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RESEARCH ARTICLE

The role of farmer networks in supporting adaptive capacity: Opening the door for innovation and transformation in the Northeastern United States

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This article explores the role of farmer networks in building the adaptive capacity of small and diversified farmers in the Northeastern United States. Previous research suggests that farmers' networks are the backbone of practical agricultural knowledge systems in the United States, serving as a critical venue where growers exchange and negotiate new ideas. Drawing upon empirical evidence from a regional survey on climate resilience and a series of focus groups conducted in collaboration with 9 farmer organizations from Pennsylvania to Eastern Canadian provinces, this article examines how the emergence of new ideas and agroecological innovations are influenced by geography, network affiliation, and perceived agency. First, we use regression analysis to identify factors that influence the use of no-till on diversified vegetable and berry farms, which is an emerging innovation in this community. Our analysis shows that geography may not be a significant driver of adoption among the population we sampled, which contrasts with previous research on explanatory factors, yet affiliation with certain farmer networks was significant in predicting the use or intended use of the practice. This quantitative analysis is complemented by qualitative data from a series of focus groups in which farmers identify the characteristics of certain networks which support them in addressing new challenges. Farmers identified that networks support them in learning about new ideas, accessing resources, and engaging in creative problem-solving, through facilitation of spaces for exchange with peers and experts and being responsive to their emerging needs.

Keywords: No-till, Agroecology, Vegetable farm, Farmer networks, Innovation, Climate change, Adaptive capacity

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1. Introduction

Projected increases in climate variability and extreme weather patterns associated with climate change pose major challenges to agriculture globally (Walthall et al., 2012; Hatfield et al., 2014; Rosenzweig et al., 2014; U.S. Global Change Research Program, 2018; Wolfe et al., 2018). Changes in farm management, at both incremental and transformative scales, are imperative to enhance farmers' ability to address and withstand climate-related risks (Howden et al., 2007; Janowiak et al., 2018). The imperative for adaptation is well founded, yet increased understanding of the factors that influence farmers' ability and willingness to adapt to climate change remain an important point of inquiry. A strong body of research has explored the way farmer perceptions influence adaptation behaviors, yet the role networks play in agricultural adaptation to climate change remains under researched (Davidson, 2016). This article fills that gap by exploring the role of networks in supporting the adaptive capacity of farmers.

Our article draws upon quantitative and qualitative data from our research with farmers in the Northeastern United States and Eastern Canada to shed light on how agroecological transformations transpire and what enhances adaptive capacity—that is, the ability to prepare for and respond to the effects of climate change (Smit et al., 2001). Our study draws from complementary theories of farmer behavior and change to contribute regional scale analysis of what influences adoption in the Northeastern United States, an undertaking we have not seen published elsewhere. Additionally, while the body of scholarship exploring the importance of farmer networks in adaptation to climate change is growing, few studies have documented both the explanatory and exploratory analyses of how differentiated characteristics among farmer networks influence the diffusion of farmer-led, agroecological innovations. Through these contributions, we explore the nature of sustainability transitions on farms in the Northeastern United States by looking at the following specific research questions, and a hypothesis tested with our qualitative data analysis:

RQ1: What drives the innovation and use of emerging agroecological strategies?

To answer RQ1, we developed a hypothesis based on research and theories. Based on the Theory of Planned Behavior (also known as the Reasoned Action Approach), climate change attitudes and other cognitive factors may influence adaptation behaviors (Fishbein and Ajzen, 2010). Based on the literature explored in the background section, we believe affiliation with farmer networks may influence adoption of farm management practices (i.e., Baumgart-Getz et al., 2012), as may perceived capacity (i.e., Niles et al., 2016). Additionally, diffusion of innovation theory posits that innovations spread among farmers via both peer groups and geographic communities (Rogers, 2003). Together these understandings lead us to test the following hypothesis:

H1: We expect climate change beliefs, perceived capacity, farmer network participation, and geographic community to influence the emergence of farm management practices for adaptation to climate change.

RQ2: How do networks support the adaptive capacity of farmers?

To answer RQ2, we use qualitative data from focus groups with farmers in sustainable agriculture networks in the Northeastern United States to better understand the nuances of how networks support their capacity to adapt to climate change.

2. The role of farmer networks: A brief review

Farmer networks represent a fundamentally different model of information sharing, innovation, and resource sharing compared to dominant top-down transfer of technology which most agricultural extension and international development programs were based on the study by Kirchoff et al. (2013). Advancements in approaches to agricultural extension have attempted to incorporate and account for participatory and nonhierarchical approaches of linking knowledge to action (Lubell et al., 2014; Heleba et al., 2016). Yet, while agricultural extension models have evolved in this direction, farmer networks that sprouted organically among agroecological movements have long relied on collaboration, peer learning, and limited resources (Kroma, 2006). These niche sustainable agriculture cases are examples of sociotechnical alternatives to a dominant food system, which successfully incubate agroecological approaches (Geels, 2011; Wigboldus et al., 2016; Anderson et al., 2019) and thus offer important lessons for enhancing the sustainability of agriculture in the face of climate change.

Agricultural innovation systems theory emphasizes how innovations emerge from the character of interactions among diverse actors in a system, attributing the development and spread of innovative ideas to the structure of knowledge exchanges and resources available within an agricultural community (Klerkx et al., 2012). Similarly, the Extension 3.0 concept highlights how networks cooperate to deliver "relevant knowledge to the right people at the right time and place" (Lubell et al., 2014, p. 1090), with the express potential to enhance agroecological resilience via farm management decisions. Both of these advancements in conceptualizing the emergence of innovations and management changes put emphasis on opportunities for exchange among multiple actors. Farmers in sustainable agriculture have developed capacities to manage change through farmer-led innovation and knowledge exchange that is catered to their unique information and farm needs (Carolan, 2006; Kroma, 2006; Dolinska and Aquino, 2016; Šūmane et al., 2017). Carolan (2006) and Kroma (2006) describe the way farmer's knowledge systems in the U.S. sustainable agriculture movement developed in the absence of the same significant support provided by traditional research and extension institutions to conventional commodity farming systems in North America.

Although previous research has identified that farmer networks play a role in supporting farmers to innovate and transform in the face of new challenges and opportunities (i.e., Hassanein and Kloppenberg, 1995; Carolan, 2006; Kroma, 2006; Nelson et al., 2014), there is limited research that focuses on how networks support farmers in addressing climate change. Farmer networks are places where knowledge is sought from peers with shared experience that can be directly applied to their individual farm (Wood et al., 2014). Farmers learn readily in networks (Conley and Udry, 2001) and preferring to validate knowledge and vet new information within peer groups (Foster and Rosenzweig, 1995; Hassanein, 1999). Peer and social networks are critical access points for new information and learning, and farmers who participate in more networks may have higher adoption of innovation rates (Rogers, 2003; Hogset and Barrett, 2010). The influence of geographic proximity is known as the "neighborhood effect" and has been empirically confirmed (e.g., Nyblom et al., 2003; Rogers, 2003; Boncinelli et al., 2015) but rarely compared to the influence of regional farmer information networks or producer organizations on adaptation behaviors.

This growing body of research on farmer networks and peer learning phenomena has limited integration with the study of what drives individual farmer climate adaptation behaviors. Many studies on adaptation behavior draw from the Theory of Planned Behavior, which puts emphasis on the intentions that lead to action, predicting that farmers behave rationally based on their attitudes, norms, and perceived behavioral controls (Fishbein and Azjen, 2010). Overall, this research has found that drivers of climate adaptation behaviors among farmers are not universal (Prokopy et al., 2019). However, research has determined that farmers' diverse concerns, attitudes, and beliefs influence their willingness to make adaptive management decisions (Haden et al., 2012; Niles et al., 2016). Perceptions of climate risk and climate skepticism have also been associated with adaptation behaviors (Chatrchyan et al., 2017; Mase et al., 2017; Lane et al., 2019). Additionally, social capital has also been identified as a tool that can access or mobilize adaptations (Pelling and High, 2005). Finally, while knowledge is an important determinant of adaptive capacity, financial resources, ecological assets, social networks, and physical infrastructure also influence farmers' capacity to address climate change (Lengnick, 2015; Williams et al., 2015). Regional differences in environmental, socioeconomic, policy and cultural factors will likely influence if these factors drive climate adaptation among farmers, and regionally specific research can help determine the way these factors manifest in each context.

3. Methods

3.1. Study design and context

This study uses a sequential convergence triangulation model of mixed methods (Creswell, 2006) to explore the role of farmer networks in agroecological transformations among vegetable farmers in the Northeastern United States (**Figure 1**). Mixed methods triangulation is described by Creswell (2006) as a more traditional style of mixed methods, which compares analysis of complementary datasets on the same topic in the discussion section. This approach brings together the different strengths of the 2 methods to enhance our understanding of the research question from multiple perspectives (Ellingson, 2013). In linking them together, the qualitative data provide useful explanatory information for the significant trends identified in the quantitative data about the role of farmer networks.

Complementary datasets were collected in a multiphase regional research project which explored agricultural adaptation and resilience to climate change in the Northeastern United States (**Figure 1**). The project was designed using principles of participatory action research (PAR) to engage farmers in each stage of the research process (Méndez et al., 2017). The key ontological assumption behind PAR is that humans are dynamic agents capable of self-change and reflexivity (Kindon et al., 2007). PAR asserts that diverse forms of knowledge make valuable contributions to research and real-world solutions, and that increasing engagement in process of knowledge coproduction leads to increased usability of information. Further, PAR draws on Lewin's assertion that inferences

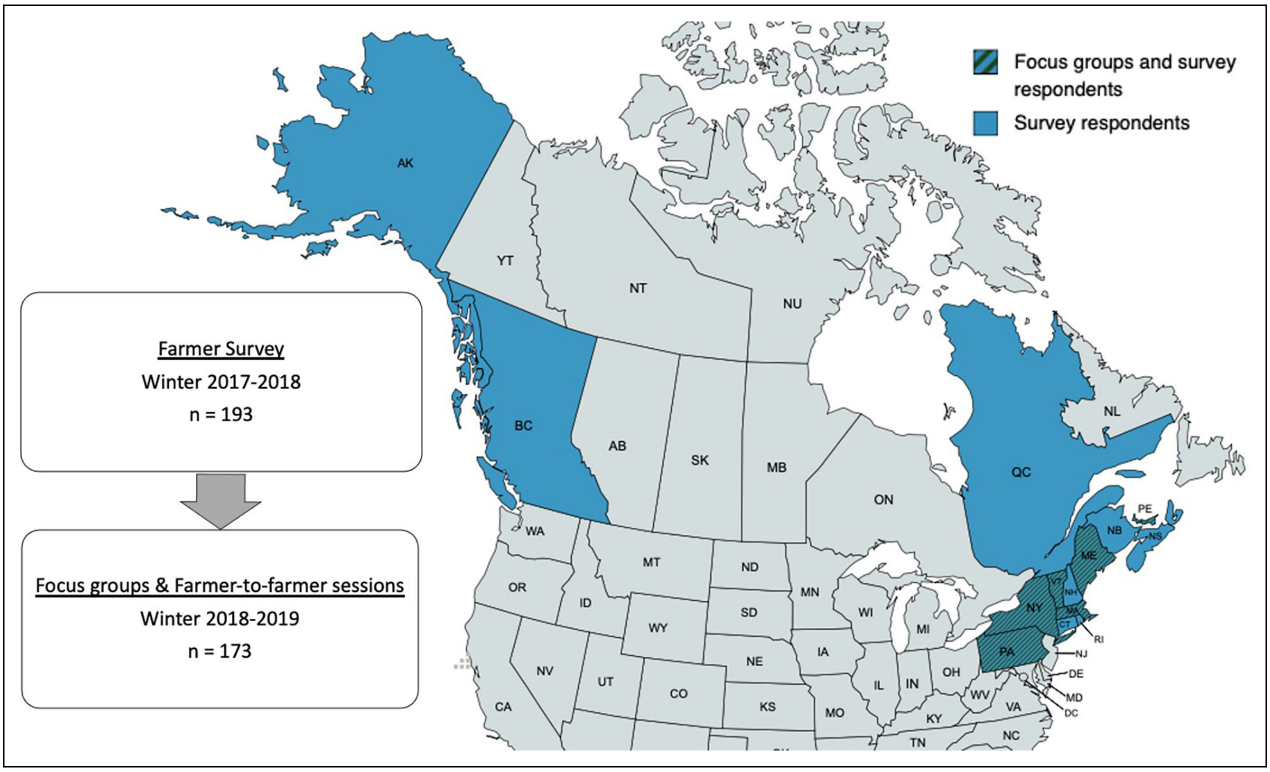

Figure 1. Complementary regional datasets were collected in the Northeastern United States and Eastern Canada in a sequential convergence triangulation model of mixed methods.

about human behavior are more valid and actionable when participants are engaged and committed to the results of inquiry (Argyris and Schon, 1989).

We embedded our project and data collection efforts within the information landscape of the farming community at the regional scale. Over the course of 3 years, our team attended 15 farmer conferences, where we collected data, presented our results, and shared relevant resources on climate resilience at exhibitor tables, amounting to over 300 h of participant observation. Observations among the research team during the course of the project informed our process of inquiry and contextualized the responses to our surveys and focus groups. The regional approach taken in this research reflects the shared socioeconomic, environmental, and cultural characteristics of farmers at a subnational level, but which crosses state lines. The study design focused originally on data collection efforts from primarily within New England states. However, farmers from neighboring states and territories who attended and participated in networks based in New England states were not excluded from participating in the survey or focus groups. Farms in the Northeastern United States account for 28% of direct farm sales in the United States, the largest of any region in the country, and the average farm size in New England is 120 acres (National Agricultural Statistics Service, 2022).

3.2. Quantitative data collection

In the first phase of our research, a regional survey was conducted with diversified vegetable and berry farmers in the Northeastern United States to identify how they were adapting to the increasing incidence of extreme precipitation and drought. The survey was developed with input from agricultural advisors and farmers and then administered in partnership with farmer organizations across New England using a convenience sampling approach and a tailored, mixed-mode survey design (Dillman, 2011) as described by White et al. (2018). Survey responses were solicited in-person at 8 farmer organization events in Maine, New Hampshire, Massachusetts, and Vermont and via email through 4 farmer list-servs between November 2017 and March 2018. Protocols and questions were approved by the University of Vermont Office for Human Research Protections.

The survey contained questions about practices used to manage for climate-related risks, planned adaptation, and strategies considered promising and innovative. The survey also included questions about farmers' experience, education, farm size, climate beliefs, perceived vulnerability and capacity, and network affiliation. Farmers were asked to identify network affiliation based on either being a member or utilizing the network as a source of information, including vegetable and berry producer associations, organic producer networks facilitated by staff, farm bureau, farmers union, permaculture groups, and research networks. The survey yielded 193 respondents with farms from across the states primarily in the Northeastern United States and Eastern Canada, though respondents were primarily from the 4 states in which we had visited to obtain the sample.

3.3. Qualitative data collection

One year after the survey, we conducted focus groups and participant observation to better understand what information and resources would support farmers' resilience to climate change. We returned to farmer network meetings across the region to share our results from the survey and were invited to additional network meetings, which represented a greater geographic scope than the first year. This included Pennsylvania, New York, and Prince Edward Island (**Table 1**). At these events, we presented the results of our survey, detailing the ways in which farmers reported already adapting to extreme weather impacts, and then invited them to participate in the analysis. This participatory analysis was invited formally through focus groups and farmer-to-farmer sessions, which were hosted

Table 1. Listening tour locations and attendance

Location	Network	Event Type	Number of Attendees
Maine, USA	MOFGA	Focus group and farmer-to-farmer session	20
Prince Edward Island, Canada	ACORN	Focus group and farmer-to-farmer session	12
Vermont, USA	VVBGA	Focus group	4
Vermont, USA	VVBGA	Focus group	9
New York, USA	NOFA NY	Focus group and farmer-to-farmer	41
Massachusetts, USA	NOFA MA	Focus group and farmer-to-farmer session	20
Pennsylvania, USA	PASA	Focus group and farmer-to-farmer session	39
Vermont, USA	NOFA VT	Farmer-to-farmer session	22
Vermont, USA	NOFA VT	Focus group	7
Total attendees			173

MOFGA = Main Organic Farmer and Gardeners Association; ACORN = Atlantic Canadian Organic Regional Network; VVBGA = Vermont Vegetable Growers Association; NOFA = Northeast Organic Farmers Association, which has state chapters; PASA = Pennsylvania Association of Sustainable Agriculture.

in tandem with the presentations, sometimes immediately afterward, and sometimes at a different time within the same network. Focus group protocols were approved by the University of Vermont Office for Human Research Protections. Overall 9 conversations with 173 farmers ensued, in what we called a listening tour among 7 farmer networks (**Table 1**). Community listening sessions bring people together to share perspectives on an issue and are often less structured than focus groups (Schreiber et al., 2020). Listening sessions and focus groups are approaches suitable for action research because they engage researchers and stakeholders in knowledge sharing spaces which depart from the historic unidirectional models of information dissemination (Schreiber et al., 2020). We used a semi-structured focus group format with discussion prompts asking farmers about what resources they rely on to support their farm's resilience to climate change, and what resources they needed to support their resilience to climate change. During farmer-to-farmer sessions, our focus group research prompts were shared, and then farmers were invited to bring up their most salient concerns and ideas. Topics of conversations were convergent among the focus group and farmer-to-farmer sessions, but in the farmer-to-farmer sessions, additional time was dedicated to address farmers' emergent concerns. This led to exchanges of knowledge among participants within the session, which both enhanced our dataset and supported peer learning in the community. During all sessions, agreement and knowledge exchange between participants was acknowledged by both verbal and nonverbal agreement cues.

3.4. Quantitative data analysis

3.4.1. No-till as an emerging agroecological innovation

Over 3 years of conducting stakeholder engaged research among specialty crop farmer groups in the Northeastern United States, our research team observed the use of no-till among vegetable producers as the subject of current farmer-led innovation and knowledge building. According to the Food and Agriculture Organization of the United Nations (FAO), "Agroecological innovations apply ecological principles—such as recycling, resource use efficiency, reducing external inputs, diversification, integration, soil health and synergies—for the design of farming systems that strengthen the interactions between plants, animals, humans and the environment for food security and nutrition" (FAO, 2016, p. 2). Further, agroecological innovations are farmer-led and "are not yet widely incorporated or mainstreamed in the current agricultural development models" (FAO, 2016, p. 3). Network models of innovation differ notably from innovation–diffusion models in that the system changes are based not on the efficacy of farmer learning but on the efficacy of farmers, researchers, and advisors in collaborating to reconstruct practices (Coughenour, 2003). Here, we use the term agroecological innovation to describe the emergence of new no-till practices among small farmers in the Northeastern United States. The no-till methods we observed are distinct from standard conservation practice no-till utilized in large acreage row crops like corn, beans, and grains. During the course of our research, we observed avid sharing of new ideas about this practice among farmers and sat in on highly attended workshops at farmer network meetings where small growers described the ways they were incorporating large sheet-plastic ground coverings (i.e., "tarps") to integrate no-till into their vegetable production operations and fashioned human scale tools to terminate cover crops organically. See Kinnebrew et al. (2023) for a description of associated tarping practices among small vegetable farmers in the Northeastern United States. We also attended 2 day-long intensive farmer-focused workshops dedicated to the use of tarps to achieve no-till, taught by a combination of extension professionals and farmers. The use of tarps to eliminate tillage was described as achieving the same ecological and agronomic benefits as the no-till used in field and commodity crop production, frequently through enhancements in soil health that increase water holding capacity and therefore drought resilience, as well as soil structure improvements that reduce erosion and increase infiltration (Derpsch et al., 2010). Yet, addressing the unique challenges of integrating tarping times into rotations and cover crops, what to use for anchoring, and how to achieve termination in vegetable production systems were subject to lively discussion.

Survey responses from the first year of our research also reflect no-till as an emerging and innovative practice. Among responses to the regional survey, farmers included no-till in answers to multiple questions. Combined, consideration or use of no-till for managing extreme precipitation risks occurred in 46% of responses. Within that, 19% of respondents said they planned to adopt no-till or considered it innovative and promising for addressing climate-related risks, 24% of respondents already use no-till to manage for the risk of drought, and 31% of respondents reported already using no-till to manage for the risk of extreme precipitation.

3.4.2. No-till model description and dependent variables

We used binomial logistic regression modeling to test the influence of a suite of predictor variables on the emergence of no-till among vegetable farmers for adapting to climate-related risks. The timing of our survey offers a unique snapshot of how this practice was being adopted and considered by the region's vegetable farming community while in a period of innovation and information sharing. In order to better understand what might be influencing the emergence of this practice, we ran models for 2 different relevant dependent variables; the adoption of no-till to manage for heavy precipitation or drought, and the occurrence of no-till in answers to any of our questions about adaptation to heavy precipitation or drought. The occurrence of no-till in our survey responses may offer a better picture of how ideas about no-till are spreading through the community, but prior research has established that the influences on adoption and intent to adopt a practice can be different (Niles et al., 2016). Thus, by comparing them, we can shed more light on how ideas about the emerging innovation are moving through the community, and what is influencing the adoption of the practice.

In the model predicting adoption of no-till, the binary-dependent variable indicates the respondent selected "no-till" in response to either, or both, multiple choice questions asking:

- Which practices do you use to manage heavy precipitation and flooding on your farm?
- Which practices do you use to manage drought on your farm?

In the model predicting the occurrence of no-till, the binary-dependent variable indicates that the respondent included no-till in the answer to any of the following questions:

- Which practices do you use to manage heavy precipitation and flooding on your farm?
- What changes have you made on your farm because of this experience with heavy precipitation or flooding?
- What changes are you planning to make in the near future which will help you manage for the risk of heavy precipitation or flooding?
- In your opinion, what is the most promising, interesting or innovative strategy for adapting to heavy precipitation and flooding that you have heard about?
- Which practices do you use to manage drought on your farm?
- What changes have you made on your farm because of this experience with drought?
- What changes are you planning to make in the near future which will help you manage for the risk of drought?
- In your opinion, what is the most promising, interesting or innovative strategy for adapting to drought that you have heard about?

Here, we used the data transformation model of triangulation methods, as described by Creswell (2006, p. 63), to thematically code qualitative data from open-ended survey questions and then dichotomously score them as present or not present for each case. This created new quantitative variables for the survey dataset, a resulting binary variable representing the occurrence of no-till for each case (respondent). This was used to perform regression analysis on relationships, similar to methods published in the study by Pagano et al. (2002).

Analysis was conducted using R studio software and the lme4 package using generalized linear models assuming binomial distribution with the logit link function (R Core Team, 2013; Bates et al., 2015). Code for running the model used the glm function, with family = binomial and a logit link. Within the dataset, missing values were replaced with NA. Binary variables (0,1) were converted to factors prior to running models. Finally, the dataset was trimmed to include only farmers who indicated that they grow vegetables, removing responses from 55 farmers who grow exclusively fruits or berries.

3.4.3. Independent variables

Independent variables considered in our model include predictors that have been shown to influence the adoption of climate adaptation practices for which we had data (details in Supplementary Materials). This includes farm size, farmer experience, level of education, organic certification, climate beliefs, and perceived capability. We also included factors that have been shown to influence the spread of innovations in agricultural communities, specifically farmer network affiliation and geographic community. We used the state in which the farm was located to identify the way geographic community influences the emergence of no-till. To incorporate the influence of farmer networks in the model, we included both the number of networks which farmers were affiliated with, and affiliation with each of 9 different farmer organizations and networks. In preparing data for the model, some variables were transformed. Full details of these methods are included in the Supplementary Materials. Pearson correlations between ordinal numeric variables identified potential collinearity. In 2 cases where collinearity occurred, comparisons of *t*-tests against the dependent variable determined which variable to include in the model parameters.

3.4.4. Model specifications

Our analysis used 4 models to determine the influence of the independent variables on the dependent variables. In the first model, we included the "state" variable as a fixed effect alongside the other independent variables. In the second model, we included the "state" variable as a random effect, with all the other independent variables being fixed. Both of these models indicated that variability in the outcome was not attributable to the "state" variable. Subsequently, we removed the "state" variable and ran 2 final models that compare the influence of the independent variables on the dependent variables. We used a binomial logistic regression model that predicts the log odds ratio of the dependent variable occurring, based on the independent variables. In our final 2 models, the regression model predicts the probability of no-till based on experience, education, farm size by gross annual income, organic certification, perceptions, climate beliefs, and network affiliation:

$$
\begin{aligned}
p(\text{no till}) = \beta_0 &+ \beta_0\text{Organic} + \beta_0\text{Years as a decision maker} \\
&+ \beta_0\text{Education level} + \beta_0\text{Gross annual farm income} \\
&+ \beta_0\text{Cliamte belief scale} + \beta_0\text{Perceived vulnerability} \\
&+ \beta_0\text{Perceived knowledge and skill} \\
&+ \beta_0\text{Perceived financial capability} \\
&+ \beta_0\text{Perceived community support} \\
&+ \beta_0\text{Network affiliations} \\
&+ \beta_0\text{Number of network affiliations}
\end{aligned}
$$

We transformed the coefficients to odds ratios for reporting and interpretation of the results. The odds ratio is interpreted as a measure of how many times more likely it is that a farmer from our sample has adopted no-till for every one unit increase in the predictor variable.

3.5. Qualitative data analysis

Analysis of transcripts from the focus groups was carried out in the tradition of grounded theory described by

Charmaz (2006) with the research question in mind (*What characteristics of farmer networks support farmers' adaptive capacity?*). Our process was inductive, comparative, iterative, and interactive (Charmaz and Belgrave, 2012). During initial readings of the transcripts, we identified portions of the conversations in which farmers discussed farmer networks as important resources that support their resilience to climate change. In our coding and iterative sensemaking process, transcripts were read by 2 researchers who independently made notes about the themes and categories within the dataset. These memos were compared and discussed and then used to create a coding tree that included both category codes and emergent themes that connected across the dataset (Maxwell, 2012). The resulting coding tree was used to code through the data using NVivo software (QSR International PTY Ltd., 2018) and then revised to better reflect additional emerging themes, in an iterative process of sensemaking.

Our analysis of the qualitative data initially focused on identifying portions of the data where farmers discussed the phenomena we center our inquiry around, but in successive readings of the transcripts, we observed portions of the transcripts in which farmers engaged in the peer exchanges of knowledge. During the analysis process, we noted that farmers identified the way farmer networks create space for peer exchange of information as 1 of the key things they valued. Subsequent readings of the transcripts revealed examples of this phenomenon of information exchange and peer learning happening within our recorded farmer-to-farmer and focus group sessions. This makes our dataset and analysis unique and rich, where participants discuss and reflect on a phenomena while also engaging in the same phenomena.

4. Results

In this section, we first present analysis of the quantitative data, which points to the importance of farmer networks in influencing the adoption of no-till among vegetable farmers for climate adaptation. Then we present the qualitative data, which explores farmers' perspectives in on how farmer networks support their adaptive capacity.

4.1. Influences in the emergence of no-till as an agroecological adaptation to climate change

4.1.1. Survey respondent characteristics

Among vegetable farmers who responded to the survey, 46% reported having organic certified acreage. Average years as a decision-maker was 14.57% of respondents reported their highest level of education as 4 years of college, 19% reported completing an advanced degree, 13% reported attending some college, 6% reported having completed a 2-year college technical degree, and 5% reported high school as their highest level of education. The average range of reported gross annual farm income was between $50,000 and $149,000.

A majority of respondents to the survey tended to agree with statements about climate beliefs (**Figure 2**). Eighty-one percent agreed that the increased intensity of droughts, storms, and floods is a result of climate change. Sixty-three percent agreed that extreme weather events in recent years have affected their long-term farm management goals. Fifty-five percent reported that they are concerned that available best management practice technologies are not effective enough to protect the land they farm from the impacts of climate change.

While most survey respondents indicated that they understand their vulnerability to extreme weather impacts, far fewer expressed confidence in their capacity to address or respond to extreme and variable weather (**Figure 3**). Seventy-four percent agree that they understand the vulnerability of their farmland to extreme weather conditions. Only 33% believe that they have the knowledge and technical skill to deal with weather-related threats to the viability of their farm operation.

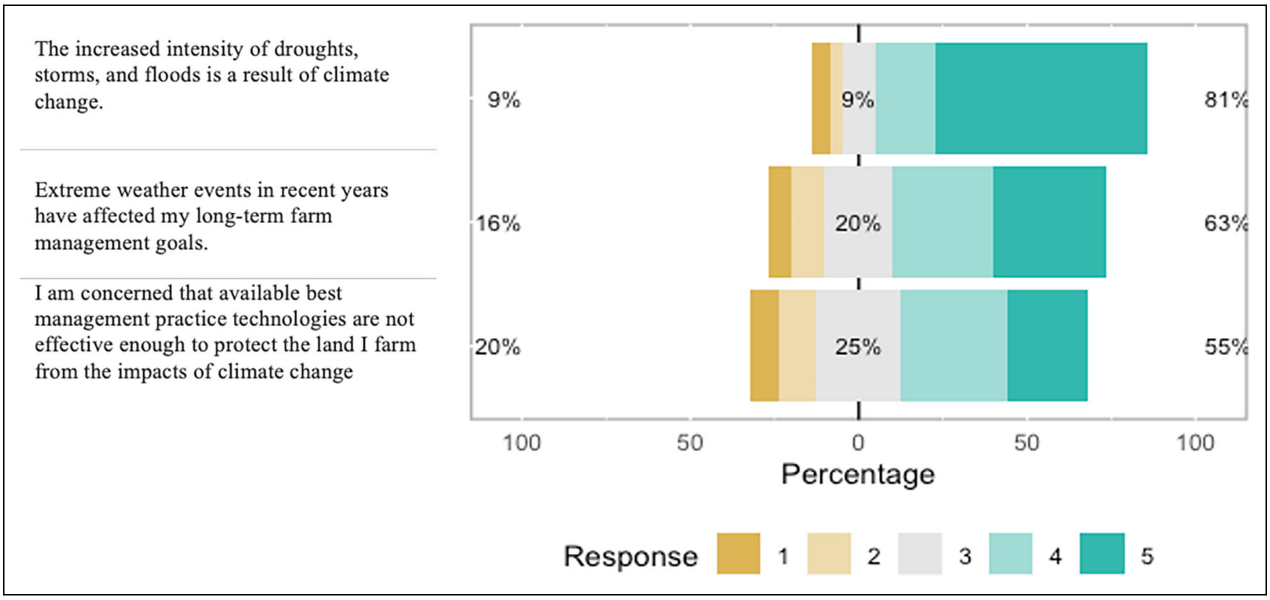

Figure 2. Vegetable farmers' level of agreement with climate belief statements, where 1 is strongly disagree and 5 is strongly agree.

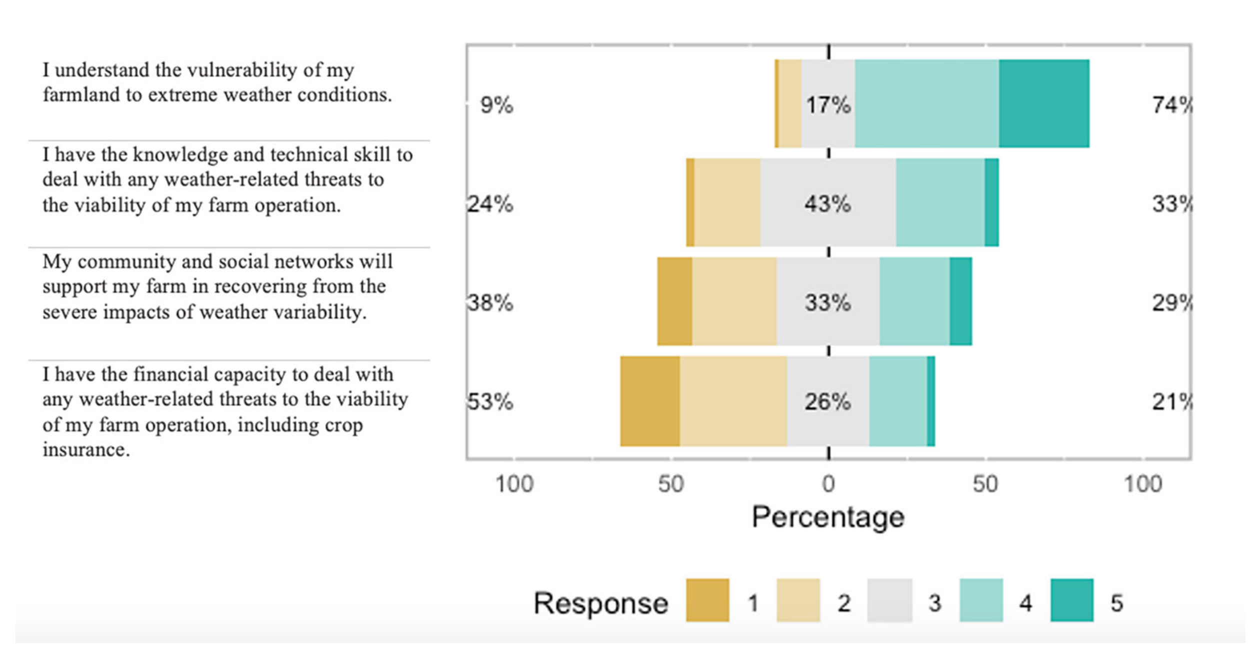

Figure 3. Vegetable farmers' level of agreement with statements about perceived vulnerability and capability, where 1 is strongly disagree and 5 is strongly agree.

Twenty-nine percent believe that their community will support their farm in recovering from the severe impacts of weather variability. Importantly, 53% do not believe that they have the financial capacity to deal with weather-related threats to the viability of their farm operation.

The average number of networks which farmers reported being affiliated with was 3. Seventy-one percent of respondents indicated affiliation with between 1 and 3 farmer networks. The highest number of networks a farmer indicated being associated with was 10.

4.1.2. Geographic influence on the emergence of no-till

Independent variables in our first models included the state in which the farm was located, reflecting our assumption that geography may have influenced the spread of the practice. In the first model, we ran all independent variables as fixed. As "state" is a categorical variable, each state became an individual binary predictor variable in the model. In the model output, none of the states were significant in predicting the outcome and had very high P values, in a range between 0.999 and 0.994. We subsequently modified the model to account for state as a random effect, and variance attributed to the random effect in this model was 0. We concluded that the state variable was not influencing the probability of no-till adoption and subsequently removed it from future models.

4.1.3. Factors influencing the adoption and emergence of no-till

Two models in **Table 2** examine factors that influence the adoption of no-till to manage for extreme precipitation and drought, and the emergence of no-till as an innovation for adapting to climate-related risks.

Belief in climate change, years as a decision-maker, perceived vulnerability, financial capacity, community support, and affiliation with some farmer networks are all significant predictors of the adoption of no-till ($P < 0.05$ and $P < 0.1$). In the model describing the emergence of no-till (as both adoption and consideration of the practice), belief in climate change, education, years as a decision-maker, perceived vulnerability, community support, and affiliation with some farmer networks are all significant. Years as a decision-maker is negatively associated with the adoption and emergence of no-till, meaning that farmers with less experience are likely to adopt no-till ($P < 0.05$). Education level is negatively associated with the emergence of no-till ($P < 0.05$) but not significant in predicting actual adoption. Farmers who believe in climate change are more likely to have adopted no-till to manage for climate-related risks ($P < 0.1$) and to have considered it adaptive. Being confident in understanding their farm's vulnerability to weather-related threats makes vegetable farmers more likely to adopt no-till ($P < 0.1$) and to consider it adaptive ($P < 0.05$). Farmers with greater financial capacity are more likely to adopt no-till ($P < 0.05$), but financial capacity had no significant bearing on the consideration that no-till is adaptive. Farmers who perceive their community will support them in addressing climate impacts are less likely to adopt or consider no-till to be adaptive ($P < 0.05$).

The heterogeneity in directionality and significance among how network affiliations predict the adoption or consideration of no-till in our model is a unique finding. Farmers affiliated with Network D were 20 times more likely to have adopted no-till, 9 times more likely if they are affiliated with Network F, and 7 times more likely if they are affiliated with Network H. Affiliations with Network A, Network C, and Network E are negatively associated with the adoption and consideration of no-till, and while not significant, this indicates that not all networks are the same in the way they influence the emergence and adoption of practices.

Table 2. Factors affecting adoption and emergence of no-till among vegetable farmers in the Northeastern United States, using binomial logistic regression

	Adoption of No-Till to Manage for Precipitation Extremes			Adoption and Consideration of No-Till for Adaptation to Precipitation Extremes		
Predictors	**Odds Ratios**	**CI**	***P*-value**	**Odds Ratios**	**CI**	***P*-value**
(Intercept)	0.00	0.00–0.81	**0.054**	0.01	0.00–0.94	**0.06**
Organic	0.99	0.96–1.01	0.605	1.00	0.98–1.01	0.60
Years as a decision-maker	0.92	0.85–0.99	**0.040**	0.90	0.82–0.97	**0.011**
Education level	0.68	0.32–1.39	0.285	0.48	0.21–0.96	**0.048**
Gross annual farm income	0.90	0.47–1.65	0.731	0.67	0.31–1.28	0.249
Climate risk belief and perception (Scale)	2.56	1.18–6.68	**0.030**	3.11	1.35–8.59	**0.023**
Perceptions of capability and response						
Understanding of vulnerability	8.05	1.19–93.80	**0.056**	31.65	3.80–506.05	**0.004**
High level of knowledge and technical skill	0.41	0.06–2.67	0.366	1.63	0.23–11.69	0.619
Moderate knowledge and technical skill	0.27	0.03–1.81	0.191	2.34	0.38–16.88	0.369
Financial capacity	6.55	1.29–46.20	**0.035**	2.13	0.43–11.64	0.359
Community support	0.19	0.03–0.90	**0.046**	0.13	0.02–0.68	**0.025**
Network affiliation						
Number of network affiliations	1.01	0.20–4.47	0.986	1.65	0.38–7.39	0.496
Network A	0.17	0.01–1.91	0.168	0.18	0.01–1.93	0.178
Network B	1.46	0.14–17.54	0.755	0.30	0.02–2.98	0.317
Network C	0.59	0.04–7.54	0.685	0.11	0.01–1.49	0.117
Network D	20.18	2.28–258.18	**0.011**	221.24	14.84–7708.07	**0.001**
Network E	0.66	0.03–14.83	0.787	0.19	0.01–4.46	0.318
Network F	9.27	0.94–135.85	**0.070**	29.06	2.38–572.80	**0.014**
Network G	1.95	0.18–25.62	0.588	0.60	0.06–6.18	0.667
Network H	7.08	0.81–89.41	**0.093**	6.07	0.56–77.17	0.139
Network I	3.23	0.21–65.56	0.414	6.53	0.30–301.02	0.269
Other networks	5.20	0.88–42.00	**0.086**	7.89	1.13–70.29	**0.045**
Observations	97			97		
R^2 Tjur	0.397			0.521		

It is important to note that not all networks promoted no-till, but we observed that among those that did promote it, many were not significant predictors in the model.

4.2. Characteristics of farmer networks that enhance adaptive capacity

Throughout the community listening tour, farmers described different ways that networks enhanced their ability to prepare for and respond to impacts of climate change. In their reflections, the farmers discussed how farmer networks in the Northeast enable growers to learn, increase access to resources, and develop collective solutions to shared problems. Here, we present our analysis of the community listening tour in this regard, starting with a description of the ways networks were reported to connect farmers with other resources. Then we share the way networks were described as being responsive to emerging needs. Finally, we explore farmers' descriptions of the different deliberative spaces for collaborative learning and problem-solving created by networks.

4.2.1. Enhanced access to other resources

Networks are, almost by definition, a collection of connections and interconnections. In the listening sessions, farmers described many of the ways their network connected them to other resources and how they valued this as enhancing their capacity to address climate change.

Networks were described as valuable in connecting farmers to each other to ends of enhancing social connectivity and personal confidence. One farmer reflected that the network, "*connects you to a larger community and other farmers*," which built her confidence and skills. She qualified her statement, saying that it depends on the extent to which 1 engages with the network. "*For me it does*," she said, but for others it might not. Social connectivity is an important role, as another farmer reflected that without the structures these networks provide, "*we get lost into our own little farms*."

Farmer networks also connect farmers to information and expertise, which helps them better adapt their agroecosystem to climate impacts and implement practices. As 1 participant explained; "*I think right now the best place that I can find information is from the farmer meetings*." In 1 meeting, we observed farmers recommend landscape planning consultants to help 1 farmer with flooding issues. In another session, a farmer asked a question about how to seed cover crops into no-till systems, and a discussion among 6 farmers ensued about how to ensure germination, how termination could be achieved and how access a no-till drill through the local conservation district. Some farmers cited formal mentor pairing programs but often described how key extension staff filled a facilitating role in directing farmers to the best sources of information and support innovative farmers to share their expertise at conferences of workshops.

In one conversation, farmers started directly comparing the different farmer networks they were part of, or knew about, describing the different benefits and resources they could access through each one. This differentiation in network niche is an interesting finding. Some networks provide an equipment borrowing library, which makes it possible for farmers to access and trial strategies that have climate risk management benefits. Networks were also described as playing a role of building markets for producers by educating consumers. Likewise, some networks were described as filling an important policy advocacy role. Other networks were described as connecting farmers to different financial resources. Some hyperlocal groups were described that functioned primarily to facilitate bulk ordering discounts, and 1 network was identified as having its own credit union, which members could access. Many networks help connect growers to loan services and Natural Resource Conservation Service (NRCS) conservation incentive cost share programs. In one meeting, an NRCS agent attended a farmer-to-farmer session and explained cover crop incentives to a few farmers that did not know they would qualify.

4.2.2. Responsive to emerging challenges and opportunities

Farmer networks are responsive to emerging challenges and evolve in response to changing needs and opportunities. In these spaces, it is often the farmers who set the agenda and create opportunities to "*advise service providers and researchers about issues that they think are important and should be focused on*." One farmer likened networks to the collective action historically coordinated by Granges.[1] He described how they are more active in the face of challenges, where the connections and community can be activated and "*get people to work together more to solve their problems when there is a hardship*." Another famer named the way they had suggested a simple market assessment to the network facilitators that would help producers like her, and the idea was welcomed and subsequently undertaken. In another meeting, a few farmers discussed the way the model for their network's farmer research funds was currently being changed to be more useful and effective for growers. One farmer aptly described how their network recognizes that farmers are already inherently doing research, and often gives them tools to do that better, sometimes through farmer research funds but also by offering to pay for soil sampling, or have a key extension agent work with them to track and share data. In these groups, farmers often described their peers as leading innovation and problem-solving in the absence of institutionalized support. To illustrate, one participant explained how, "*right now it's just farmers themselves coming up with the answers*," and they have to "*do it yourself or do it as a collective*" because "*there isn't any research dollars out there to help us*."

A few discussions highlighted examples of the way networks have supported farmers in responding to both unexpected and expected pest and disease challenges. One farmer described how pest reports and email groups helped him track phenology of pest emergence, which are less predictable by date in a changing climate. He explained, "*if it's gonna come through Nova Scotia and people are chirping in northern Vermont, I know I got a week or two because I'm in Saratoga Springs*." In another of the focus groups, farmers described how network coordination guided their community in dealing collectively with an early bout of late blight (*Phytophthora infestans*). As the airborne fungus swept the area, killing all tomato plants, their network served as a source of information for farmers "*in a panic*." The network guided collective actions to addressing the new challenge, by keeping growers, "*updated about what was happening, why it was happening and what [they] could do.*"

4.2.3. Spaces for exchange of contextualized knowledge and collaborative problem-solving

Farmers cited collaborative problem-solving opportunities as one of the most important ways they address emerging challenges like climate change. Networks create deliberative spaces for information exchange and collective problem-solving that support farmer driven innovation from the ground up. Venues for discussion, like conferences, on-farm workshops, social media groups, and email list-servs enable growers to exchange and discuss new information and ideas with other farmers and address the most salient challenges through collaboration with peers.

Farmers value workshop style spaces for stimulating questions that get deep into the contextual similarities and specific characteristics of their agroecosystem. One farmer enthusiastically described the uniqueness of conversations in those spaces; "*it's like we can ask each other questions about what's working, what system do you have … face to face, talking about things that you don't*

1. The Grange movement emerged in post-civil war America and provided a medium for collective action in the face of larger economic forces at play for which farmers had little individual capacity to address. Granges also offered education and camaraderie (see McCabe, 1969).

normally ask each other." The quality of information from peer networks was described as being preferable and trusted because it is filtered and catered to the local context. As one farmer described:

> *I'm capable of understanding scientific research. I don't have the time to go through and sift through it all, so I really depend on people I trust who done it and have succeeded or failed but are that I can identify with who can tell me the short cut ... I'm going to use the tools that exist right now because I don't have the time or the resources to invent something new. And so to be able to connect to those as quickly as possible and to find something that works in my neighborhood is going to be much more effective for me. So that's why I like this kind of peer to peer.*

The interactive and collaborative elements of these deliberative spaces stimulate creative problem solving. As 1 farmer reflected, "*when farmers get together, we always figure something out*." This includes both a "*discussion aspect, but also just practical skill sharing and technique sharing.*" Peer-to-peer sharing of experiences of loss due to climate impacts, supports others in better preparing to address similar situations on their own farm. A farmer described how; "*one of the more impactful things for me has been ... anecdotes from farmers who have been impacted by like specific storms, or specific events, or climate disruption in a big way and seeing how they've dealt with it and recovered from it.*"

The quality of these spaces was described as being inspirational in unexpected ways and generating new perspectives for growers, in addition to helping them find answers to questions. As one farmer described it:

> *sometimes you're looking for an answer to a specific question and then there are other times, where you don't even know what you're looking for ... a farm tour or a meeting like this ... it stimulates your imagination and, you see something, [and think] "Oh my god, I never thought of that. I would never even thought to ask that question." ... There's two things—that sort of inspirational thing, and asking a specific question.*

Similarly, new farmers gain invaluable perspective from observing conversations and questions from more experienced farmers. A new farmer directly addressed more experienced farmers in the group and said, "*you're asking a question that I haven't even thought to ask and when you ask it, it automatically makes me get a little closer to where you're at.*"

Deliberative spaces created by networks are characterized by drawing together diverse types of expertise. In many networks, staff or key extension agents play a facilitation role that enhances the dialogue and connection. A farmer reflected on how on a key person, "*makes it possible for me to connect with other growers and learn*," and is aware that it is unique in being, "*a very different model than the conventional top down extension.*" Everyone's perspective is valued in these spaces, and farmers' comments are often qualified with an introduction that explains their level of experience and scale of production, allowing others to contextualize and compare their perspective appropriately.

Finally, moderated grower list-servs were repeatedly called out as especially valuable in bringing together collective knowledge and experience to address emerging issues. One farmer remarked, "*as soon as I'm on that list ... I'm ahead of the game.*" One list uses a format where when one grower asks a question; "*they get a bunch of responses and they summarize it and send it back out*," taking on the task of synthesizing the collective group knowledge and sharing it with the entire community. The list-servs often bridge the collective knowledge of many different types of farmers' expertise including, "*conventional farmers, organic farmers, Vermont farmers, Maine farmers, New Hampshire, New York, everything ... it's a big deal!*" Some of the most experienced and respected growers in the region, and extension agents, are known to offer advice on list-servs.

5. Discussion

This article presents the results of a multiphase mixed-methods research effort on climate adaptation and resilience in the Northeastern United States that highlights the role of farmer networks. Farmers were first asked about how they were adapting to extreme weather climate impacts in a survey format and then asked to identify what supports their resilience to climate change in facilitated discussions. The results of our quantitative data analysis add new insight on the factors that influence the emergence and adoption of agroecological innovations for climate adaptation, including network affiliation and a perceived lack of community support. Our complementary qualitative data analysis then explains the mechanisms through which farmer networks enhance collaborative problem-solving.

Considered together, the results of our survey and focus groups point to the important role of farmer networks in enhancing the capacity of farmers to address climate change and new challenges. First, our research demonstrates that some farmer networks have influenced the emergence and adoption of farmer-led agroecological innovations for addressing climate-related risks on vegetable farms in the Northeastern United States. Our findings suggest that not all farmer networks do this to the same extent. Second, farmers identified that networks support them in learning about new ideas, accessing resources, and engaging in creative problem-solving, through facilitation of spaces for exchange with peers and experts and being responsive to the emerging needs of producers. These qualities of networks were identified as directly enhancing farmers' capacity to adapt to climate change when farmers were asked about what supported their resilience to climate change. Belief in climate change, perceived vulnerability, financial capacity, and perceived community support were significant cognitive factors in our model predicting the likelihood that vegetable farmers in the Northeast would have adopted no-till as a climate adaptive practice in 2017–2018. The extent to which farmers consider climate change in their long-term farm planning, and their confidence in understanding their vulnerability to climate-related risks influences climate adaptation decision-making. The importance of climate beliefs and perceptions as precursors to adoption decisions is consistent with recent American scholarship referencing the Theory of Planned Behavior (e.g., Arbuckle et al., 2013; Mase et al., 2017). Financial capacity was significant in predicting the adoption of no-till, but not the consideration of it as adaptive. This suggests that financial capability makes the difference between considering a practice adaptive and actually adopting it.

Our study also found that famers who perceive that their community will support them in recovering from the impacts of climate change are less likely to have adopted no-till and are less likely to consider it adaptive. It is important to note here that this community is a farmers' local neighborhood and direct customer base, not necessarily farmer networks, which can often span multiple states in scale. We posit that farmers who perceive that their community will support them in bouncing back from severe climate impacts may have less imperative to invest in climate adaptation practices, as they have this community safety net. Whereas farmers who do not perceive that they have a community who will catch and support them when severe weather impacts set them back may have a stronger desire and need to build greater coping capacity into their production systems. We conceptualize a portfolio of assets a farmer may rely on for coping, adaptation, and resilience (i.e., Lengnick, 2015; Williams et al., 2015), where different farmers have different combinations of assets to support their resilience. For example, a farm with a subscription-based community-supported agriculture (CSA) business model has unique social and financial support mechanisms for addressing risks built into their farm operation through their direct relationships with customers, whereas a wholesale commodity crop production farm would not have those same safety nets and may invest more resources into adaptive practices or crop insurance. When community support is a strong asset in the portfolio to support resilience, the imperative to invest in other assets, such as adaptive practices, may be reduced. Notably, this community support is enabled by a local bonding type of social capital but is likely different than the bridging social capital within the farmer networks highlighted in other parts of this research (i.e., Putnam, 2000). This finding is an important point that deserves further research to better understand why.

Less experienced farmers are significantly more likely to adopt or consider no-till in our study. This is consistent with other research on the determinants of conservation practice adoption (Carlisle, 2016). Conversely, greater levels of education have been correlated with the adoption of conservation practices (Carlisle, 2016), yet our model indicates that education is negatively associated with adoption of no-till among vegetable farmers in the Northeast.

The results of our modeling indicate that network affiliations can have strong and significant influences on the adoption and consideration of emerging agroecological practices, and that network affiliation may be an important driver of the spread of this innovation than geography, which is an important contribution of our research to the theory of diffusion of innovations (Rogers, 2003). Not only did network affiliation have a stronger effect, the geographic "neighborhood effect" at the state scale had no influence on adoption or emergence of innovations in our study. This may reflect the large spatial scale of our analysis, where the state variable was not able to detect a neighborhood effect. Perhaps a county scale variable or other geospatial analysis would be better suited to test this. It is also possible that dramatic changes in information sharing pattern due to technology in the last 2 decades have altered the "neighborhood effect" phenomenon. Further research on the influence of geographic communities is needed.

In our study, vegetable farmers affiliated with some networks were significantly more likely to have adopted no-till for climate adaptation. While these networks were significantly associated with the occurrence of no-till, there are many other farmer networks in the region which had no significant impact on adoption detected in our study. Some of the networks that promoted no-till innovation were significant, and some were not. This suggests that there may be characteristics of some networks, which were more conducive to the spread and advancement of this practice.

Strong social bonding and peer influences have been shown to influence adoption of organic practices (Wollni and Andersson, 2014) and could be responsible. Likewise, members of these networks may have shared beliefs and awareness of climate risk, which influence adaptation behaviors (Mase et al., 2017). Another possible explanation is that a network may have enhanced learning opportunities that speeds up the diffusion of innovations process, increases peer learning or may have an influential early adopter (Rogers, 2003). Each, or all, of these mechanisms may be at play, but the latter is most strongly supported by our complementary qualitative research. Our research identified that farmer networks build adaptive capacity by creating space for learning, information exchange among peers, and coproducing new ideas to address shared challenges. These spaces facilitate new and enhanced relationships among farmers and increase access to other resources that enhance farmers' capacity to address and plan for climate change. In addition to enhancing access to other resources, networks also generate new resources based on reflexive listening to farmers needs and unique contexts. The discourse constructed by farmers in these spaces addresses their most salient concerns and links the kind of tacit local knowledge among farmers described by Šūmane et al. (2018). This advances the compatibility of innovative ideas to each unique context, influences adoption of adaptation practices, and builds important relationships among farmers and the agricultural community that can be brought to bear on other challenges. Here, we have seen evidence that reflexive engagement in research results in the salient and usable outcomes espoused by PAR (Kindon et al., 2007), but that this happened with or without academic experts as partners in the process.

In our study, extension agents were named as playing valuable roles in facilitating change and transition for farmers by hosting spaces for discussion and exchange of ideas and linking farmers to other peers with more experience. Farmers' appreciation of experts as facilitators in farmer peer learning departs from claims by Wood et al. (2014) that facilitators in farmer networks are not valuable, but is consistent with agricultural innovation systems theory (i.e., Klerkx et al., 2012; Wigboldus et al., 2016), which has emphasized the importance of facilitation roles in advancing farmer innovation. This finding also reflects the role of extension in adaptive capacity as described by Extension 3.0 theory (Lubell et al., 2014), whereby extension can enhance agricultural adaptive capacity through mediating network-based knowledge systems in ways that help farmers react to changes in economic, social, and environmental processes. The majority of networks we observed had facilitators, some stronger than others, but we are limited in the extent to which we can explore this here as we did not assess the facilitation characteristics or modes of engagement of these networks in a systematic way. Rather we rely on the observations of farmers about this in focus group discussions. Interestingly, farmers shared examples of extension agents who could both facilitate peer-to-peer learning and bring science-based knowledge to their conversations as key individuals. Farmers did not specifically mention individuals who lacked science-based knowledge, but that does not mean individuals who perform purely facilitation roles are not contributing. This is a topic ripe for further inquiry and research.

Importantly, our research suggests that networks have different niches in supporting farmers to meet their goals and access capitals. This aligns with Ostrom et al. (2007), whose work emphasizes caution in making claims about consistency across contexts and situations. Networks may play different roles in enhancing farmers' adaptive capacity, and to different extents. Further research is needed on the way network structures, cultures, and goals interact with farmers' adaptation behaviors and adaptive capacity. Specifically, a characterization of farmer networks in the Northeastern United States, including their roles and modes of engagement, would further our understandings of how farmer network structures interact with innovation processes.

Our findings align with other research identifying how shared learning in niche famer networks supports transformation, problem-solving, adoption of new practice and collective action among farmers (Hassanein and Kloppenberg, 1995; Kroma, 2006; Nelson et al., 2014). Our research work explores the specific role of grassroots farmer networks in the Northeastern United States in agroecological transformations and aligns with theories of democratic innovation systems that place farmers perspectives as central to solutions, such as the Farmers First theory (Scoones and Thompson, 1994). Farmer networks that are nimble, deliberative, and responsive create alternative structures to support farmer-led agroecological transitions from the ground up, and can build alternative structures to enhance resource access and adaptive capacity. From a community development perspective, social capital emerges as the most important factor at a systems level which enables innovation and new ideas to grow, other capitals to be used, and develop collective solutions to shared problems (like market pressures, regulatory pressures, new production issues like pests and weather). This is consistent with the way social capital has been widely understood to enhance adaptive capacity (Pelling and High, 2005), though our research also suggests that social capital can grow human capital, as confidence and knowledge.

A growing body of research on agroecological sustainability transitions highlights niche sustainable agriculture movements as important case studies for understanding the leverage points for change toward a paradigm with a fundamentally different relationships between the ecological health and agricultural production (International Panel of Experts on Sustainable Food Systems, 2018). The question of how to scale up lessons from these niches is at the heart of current sustainability transition debates (Augenstein et al., 2020). Farmer networks and social organization have been identified as key drivers of bringing agroecology to scale (Mier y Terán Giménez Cacho et al., 2018). Both the human relationship dimensions of this story in our research, and the local/contextualized nature of knowledge exchange in this niche, make scaling hard to envision. It is possible that small scale and niche aspects make the kind of collective action and collaboration we observed possible. And interestingly, farmer-led innovation was identified in our study as being stimulated by scarcity of research investments, and collective action as a response to challenges. This may suggest that some of the emergent strategies that have enhanced adaptive capacity of niche sustainable agriculture, are simply not scalable. At the level of regime, where resources and supports are more abundant, the driving force of lean resources may be absent.

5.1. Implications and future research

Our findings imply that extension professionals and farmer networks are crucial elements of a social-technical system that supports farmers in innovating and adapting to climate change and other new challenges. Agricultural policy should invest in supporting both extension and farmer networks as structures that are responsive and adaptive. Additionally, policy that supports farmers' financial capabilities could provide the critical resources that enable growers who are considering adaptation practices to adopt them. Financial support programs may make the difference between considering a practice adaptive, and actually adopting it.

Outreach can enhance farmer adaptation to climate change by engaging in farmers networks as key spaces where learning happens and innovations are advanced. Our research also suggests that understanding vulnerability is a precursor to adaptive planning and management decisions. Therefore, extension programs should build farmers' understandings of their farm's vulnerability to climate impacts, in order to support proactive adoption of climate adaptation practices.

All of this work merits greater investigation and exploration, in the Northeastern United States with other types of farmers, and elsewhere. In particular, future research should explore the specific explanatory factors behind the way networks influence adaptation behaviors, and the way network structures, cultures and goals interact with both farmers' adaptation behaviors and adaptive capacity. Systematic characterization of farmer networks and their facilitation methods would aptly complement this inquiry. Further research is also needed to explore the way scarcity and challenges influence collective action, and sustainability transformations in agriculture. Research that explores differences among farmer network structures, norms, and governance styles would complement our understandings of how farmer networks support climate adaptation. Likewise, our findings would be complemented by investigations from the perspectives of extension professionals and network staff on the same topics. Finally, on-farm research trials that evaluate the benefits and drawbacks of farmer-led innovations for climate adaptation should be prioritized.

5.2. Limitations

This study is exploratory and participatory. Our data collection was conducted using a convenience sampling approach at a single time, which limits the extent to which we can generalize the results of our finding. However, our sampling did occur across state and network lines, suggesting that the phenomenon we observe and describe is happening at the regional scale, and across different networks. Our qualitative data were gathered in a participatory setting, which traded consistency of focus groups for community impact. Follow-up research could gather more specific and targeted perspectives on the ways farmer networks enhance adaptive capacity by using semi-structured interviews, documenting governance styles, and modes of interaction.

6. Conclusion

Our research indicates that farmer networks, climate beliefs, and perceived vulnerability are associated with the emergence and adoption of agroecological innovations for addressing climate-related risks among vegetable farmers in the Northeastern United States. Geography had no impact on the diffusion of innovations in our model, yet farmer networks emerged as important drivers of the spread and adoption of innovative agroecological practices for climate adaptation.

Farmer networks that are nimble, deliberative, and responsive support farmer-led agroecological transitions from the ground up and can build alternative structures to enhance resource access and adaptive capacity. Not all networks are the same in this regard. Among the characteristics of networks that enhance farmers' capacity to innovate and adapt to climate risks, creating spaces for information exchange and collaborative problem-solving emerges as among the most important ways that networks support farmer-driven adaptation and transformation. Features of networks that enhance adaptive capacity include the facilitation of new and enhanced relationships among farmers, enhanced access to diverse resources, and the generation new resources based on reflexive listening to farmers' needs.

Our work reveals that farmers are innovating to adapt to climate change in the absence of formal climate focused outreach and support. Outreach, policy, and research can support, enhance, and inform the advancements and innovations farmers are making toward sustainability and resilience. Networks, extension, and deliberative spaces for collaborative problem-solving are valuable assets to the socio-technical system which enhance farmers' capacity to adapt to climate change and address new challenges. Tools or programs that help farmers better understand the vulnerability of their farm to weather-related threats and offer financial assistance may support them in taking proactive measures to adapt. Finally, resource scarcity was identified as a catalyst for collective action and innovation, an idea that suggests scaling the conditions conducive to farmer-led innovation may be limited.

Data accessibility statement

Participants in this study did not agree for their data to be shared publicly. Deidentified portions of the data that support the findings of this study may be available from the corresponding author, AW, upon reasonable request.

Supplemental files

The supplemental files for this article can be found as follows:

Text S1. Detailed description of the preparation of independent variables for quantitative analysis. (DOC)

Table S1. Independent variables considered in the logistic regression models. (DOC)

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Author contributions
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Contributed to acquisition of data: AW, JWF.

Contributed to analysis and interpretation of data: AW, JWF, MTN, DC, VEM.

Drafted and/or revised the article: AW, JWF, MTN, VEM, DC.

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