition, a unit increase in gross sales increases the likelihood that farmers choose “likely” for cover crops and no-till/reduced tillage by 5% and 6.5%, respectively (Tables 4-6). These results suggest the importance of gross sales in the decisions of the farmers to adopt these conservation practices. As farmers’ revenues increase, they are more likely to invest in conservation practices (Prokopy et al., 2019; Wang et al., 2021b). Larger farmers are also more likely to offset the risks associated with adopting conservation practices.

4. Conclusions

This study examined how farmers’ perceived frequency of drought and flooding influence their decisions to adopt conservation practices in their conventional crop fields in the future. Using survey data from 350 SD farmers and descriptive and multivariate probit

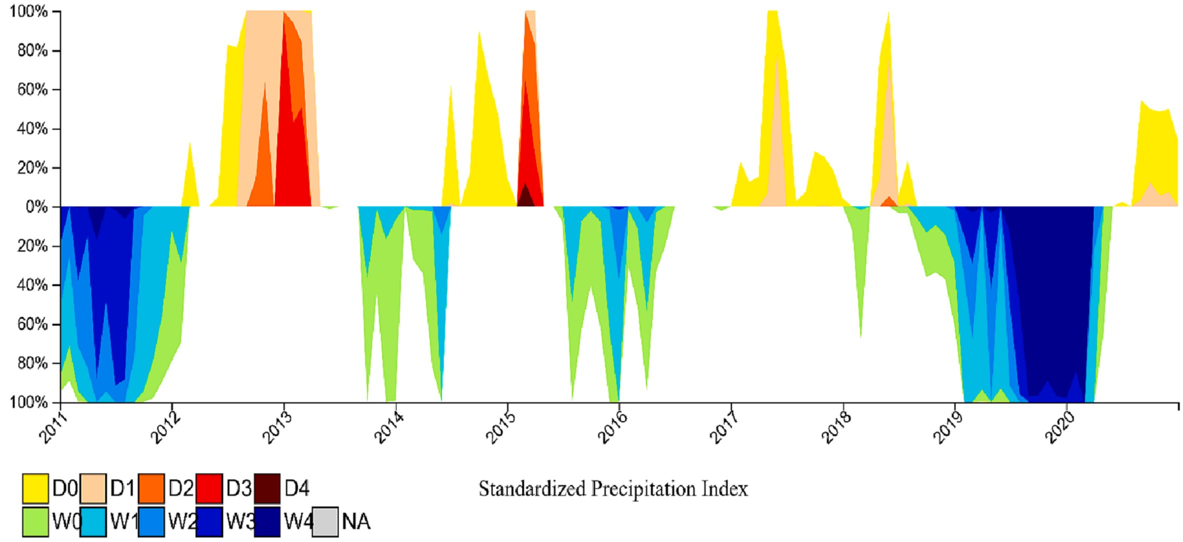

Fig. A1. Statewide average drought (D0-D4, with D4 being an extreme drought) and flooding (W0-W4, with W4 being an extreme flood) conditions in South Dakota, 2011–2020.
Source: Drought.gov (2021)

analyses, we have two main findings in this study. First, we found that 87% and 98% of farmers reported at least one year of drought and flooding from 2011 to 2020, respectively. Second, we found a significant relationship between the future use of conservation practices and drought, but not with flooding. Consistent with Ding et al. (2009), we found that the perceived frequency of drought significantly affects the likelihood of using no-tillage/reduced tillage and diversified cropping.

This study contributes to the extreme weather and conservation practices literature in two ways. First, we assess farmers' future likelihood of adopting conservation practices in response to their perceptions of extreme weather events. As differences in risk perceptions exist between experts and farmers, adaptation policies might fail without a better understanding of farmers' perceptions of extreme weather events. Thus, this study is important for designing and implementing adaptation strategies that are suited to the needs and experiences of farmers (Eitzinger et al., 2018). Second, we provide insights on which conservation practices SD farmers are more likely to use in the future as adaptive measures to extreme weather events. Given that the benefits that accrue from conservation practices differ, our study informs policymakers and extension educators about the priorities of farmers.

The policy implications of these results are as follows. First, establishing a relationship between farmers' use of conservation practices and their perception of drought and flooding is necessary for promulgating extreme weather adaptation policies. For example, we found that the relationship between conservation practices and drought is significant while the relationship between conservation practices and flooding is insignificant. This finding suggests that drought adaptation policies would differ from flooding adaptation policies. While conservation practices might be suitable for adapting to drought, a different set of management systems might be required for adapting to flooding. Thus, our study provides information that might help policymakers and extension educators in making policies and educating farmers. Second, our study raises awareness about the specific conservation practices that farmers might use in the future. For example, we found a significant relationship between drought and no-tillage/reduced tillage and diversified cropping, but an insignificant relationship between drought and cover crops and crop-livestock grazing. This suggests that drought adaptation policies that promote conservation practices must be tailored to farmers' priorities to be effective.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix

Fig. A1

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