RHODE ISLAND'S AGRICULTURAL PRODUCTION AND CLIMATE CHANGE:
PRACTICES, PERCEPTIONS, AND LIMITATIONS

BY

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ABSTRACT

Climate change is projected to have significant impacts on the productivity and sustainability of agricultural production in coming years. In order to safeguard agricultural productivity and strengthen the resilience of regional food systems, farmers and other agricultural stakeholders will need to explore and adopt on-farm practices that are adaptive and/or mitigative. Understanding how farmers perceive and respond to climate change on their farms is essential to resilience building efforts.

The goal of this research is to address the lack of information on the concerns and response strategies of food-producing specialty crop growers in the U.S. Northeast, specifically the state of Rhode Island. Mixed-methods were used to explore the climate change perceptions and responses of farmers in the state. An additional survey of Cooperative Extension professionals in the U.S. Northeast was conducted and complemented by a content analysis of Cooperative Extension outreach on the websites of ten land grant universities in the Northeast.

Quantitative survey and qualitative interview findings indicate that farmers in Rhode Island have discerned changes in the frequency of extreme temperature and precipitation events and general shifts in the nature of seasons but have difficulty tracking changes in other specific climate change factors. Farmers preferred climate-wise practices that are adaptive rather than mitigative and serve multiple functions. Results from the Cooperative Extension survey and content analysis found low levels of outreach to farmers on climate change and agriculture in the Northeastern U.S., often in ineffective mediums. Online outreach, however, has been

well focused on the climate change-related concerns of farmers and Cooperative Extension professionals.

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PREFACE

This thesis has been prepared using University of Rhode Island graduate school Manuscript Thesis Format. The manuscript of included in Chapter 3 is in the process of revision for submission to *Agriculture and Human Values* and formatted to meet the required standards. Chapter 4 was written in accordance with the submission guidelines of *Sustainability* and is still under revision.

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CHAPTER ONE

INTRODUCTION

1. Introduction

Agricultural production is highly dependent upon climatic conditions and, in turn, so is the stability of the food system. Climate change effects have the potential to undermine regional food security efforts such as New England's 50 by 60TM plan, which has set a goal of meeting 50% of food needs sustainably from regional sources by 2060. While the target date of the plan is 2060, viable on-farm responses to changing climatic factors must be identified now, and producers must be encouraged to prepare for their impacts on production, farm resilience, and farm livelihoods. These on-farm responses may be characterized as either adaptive or mitigative. Adaptive measures seek to moderate harm and/or to exploit new opportunities, e.g. using drip irrigation to mitigate precipitation variation or shifting planting dates to accommodate changing growing seasons. Mitigative measures are intended to reduce the sources of greenhouse gases or to increase the sinks for these gases, e.g. through no-till agriculture or zero-acreage farming. Despite the strong influence that environmental conditions have on farming practices, socioeconomic tradeoffs may influence on-farm decisions about whether and how to respond to climate change. Farmers' perceptions of climate change and climate change effects, actual or perceived barriers to response, and the broader literature and discussion of practices or response strategies may also affect on-farm decision-making.

Existing research on the interplay of agriculture and climate change is often conducted at global, regional, and on-farm scales. The primary foci of this research can be grouped into two themes: 1) scientific investigation of potential response methods and 2) projected climate change and response impacts. Research on response methods focuses on proposing and/or evaluating new tools, techniques, or systems to increase crop yields or resilience. Projection-based research, on the other hand, focuses on quantifying crop yields under certain climatic conditions, predicting the economic implications of climate change, or modeling land-use changes. While there is no shortage of research dedicated to these topics, there is a relative lack of research that attempts to characterize or quantify the type, degree, and frequency of real-world agricultural responses to climate change. Predictive- or assessment-based versus observation-based approaches break largely along lines of national development—with research in industrialized nations focusing more on the former and research in developing nations on the latter.

Studies conducted in Africa, Asia, Central America and Mexico have utilized surveys, interviews, and on-farm observations to gather information regarding how farmers are responding to climate change. These studies attempt to characterize and understand how farmers in their region have changed their on-farm practices in response to climate change while simultaneously evaluating the socio-economic drivers and influences behind those responses. The majority of research on agriculture in the United States concerning climate change responses, on the other hand, has been conducted with the goal of furthering or establishing new agricultural practices that

will increase yields and resilience. An archetypal example of this research focus is the USDA's 2014 report titled, *Climate Change and Agriculture in the United States: Effects and Adaptations*, which provides a series of proposed response strategies and an assessment of their anticipated efficacy (Walthall et al., 2013). Also notable with regard to research on climate change in the U.S. are 1) the lack of observational research on on-farm practices and 2) the almost exclusive focus on small grain production in the Midwest and West. The existing literature on climate change research in agriculture is more completely reviewed in Chapter 2.

The overall goal of the research described in this thesis is to address the lack of information on the concerns and response strategies of specialty crop growers in the Northeastern United States, specifically the state of Rhode Island. Rhode Island presents a relatively unique set of spatial circumstances for this research. It has a diverse population of producers—including conventional and organic farms plus farms that are not organic certified but follow sustainable practices—coexisting within a small geographic area where they face similar socioeconomic and biophysical conditions of production. The relative uniqueness of the production environment provides an ideal background for identifying other factors that influence farmers' decisions on whether and how to respond to climate change. Consequently, findings from Rhode Island could be generalized and applied to other states in the region.

Because the literature suggests that informational resources and interactions with experts influence farmers' adoption of mitigative and adaptive practices and the nature of those practices, a content analysis of the climate-change-related content of

the Cooperative Extension websites of regional land grant universities was conducted, and staff with specialty-crops extension outreach responsibilities were invited to complete an online survey on climate change (Lawandy, 2019). Results from the content analysis and survey are described in Chapter 3. To characterize on-farm responses and their determinants, vegetable, fruit, nut, and herb farmers in the state were invited to complete an online or paper quantitative survey collecting farm and farmer background data, information on crops and production practices, and current and planned mitigative and adaptive practices. Qualitative interviews were subsequently conducted with a purposive subsample of respondents in order to explore in greater detail production practices, on-farm responses to climate change, and limitations to response. Results from the quantitative survey and qualitative interview are discussed in Chapter 4.

This research potentially benefits the agricultural sector by 1) filling an existing research gap, 2) informing growers of how their peers have successfully or unsuccessfully responded to climate change factors, 3) providing insight to advisors about agriculture in their state, 4) helping policymakers develop systems that facilitate both environmentally and economically stable practices for farmers, 5) establishing a generalizable methodology, and 6) ultimately providing information that can be used to enhance the resilience and productive capacity of local food systems.

CHAPTER TWO

REVIEW OF LITERATURE

1. Introduction

Agricultural productivity and climate are inherently enmeshed. Agriculture is reliant upon natural resources, ecosystem services, and an environment suitable to plant survival—all of which are subject to climate or changes in climate (Adams et al., 1990; Walthall et al., 2013). Increased global surface temperatures, extreme and variable precipitation patterns, growing season length, soil degradation, and elevated atmospheric carbon dioxide levels are the most impactful aspects of climate change with respect to agriculture but hardly the only impacts (Adams et al., 1990; Hatfield and Takle, 2014; Walthall et al., 2013). Changes to the production environment will undermine the production capacity of some regions while bringing benefits to others (Antle, 2008; Parry et al., 2004). The potential impact, both negative and positive, is highly significant, with some modeling scenarios predicting up to a 30% decrease in African and South Asian crop yields by 2080 (Parry et al., 2004) and others projecting an 8-50% increase in yields in the United States by 2090 (McCarl and Reilly, 2006).

Conversely, agricultural activities also influence climate. These activities, particularly industrial/chemical production techniques and practices, are widely recognized as a major contributor to environmental degradation and greenhouse gas emissions (Friel et al., 2009; Garnett, 2013, 2011). According to multiple studies, the agricultural sector—from production through transportation and processing—is responsible for up to 30% of global greenhouse gas (GHG) emissions (Bellarby et al.,

2008; Garnett, 2013; The World Bank, 2008). Agricultural production has other direct and short-term influences on the environment and climate, including intensive water usage, agrochemical pollution, soil degradation, and continued deforestation (Garnett, 2013; The World Bank, 2008).

The interplay of agricultural production and climate does not occur in a vacuum but is subject to external drivers including population growth and increased food demand (Tilman et al., 2011; Walthall et al., 2013). In the United States, shifts in consumption patterns, particularly among high income populations, will increase demand for fruits, vegetables (except potatoes), cheese, yogurt, and fish (Blisard et al, 2003). A growing population, rising income, and demographic shifts is projected to increase food spending in the United States by 26.3% (from 2003 to 2020) with fruit seeing the largest increase of any crop type at 275% (Blisard et al., 2003). Demand for crop calories may increase by as much as 110%, with the potential for a 117% increase in demand for crop protein by 2050 (Schmidhuber and Tubiello, 2007). Other projections indicate a 50% increase in demand for agricultural products by 2030 and an additional 170 million individuals at risk of hunger by 2080 (Food and Agriculture Organization (FAO), 2002; Tilman et al., 2011). Climate change and increased food demand have compounding effects that could undermine the stability of food systems by amplifying environmental and economic volatilities (Wheeler and von Braun, 2013). Depending on the climate change scenario, the agricultural sector in the United States could suffer anywhere from losses of \$250 million to gains of roughly \$5 billion annually (Antle, 2008). Crop production in the Northeastern United States was

valued at \$9 billion in 2012, and the region is ranked high in terms of its production of high value vegetable, fruit, and other specialty crops (Wolfe et al., 2018). It is thus imperative that agriculture respond to climate change while at the same time producing more food, potentially through a combination of production intensification and the implementation of climate responsive practices. However, current methods of agricultural intensification commonly contribute to GHG emissions, deforestation, eutrophication, and soil degradation; their expanded use, without modification, can be expected to exacerbate climate change and further degrade the environment, undermining long-term farm viability (Friel et al., 2009; Garnett, 2013; Garnett et al., 2013; Tilman et al., 2001).

The climate change responses available to agricultural producers can take myriad forms, and their successful implementation is highly dependent on site-specific characteristics. Despite the recombinant and overlapping nature of climate-driven on-farm agricultural responses, the majority of these practices or methods can be characterized as either adaptive or mitigative. The distinction between an adaptive measure and a mitigative measure is found in their short-term or long-term focus. Adaptation measures are generally reactive in nature and provide benefits within a growing season. Mitigation as a concept is more ambitious than adaptation, as it seeks to actively shape the environment and future climate through processes that provide cumulative benefits over multiple growing seasons. Mitigative measures leverage processes like soil carbon sequestration to lessen the impacts of previous GHG emissions or to reduce current emissions. The Fourth Assessment Report of the UN

IPCC formally defines mitigation as “an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases” (United Nations IPCC, 2014).

Adaptive measures, on the other hand, are designed to reduce negative outcomes and increase benefits from climate change. As such, adaptation is an inherently reactive concept that has been a part of agriculture sector throughout its history as farmers try to improve their practices relative to their environment. The UN defines adaptation as “adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm and exploits beneficial opportunities” (United Nations IPCC, 2014).

Climate change responses may also be categorized as *incremental* or *planned transformational* (Anwar et al., 2013; Smit et al., 2000; Smit and Skinner, 2002).

Scale determines whether actors can engage in incremental or planned transformational responses and the scope of impact stemming from their actions (Anwar et al., 2013; Kates et al., 2012). Incremental adaptations, “actions and behaviors that already reduce the losses or enhance the benefits of natural variations in climate and extreme events,” occur at the on-farm level, often in response to a specific stimulus (Kates et al., 2012). Because of the *in situ* scale of incremental responses, farmers are responsible for their implementation and management. On the one hand enabling, this characteristic of incremental response can have limitations when farmers lack the means or information to respond incrementally to perceived risks (Deressa et al., 2009; Kates et al., 2012). While incremental responses generally occur as a minor alteration to a specific agricultural site, transformational responses are those which

either 1) fundamentally alter the region by processes such as land-use changes or the collective orientation of individual incremental responses or 2) occur at a broader, more system-wide scale, often guided by institutional or community level actors (Kates et al., 2012).

Farmers face their own individual sets of vulnerabilities based on their socioeconomic and biophysical context (Crane et al., 2011; Harvey et al., 2018; Howden et al., 2007), resulting in a high degree of variability in the impacts of climate change on farmers and their adaptation needs (Crane et al., 2011; Harvey et al., 2018). Degree of vulnerability also varies by crop and by production system. Specialty crops are also particularly relevant to food systems initiatives in the Northeastern United States such as New England's 50 by 60TM plan, which has set the ambitious goal of meeting half of regional food needs through local production by 2060. (Field crop production is of relatively limited importance in New England; in Rhode Island, for example, oilseed and grain farming contributed less than 1% of the state's agricultural production in 2012.)

The purpose of this review is to examine the scholarly literature in the social sciences of agriculture on climate change and agriculture in order to identify proposed and documented incremental (on-farm) climate responses and research gaps in the existing literature. The research reported in the reviewed articles can be grouped into two broad categories: experimental research evaluating proposed adaptive or mitigative methods and observational studies documenting on-farm adaptation and mitigation. The latter studies often take a multi-disciplinary approach to the

assessment of agricultural response with the collection of both quantitative and qualitative data about on-farm decision-making and climate change response. This research is primarily conducted at an on-farm or local level and strives to identify the actualized responses on farms, farmers' perceptions of climate change, and the limitations to or determinants of climate change response. This review does not include studies that are dedicated to projecting or modeling the impact of climate change on agriculture or crop production across sectors or region.

1.1 Methods

The research included in this review was identified through a keyword search of multiple databases, Google Scholar alerts, and the works cited sections of previously catalogued literature. The literature that was eligible for inclusion in this review were, e.g., reviews, original research articles, institutional or NGO reports, and meta-analyses. All of the articles featured in this review were published in English. As the most comprehensive academic search engine (Gusenbauer, 2019; Martín-Martín et al., 2019), Google Scholar was the primary resource for finding articles through keyword searches. Mendeley was used to locate relevant citations from previously catalogued studies that could not be found in Google Scholar. The following keywords were paired with "agriculture" in searches: "climate change," "climate change adaptation," "climate change mitigation," "climate change response," "climate change perceptions," "on-farm response," "climate change," "determinants to adaptation," "decision making, climate change," "climate change impacts," and "climate change effects." These search terms did not include specific locations, such as "United States"

or individual climatic factors like “drought.” A total of 145 studies were analyzed for this review.

After relevant literature was identified, the contents were coded in Microsoft Excel. Coding was done by identifying relevant keywords or phrases and patterns in subject matter to identify emergent themes related to proposed or observed on-farm climate change response. This was followed by a traditional narrative review of the coded data (Collins and Fauser, 2005; Jesson et al., 2011). The review was scoping in nature and sought to characterize existing research and then to use that characterization to identify knowledge gaps and inform future research (Jesson et al., 2011).

2. Proposed responses

Academic research on on-farm responses to climate change has largely focused on evaluating new growing methods or technologies as a means of addressing a particular climatic stimulus or achieving a specific agronomic goal. This research includes controlled research trials, crop production models, and assessments of the sustainability and intensification value of different growing methods. The nature of on-farm agricultural responses is highly specific to climate and production system as well as the farmer’s socio-economic position. Consequently, the scientific literature specifically addressing climate change focuses on conceptual or goal-based strategies of adaptation such as water conservation with less attention to specific regions, crops, or climate factors or on individual practices like drip irrigation (Crane et al., 2011; Harvey et al., 2018; Howden et al., 2007; Perfecto, 2015).

Discussions of incremental adaptation often focus on overall goals or strategies as opposed to specific recommendations. An example of this would be to say that farm management is proposed as a response strategy to a longer growing season, while adjusting planting schedules is a specific practice within the proposed adaptation strategy. Many of these specific practices are contextually dependent constituents of a broader response strategy, and in general are not a wholly sufficient means to an end (Howden et al., 2007; Walthall et al., 2013).

The responses most commonly proposed in the literature are adaptation, not mitigation, based strategies. In the United States, this bias may be attributable to the findings of studies conducted in major production regions which show that a minority of farmers support actions to mitigate GHG emissions while a majority express strong faith that technological advancement of agricultural technologies will overcome environmental stressors (Arbuckle et al., 2015, 2013; Gardezi and Arbuckle, 2018).

Key adaptation or mitigation strategies drawn from major reports published by the USDA, the United Nations IPCC, the World Bank, the United States Global Change Research Program and previous academic reviews include: crop diversification, altered farm management, water conservation strategies, financial management plans, no-till or conservation tillage, and biochar for soil carbon sequestration (Anwar et al., 2013; Howden et al., 2007; Sauerbeck, 2001; The World Bank, 2008; United Nations IPCC, 2014; Walthall et al., 2013).

2.1. Adaptation strategies

Farm management

Altering farm management strategies as a climate change response option has been proposed frequently due to its adaptability and wide applicability. It is also the most broad concept discussed in the climate change adaptation literature, encompassing most other response options. Because the intensity, duration, and variability of climatic conditions determine the viable growing season for a farm, farm management adaptations are often temporal in nature, shifting the timing of cropping or peak plant growth to match favorable climatic conditions (Anwar et al., 2013). Altering sowing or transplant dates, for example, can be an effective farm management strategy to avoid frost both early and late in the growing season, to alter canopy development for optimal yield benefits, to avoid pest pressures, and, ultimately, to shift harvest dates (Anwar et al., 2013; Chen et al., 2012; Kistner et al., 2018). Farmers could also increase their input use efficiency by correlating applications of fertilizers and pesticides to weather forecasts (de la Poterie et al., 2018).

Other non-temporal changes have been proposed in the literature. Conversion from conventional to organic production standards has been advanced as an environmentally sustainable climate change adaptation (Anwar et al., 2013; Boron, 2006; Scialabba and Müller-Lindenlauf, 2010). While this shift represents a more dramatic approach to climate change response than, say, altering sowing times, it does not necessitate that a farm entirely alter its system of production. Crop choice and land use may largely remain unaltered, ultimately making this an incremental response (Kates et al., 2012; Perfecto, 2015; Scialabba and Müller-Lindenlauf, 2010). The

effectiveness of this strategy, however, is contentious. Smith et al. (2019) found that, if adopted at a broad scale in England and Wales, conversion to organic agriculture could lead to increased emissions compared to conventional production because of reduced yields and the need for increased production area abroad and, consequently, deforestation (Smith et al. 2019). At the opposite end of the spectrum, adoption of conventional agricultural tools such as genetically modified, improved seeds, increased intensification of inputs, and synthetic pest management systems has been proposed as a potential climate change adaptation strategy (Chen et al., 2018; Smit and Skinner, 2002; United Nations IPCC, 2014). Evidence from studies of farmers in the U.S. Midwest, however, suggests that the techno-optimism embodied in these tools has overall resulted in delayed adaptation and response by farmers (Catton Jr. and Dunlap E., 1978; Gardezi and Arbuckle, 2018).

Diversification

Diversification has emerged as a widely proposed and promoted adaptation strategy because it provides farmers with a highly adaptable set of recombinant options that can be applied to meet specific agronomic needs or to respond to climatic factors (Altieri, 1999; Lin, 2011). It has been studied at varying scales, from the crop to the landscape and region, and with varying degrees of specificity with regard to crop species and production system (Anwar et al., 2013; Farrell et al., 2018; Houston et al., 2018; Klocker et al., 2018; Walthall et al., 2013). Diversification as a behavior can take many forms based on the end goal of the grower, and methods of diversification are categorized by their impact on genetic variety, species, and

structural elements of production (Lin, 2011). Diversification at the crop scale can refer to growing different varieties of the same crop or using a combination of crop varieties that have different and complementary structural and physiological tendencies in the same planting space (Lin, 2011). Diversification at the field scale is the differentiation of crop types within the same field and can also refer to the planting of trap crops or habitat strips within or around the field. At the landscape scale, diversification may be achieved by integrating multiple production systems, such as mixing agroforestry management with cropping, livestock, and fallow to create a highly diverse piece of agricultural land (Altieri, 1999; Gurr et al., 2003; Lin, 2011).

The wide range of diversification methods can entail changing the spatial and temporal order or assemblage of crops grown, increasing the crop type diversity, and increasing the intensification of specific crops as well as selecting more climatically or agronomically appropriate varieties of crops already being produced by the grower (Anwar et al., 2013; Howden et al., 2007; Lin, 2011; Olesen et al., 2011; Vermeulen et al., 2012; Wall and Smit, 2005). This strategy allows farmers to both increase the agricultural resilience of their operations and improve upon or expand into new markets or sales channels that build economic resilience at farm and food system scales (Altieri, 1999; Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, 2018; Gurr et al., 2003; Walthall et al., 2013).

Water conservation and management

Changes to temperature zones and seasonality as well as increased variability and disruption in precipitation patterns increase the importance of efforts to improve

water conservation and management in agricultural settings (Adams et al., 1990; Food and Agriculture Organization (FAO), 2002; Gowda, P., J.L. Steiner, C. Olson, M. Boggess, T. Farrigan, 2018; Hatfield and Takle, 2014). As a response strategy, these efforts have two primary objectives: 1) to improve on-farm water collection and storage techniques as a buffer against precipitation variability and 2) to increase the distribution efficiency of available water (Campbell et al., 2014). Responses with the latter objective are designed to distribute and maintain available water supplies as opposed to increasing the total water available for agriculture. The most commonly discussed *in situ* manifestation of this strategy is the installation of drip tape or other irrigation systems that allow farmers to limit their reliance on rainfed agriculture as the variability in patterns and levels of precipitation change around the globe (Baca et al., 2014; Chengappa et al., 2017; Kerr et al., 2018; Kistner et al., 2018; Walthall et al., 2013). On-farm decision making tools and data collection systems such as soil moisture monitors and weather forecasting tools allow farmers to more efficiently apply irrigation water (Walthall et al., 2013). Although the use of genetically modified crop varieties is not a water distribution system, crop varieties with reduced water requirements or increased uptake efficiency have been suggested as a means by which farmers can effectively limit their water use and address water conservation and management issues (James, 2006; James and Krattiger, 1996).

Responses designed to improve water collection and storage are highly spatially, climatically, and crop dependent. This variability can be seen at a national scale in the United States. The United States draws 58% of its agricultural irrigation

water from surface water resources (Walthall et al., 2013). The impact of climate change on surface water availability will differ from region to region across the country (Walthall et al., 2013). The northern and eastern parts of the country are expected to see an increase in precipitation and streamflow, whereas the semi-arid or southern plains regions are projected to see a higher proportion of precipitation falling in the winter and lessened streamflow (Walthall et al., 2013). Consequently, for farmers in the northern or eastern portions of the country, it may be reasonable and beneficial to install rain catchment systems or flood plain management techniques, while for those in regions projected to experience lower precipitation levels during the growing season increased use of mulch or cover crops might be a more appropriate response (Walthall et al., 2013). For all areas, tile drainage is promoted to manage excess water, particularly for large field monocultures of corn, soybeans, or small grains, and cover cropping is recommended to capture nutrients at the end of the season that would otherwise leach from the soil due to heavy precipitation (Kistner et al., 2018; Smit and Skinner, 2002; Walthall et al., 2013).

Attempts to better collect and store water for agriculture on farms can be aided by the use of additional weather forecasting tools that increase the information available to farmers and enhances their water and nutrient management by optimizing their fertilizer and input use efficiency (Anwar et al., 2013). The usefulness and resilience building capacity of these tools has been proposed in multiple studies in both developed and developing countries (Chen et al., 2018; Harvey et al., 2018; Olesen et al., 2011; Quang et al., 2018; Walthall et al., 2013). In the United States,

multiple government funded extension agencies provide access to climate and weather forecasting tools comparable to The Ohio State University's Field Application Resource Monitor (FARM), which allows users to define their locations of interest and receive 12- and 24-hour precipitation forecasts to aid in the application of fertilizer, manure, and/or pesticides ("Welcome to Farm", 2019).

Financial management

Financial management strategies such as crop insurance, government loans and subsidies, and programs to increase smallholder access to inputs and biotechnology can provide farmers with a means of building resilience that is not dependent upon manipulating environmental or climatic conditions yet prepares farms for extreme weather events or crop failures. Government expansion of or increased farmer participation in crop insurance programs, for example, is commonly proposed as a climate change adaptation because it reduces risk from crop failures or shifting markets by providing farmers with economic support (Crane et al., 2010; Kistner et al., 2018; Smit and Skinner, 2002). By providing a financial buffer to increasing climatic variability, crop insurance and similar strategies, it has been argued, enable farmers to engage in incremental responses at a higher rate than they would in the absence of that buffer (Assan et al., 2018; Bryan et al., 2009; Bryant et al., 2000; Hassan et al., 2010; Wienhold et al., 2018; Zizinga et al., 2017). Consequently, crop insurance and other financial support programs have been promoted as a way to encourage farmers with limited economic resources—particularly those in developing countries—to build overall farm-level responsive capacity (Bryan et al., 2009; Falco et

al., 2014; Food and Agriculture Organization, 2002; Schroth et al., 2009; Zizinga et al., 2017).

Specialty crops require more agronomic management and are often grown on limited acreage by small farmers, making them more difficult to insure. However, the diversity of crop species and varieties available to and grown in specialty crop systems provides natural insurance against climatic conditions (Falco et al., 2014; Kistner et al., 2018; Walthall et al., 2013). Crop diversification and financial insurance serve the same function by limiting the risk that farmers face from a single crop failing, and research suggests a negative relationship between on-farm crop diversity and farmer willingness to purchase crop insurance (Annan and Schlenker, 2015; Falco et al., 2014; Schroth et al., 2009).

2.2 Mitigation strategies

Conservation or no-till field management and biochar application are two widely-proposed mitigation responses for reduction of greenhouse gas emissions and soil carbon sequestration.

Conservation or no-till field management

Conservation tillage systems are characterized by a fundamental adherence to minimal physical disturbance of the soil coupled with varying degrees of crop residue management options based on the percentage of crop residues left on the field surface or incorporated into the soil (Powlson et al., 2016).

Conservation/minimal/no-till systems may be designed to sequester carbon in the soil, mitigate previous greenhouse gas emissions, improve soil structure, and/or aid in

water catchment and retention and are one of the most commonly discussed mitigative responses to climate change. While no-till is widely recognized as improving soil structure, its efficacy as a greenhouse gas mitigation tool and its impacts on yields are contentious (Neufeldt et al., 2015; Powlson et al., 2016; van Kessel et al., 2013; VandenBygaart, 2016). Points of specific disagreement include the total carbon storage capacity of agricultural soils, the rate and duration of carbon sequestration, the scale and rate of response strategy implementation, and level of yield reduction (Lal, 2004; Powlson et al., 2016, 2014; Smith et al., 2000; Stockmann et al., 2013). There is a high degree of uncertainty associated with predicting the ability of agricultural soils to sequester carbon and mitigate greenhouse gas emissions as a result of the specific soil being managed, local climate, socio-economic context, and modeling methods (Lal, 2004; Smith et al., 2000; VandenBygaart, 2016). This uncertainty extends beyond modeling total mitigation capacity and to the impact of no-till management on yields (Six et al., 2004; van Kessel et al., 2013). Pittelkow et al. (2015) conducted a meta-analysis of 610 studies that found no-till reduced yields unless practiced under the right climatic and production conditions—rainfed agriculture in arid environments—but these negative impacts could be lessened by pairing this practice with cover cropping and retention of crop residues in the field. Similarly, a 2013 meta-analysis of conservation/no-till studies found an average reduction in yield of 5% compared to conventional tillage, posing a potential tradeoff to farmers who would adopt this practice (van Kessel et al., 2013). Powlson et al. 2016 also found that while conservation/no-till practices improve soil physical properties and reduce

atmospheric greenhouse gases, impacts on yields are inconsistent from year to year (Powlson et al., 2016). Durability of carbon sequestration through no-till management is highly unstable and capable of being lost after a single tillage event, thus reversing previous mitigative efforts and limiting the effective capacity of conservation/no-till practices to their continuous use (Conant et al., 2007; VandenBygaart, 2016; VandenBygaart and Kay, 2010). Because no-till's agronomic effects and contributions to global sustainability are limited or potentially detrimental, this strategy may be most effective for farmers seeking to improve the soil health and structure of their farms or to contribute to broader environmental efforts despite yield losses. It may not currently be a response strategy to responsibly advocate to farmers whose underlying goal is to protect profitability and yields in the short- or long-term.

Biochar

Research on the benefits of biochar as a soil additive has largely been conducted in tropical climates, while studies conducted in temperate climates have suggested that its value may be limited due to negative effects on yield. In an agricultural context, biochar is the addition of biomass that has undergone pyrolysis to the soil with the goals of increasing fertility, improving structure, and sequestering carbon (Stavi and Lal, 2013; Verheijen et al., 2009). Suitable biomass feedstocks include greenwaste, forestry waste, poultry litter, cattle feed-lot manure, paper mill waste, cane trash, mill mud and bagasse (Van Zwieten et al., 2008). Biochar has been reported to lessen the emissions of three major greenhouse gases—carbon dioxide, nitrous oxide, and methane—while simultaneously providing potential yield and other

agronomic benefits to farmers given the correct conditions (Stavi and Lal, 2013).

Jeffery et al. (2017) found that when applied in temperate soils, biochar has no effect or negative impacts on yields but provides improvements to soil remediation, crop disease and pest suppression, and soil water retention, as well as reduced greenhouse gas emissions and fertilizer costs.

Biochar removes carbon from the carbon cycle by storing it in a more chemically recalcitrant form than crop residues or non-pyrolyzed vegetative matter, which are often re-released into the atmosphere as carbon dioxide after microbial breakdown (Lehmann, 2007; Stavi and Lal, 2013). While the carbon sequestration benefits of biochar are clear, the process by which nitrous oxide emissions are reduced through biochar usage are less clearly understood but believed to result from its influence on soil water storage capacity (Sohi et al., 2009). Nitrous oxide emissions reduction and other benefits of biochar appear to depend on local conditions; large reductions in nitrous oxide and methane emissions and increases in yields, particularly for leguminous crops, have been observed in highly acidic and nutrient-limited soils (Rondon et al., 2005). These benefits coupled with a reduction in fertilizer use positions biochar as both an effective greenhouse gas mitigation response to climate change and a potential source of improvement for farm profitability and fertility under some environmental conditions (Roberts et al., 2010; Rondon et al., 2005)

As a tool for long-term soil carbon sequestration, additions of biochar to agricultural soils may address the shortcomings of conservation/no-till land use strategies (Stavi and Lal, 2013). While the latter strategies are limited by their

sensitivity to reversal and re-emission of carbon, their length of commitment, and potentially negative impacts on yield, biochar additions can be made incrementally and episodically without a continual commitment yet provide a stable and long-term carbon sink (Lorenz and Lal, 2014; Sohi et al., 2009; Stavi and Lal, 2013; VandenBygaart, 2016). Reported soil stability estimates for biochar range widely, from 8.3 years in slash-and-burn conversion to farmland to 3,624 years in a system comprised of pyrolyzed mango prunings (*Mangifera indica* L.)—some claims have extended the soil stabilization period to “tens of thousands” of years (Gurwick et al., 2013; Major et al., 2010; Nguyen et al., 2009; Sohi et al., 2009). The mean residence time of sequestered carbon and the total sequestration capability of biochar are determined by the specific physio-chemical interactions between biochar and its environment and the diversity of biochar feedstock (Joseph et al., 2010; Lorenz and Lal, 2014).

Multiple studies have demonstrated that biochar is capable of providing farmers with a climate change response option that also increases their yields (Marris, 2006; Stavi and Lal, 2013), but there is limited comparability across studies in terms of methods, crops, and environmental conditions, including edaphic conditions. A 2004 study conducted in Ejura, Ghana on maize yields under a biochar system demonstrated a 91% increase in grain yields and a 44% higher yield of biomass when compared to the control areas (Oguntunde et al., 2004). Similar results were observed in a 2006 study at the CIAT's (Centro Internacional de Agricultura Tropical) greenhouses in Cali, Colombia in which common bean (*Phaseolus vulgaris* L.)

overyielded by 46% when compared to non-biochar enhanced controls (Rondon et al., 2007). However, a 2017 study found that while biochar may provide both agronomic and yield benefits when applied to tropical soils, there were no or negative impacts on yields when applied in temperate soils (Jeffery et al., 2017). Due to the highly variable nature of the interactions between biochar, soils, and crops, further research is required in order to accurately model the mitigation potential of this response under different climate change scenarios. Unlike most responses designed either to protect yields and profit or to enhance environmental quality, e.g., through reduced greenhouse gas emissions, biochar may be effective at realizing both production and sustainability goals, depending on environmental conditions.

3. Observed responses

The majority of empirical research on climate change responses has been conducted in developing countries (Yaro, 2013). This pattern may have emerged from the differences between regional climate change projections for developed versus developing countries. Climate change is projected to have more immediate and negative impacts on agriculture in semi-arid and arid regions than in temperate regions, which may benefit from average warming of up to 2 °C (Yaro, 2013). Communities in the Global South are also more dependent upon natural resources for their livelihood, making them more vulnerable to the impacts of climate change. This reliance upon natural resources extends to multiple scales. Agriculture's role in the national or local economy has been a driver of research on climate change and agriculture in Africa (Bryan et al., 2013; Fosu-Mensah et al., 2012). Analyses of

on-farm responses in Ethiopia, for example, have stressed the importance of agriculture to the national economy; it accounts for the majority (52%) of the GDP, foreign exchange earnings (85%), and national employment (80%). The impacts of climate change at smaller scales were highlighted in an analysis conducted in Pakistan that emphasized the income dependence of rural communities on agricultural production in a nation where nearly two-thirds of the population lives in rural areas and is dependent upon agriculture for income and subsistence (Abid et al., 2016b).

The dependence on agriculture in developing nations is pervasive, with approximately 475 million smallholder farmers working on less than 2 ha of land across the globe (Harvey et al., 2018), and an estimated 2.5 billion people relying on agricultural production for their livelihoods (IFAD and UNEP, 2013). Additionally, smallholder farmers are responsible for around 80% of the food produced for consumption in developed countries (IFAD and UNEP, 2013). At the same time, the majority of greenhouse gas emissions from agriculture can be attributed to production in developed countries (Barnes and Toma, 2012), where the agricultural sector accounts for between 15 and 28 percent of total greenhouse gas emissions (Garnett, 2011).

Farmers in both developed and developing countries are exposed to stressors beyond just their environment that may influence their capacity or willingness to respond to climate change. In addition to altering their production methods to meet environmental or sustainability goals, farmers may be motivated by economic or social forces to adapt their growing methods. This may be particularly true in

developing countries, in which growing food demand due to population increase, improving dietary quality, and shifting consumption patterns—in combination with climate change—pose a substantial threat to global food security (Wheeler and von Braun, 2013). The specifics of exactly how much food demand will increase vary based on modeling criteria—primarily the caloric intake estimates for each nation through time – but all models indicate a significant increase in demand by 2050 with commensurate increases in production, from a 70% increase in global production (FAO, 2009) to 110% and 117% increases in crop calories and crop protein, respectively (Tilman et al., 2011). Increased crop demand coupled with additional climatic variability and changes could result in an additional 170 million individuals at risk of hunger worldwide by 2080 (Schmidhuber and Tubiello, 2007).

Farmers in more temperate climates and developed countries with greater adaptive capacity, such as the U.S., may have the opportunity to leverage positive impacts of climate change, e.g., increased growing season length (United Nations IPCC, 2014), though the direction and magnitude of the impacts on agriculture are to some extent uncertain. Under climate change and with appropriate incremental and transformational responses, the U.S. agricultural sector, for example, could sustain annual losses of \$250 million up to gains of roughly \$5 billion (Antle, 2008).

In the following review of observational studies, discussion of farmers' perceptions of climate change, their actual on-farm responses, and the determinants of, motivations for, and limitations to response, are discussed first by developed versus developing countries and then by region and/or country. The difference in agricultural

production methods, farm typology, and access to resources found between these two economic classifications may stem from the lingering effects of colonial relationships on national and agricultural development. Additionally, the impacts of the Green Revolution have been mixed, with many developed countries seeing benefits while an analysis of agricultural productivity in 18 developing countries found, on average, that yields declined from 1961 to 1985 (Fulginiti and Perrin, 1998).

3.1. Developing countries

The foci of empirical research on on-farm response conducted in developing countries vary by cropping system, scale, and locale, but patterns emerge in research on farmers' perceptions of climate change, their choice of on-farm response strategies, and their limitations to response. The majority of studies in these countries have focused specifically on perceived and actual changes in temperature and rainfall levels. In nearly all studies, a majority of farmers have reported shifts in temperature and rainfall across Africa, South Asia, Mexico, and Central America. However, across regions, additional climate change factors and impacts of temperature and precipitation changes are highly variable.

Farmers have demonstrated a preference for response options that do not require a high degree of technological or infrastructure investment on their farm, including diversification, shifts in the agricultural calendar, and agroecological intensification through the planting of shade trees and wind-breaks. This preference is largely due to limited access to credit or financial support systems. Additionally, a lack of knowledge about the benefits, risks, and functionality of specific responses or

access to extension services has been observed to be a major impediment to on-farm response.

The depth of the literature on climate change and agriculture in developing countries warrants further discussion of each region's environmental and climatic context along with its vulnerabilities and farmers' perceptions, preferred response options, and reported limitations to adaptation or mitigation.

Africa

The interconnectedness of national economies, individual livelihoods, and the agricultural sector is pervasive and deep in Africa. As the driving economic force in multiple national economies and in millions of households, the productivity and sustainability of agriculture must increase as the effects of climate change worsen, even to maintain the status quo. In Uganda, for example, the agricultural sector contributes roughly 70% of the GDP and employs 75% of the labor force (Zizinga et al., 2017). Similarly, in Ethiopia, 52% of the national GDP and 85% of foreign exchange earnings are derived from agriculture, which provides employment for up to 80% of the population (Deressa et al., 2009). In West Africa, in the Sahel, 70% of Nigeria's population lives in rural areas, where 90% of the population engages in agriculture (Fatuase, 2014). In Ghana, agriculture provides 55% of the population's employment and more than a third of the national GDP and foreign exchange earnings (Fosu-Mensah et al., 2012). The West African Sahel, has experienced high population growth (3.1%) coupled with rapid urbanization resulting in the loss of agriculturally viable land and employment opportunities in agriculture (Mertz et al., 2009; Nyong et

al., 2007). Increased demands on agriculture from a growing population and reduced arable land area will exacerbate food security concerns, even without the negative impacts of climate change, and will necessitate sustainable intensification.

At 15% on a regional scale, the relative contributions of agriculture to GDP are lower in sub-Saharan Africa than in other regions (WWAP, 2019). However, farmer's dependence on rainfed agriculture, which constitutes 90% of staple crop production (Rosegrant et al., 2002) and endemic malnourishment—the highest level in the world (Knox et al., 2012a)—make the region particularly vulnerable to the negative impacts of climate change on agriculture, particularly increasingly variable precipitation patterns. This makes successful adaptation to the environment a necessity in order to address food insecurity in the region.

For these reasons, empirical research on how farmers perceive and respond to climate change has been conducted in Africa more frequently than anywhere else in the world, with East Africa, specifically Ethiopia, the epicenter of that research based on the number of articles found in the course of this review. While the Green Revolution of the 1960-70s largely bypassed Africa, instead focusing on Asia's growing population, rising poverty, and dependence on food aid, current efforts to replicate the Green Revolution in Africa have resulted in an increased number of studies examining the African agricultural sector and production methods (Diao, Headey, and Johnson 2008).

Climate change impacts on agriculture

While some climate change factors such as increased atmospheric carbon dioxide may provide yield and other agronomic benefits to farmers in Africa, the negative impacts of increased temperature, greater precipitation variability, more extreme weather events, and attendant increases in pest pressure are expected to outweigh those benefits. Yield losses of up to 30% are expected under certain UN IPCC emissions scenarios (Parry et al., 2004), threatening the already tenuous food security of the continent (Bryan et al., 2013; Deressa et al., 2009; Juana et al., 2013; Zizinga et al., 2017). Impact will be widespread. By 2025, 22 out of 28 countries in Africa are projected to suffer from climate change-related water scarcity compounded by increasing water demands of a growing population. Water scarcity will further limit the use of irrigated agricultural systems and will heighten reliance upon rain-fed systems (Cooper et al., 2008). Water scarcity will be further exacerbated by increased average temperatures, which are expected to rise 3-4°C, which is 1.5 times the global average, and an increase in potential evapotranspiration (Bryan et al., 2013). Analysis of survey data from 8,000 farms across 11 African countries indicates that monoculture or specialized crop production is particularly vulnerable to climate change and could result in substantial crop losses or yield declines under poor environmental conditions (Hassan et al., 2010). Decreased productivity at the farm level has negative ramifications for multiple sectors associated with agriculture (Juana et al., 2016), with a loss of up to 7% of GDP in parts of sub-Saharan Africa and 4% in West and Central Africa by 2100 (FAO, 2009).

East and West African nations face a similar set of climate change projections. Both regions are anticipated to experience increased average annual temperatures (Bryan et al., 2013; Yaro, 2013). East Africa is also projected to see an increase in overall precipitation levels, which is not expected to increase agricultural productivity because increased variability and bi-modality of rainfall patterns will worsen water access issues (Bryan et al., 2013). The precipitation outlook for West Africa is less clear, with varying assessments of whether overall precipitation levels will increase or decrease (Yaro, 2013). However, even with increased precipitation, greater evapotranspiration due to increased ambient temperature threatens to accelerate desertification and the loss of arable land in subtropical or savanna zones in the Sahelian semi-arid and arid regions of West Africa (Yaro, 2013). Currently, only 8% of land in the Sahel is arable. Reductions in the area of arable land under climate change will exacerbate existing food access problems and other social and economic issues for what is considered to be one of the world's most ecologically, socially, and politically marginalized populations (Mertz et al., 2009). In the Sahel, water access is the most limiting constraint on agriculture. Only 5% of arable land is irrigated (Nyong et al., 2007). Under almost all climate scenarios, water access will become even more limited, even with increased overall precipitation levels (Nyong et al., 2007; Yaro, 2013), precluding agricultural intensification, which relies on irrigation. An expected shift towards a more bi-modal precipitation regime will make rainfed agriculture in the region even more difficult (Nyong et al., 2007). Almost total reliance on rainfed crop production increases the vulnerability of the Sahel to climate change. Agriculture will

require adaptation or mitigation strategies such as increased use of drip irrigation or rain catchment systems in order even to maintain current levels of productivity, let alone meet the food demands of a growing population

Compared to East and West Africa, sub-Saharan South Africa is climatically more diverse, with a north to south gradient from subtropical to semi-arid and arid climates (Cooper et al., 2008; Juana et al., 2013). Thus far, the recorded impacts of climate change on farms in the region have been increased average temperature resulting in greater crop water requirements as well as increased pest and disease pressure resulting in decreased yields and a heightened risk of crop failure (Gandure et al., 2013; Gbetibouo, 2009). Generally, sub-Saharan Africa's precipitation predictions indicate a trend towards decreased rainfall during the wetter winter season and increased variability (Cooper et al., 2008). Regional agriculture would be greatly impacted by a decrease in rainfall totals and water availability, because 90% of staple crop area is rainfed (Rosegrant et al., 2002).

Perceptions of climate change

Decreases in overall precipitation levels and increases in average temperature are the climate trends most commonly identified by farmers across Africa. Half of respondents in a survey of 8,208 farmers in 11 African countries reported long-term temperature increases and precipitation declines, one-third identified a shift in the timing of rainfall, and one-sixth indicated that droughts are occurring more frequently (Hassan et al., 2010). In a survey of 750 Kenyan farmers, 94% reported an increase in average temperature and an 88% decrease in precipitation (Bryan et al., 2013). Of

farmers surveyed in Ghana, 92% discerned an increase in average temperature and a 87% a decrease in precipitation (Fosu-Mensah et al., 2012). While not as overwhelming a majority, in Ethiopia, 50.6% of surveyed farmers perceived an increase in average temperatures and 53% perceived a decrease in rainfall over the previous 20 years (Deressa et al., 2009). While farmers' perceptions of increases in temperature are accurately aligned with predicted and recorded changes in climate, their perceptions of trends in precipitation are not—climate change predictions for both East and West Africa indicate an increase in overall precipitation levels (Bryan et al., 2013; Cooper et al., 2008; Fosu-Mensah et al., 2012). However, despite increased total rainfall, increasing average temperature coupled with greater bi-modality of precipitation patterns will cause regional drying that ultimately worsens water access (Nyong et al., 2007; Yaro, 2013). Farmers' perceptions of a decrease in precipitation may be more closely associated with their experiences around water access, which is negatively impacted by increasing temperature and bimodality of precipitation patterns, than total rainfall. In many cases, water availability is site specific and subject to socioeconomic influences such as rurality and cost that total rainfall is not (Bryan et al., 2013; Cooper et al., 2008; Fosu-Mensah et al., 2012).

Regardless of the region in Africa, farmers reported changes in precipitation as the greatest long-term threat to their agricultural production. Farmers in the Sahel most frequently identified decreased overall precipitation levels, heightened risk associated with major rainfall events, and desertification resulting from increased average temperature as threats to agricultural production (Fosu-Mensah et al., 2012; Mertz et

al., 2009; Nyong et al., 2007). In Senegal growers interviewed at both the household and community scale indicated that the secondary effects of large rain events such as strong winds and flooding were the primary source of negative impacts to crop production yet cited reduced rainfall as their primary concern (Mertz et al., 2009). Similarly, farmers in sub-Saharan South Africa reported a decrease in the overall rainfall levels coupled with an increase in the intensity of rainfall events leading to more frequent droughts and floods (Gandure et al., 2013; Hassan et al., 2010; Mandleni and Anim, 2017). The increased frequency of droughts and floods can be attributed to the delayed onset of the rainy season and its premature cessation (Gandure et al., 2013; Nyanga et al., 2011). Expanded time between rainy periods in South Africa is coupled with a reported increase in temperature and heightened temperature differentials between the warm and cool months of the year, which in combination magnifies water collection, storage, and allocation problems for growers (Gandure et al., 2013).

Responses to climate change and limitations to response

Degree and type of on-farm response to climate change varies in Africa. In some cases, response is a constant in agricultural production. Despite concerns about the impacts of climate change, many farmers are unable to or choose not to alter their growing practices. Most notably, in East Africa, 42% of Ethiopian farmers, (Deressa et al., 2009) and 19% of Kenyan farmers (Bryan et al., 2013) reported not making any on-farm adjustments in response to perceived changes. The climate of the West African Sahel, however, has a long history of variability—particularly with respect to

drought or extreme storm events—which has fostered the development and implementation of a multitude of adaptation or mitigation strategies by indigenous growers to preserve livelihoods (Mertz et al., 2009; Nyong et al., 2007; Yaro, 2013). These strategies include intensification and wider adoption of traditional conservation tillage practices that rely on heavy crop residue incorporation, mulching, and other agroecologically derived growing methods designed to preserve water (Nyong et al., 2007).

Crop diversification, water management, and the diversification of income sources are African farmers' most common response strategies. Crop diversification efforts in Africa are dominated by a turn to short-season or early maturing varieties that can withstand pressures from changes in precipitation patterns. In instances where East African growers chose to engage in active on-farm response, they favored crop diversification plus planting shade trees or altering the planting and harvest dates of crops (Bryan et al., 2013, 2009; Deressa et al., 2009; Gebrehiwot and Van Der Veen, 2013; Mesfin and Bekele, 2018b; Zizinga et al., 2017). A preference for early maturing or drought and temperature tolerant varieties and increasing the diversity of in-field crop assemblages characterized crop diversification in this region (Mesfin and Bekele, 2018b; Zizinga et al., 2017). Not surprisingly, West African farmers in the highly volatile growing context of the Sahel diversify by planting short-season varieties that are capable of maturing within the increasingly bi-modal precipitation season or of withstanding periods of drought (Assan et al., 2018; Fosu-Mensah et al., 2012; Mertz et al., 2009; Yaro, 2013). Sub-Saharan farmers similarly have switched to

less water intensive or shorter season varieties (Gandure et al., 2013; Gbetibouo, 2009; Hassan et al., 2010; Mandleni and Anim, 2017; Nyanga et al., 2011).

Farmers seeking to manage water levels and efficiency of distribution on their farms manage increased precipitation volatility by increasing overall rain capture and minimizing dry season losses. To this end, farmers in West Africa build stone ridges or bunds, increase the number of boreholes and wells at a given site, and implement soil water conservation techniques such as heavily mulched dryland farming or increased crop residue coverage via no-till or conservation tillage (Assan et al., 2018; Mertz et al., 2009; Nyong et al., 2007). Sub-Saharan farmers have altered their planting dates to better coincide with rainfall patterns and have implemented water catchment and storage systems or, if precipitation is insufficient, have shifted from arable crop production to livestock farming or diversifying to off-farm sources of income (Gandure et al., 2013; Gbetibouo, 2009; Hassan et al., 2010; Juana et al., 2013; Mandleni and Anim, 2017; Nyanga et al., 2011). Disengagement from the agricultural system by younger generations of families is a common strategy in both West and sub-Saharan Africa that seeks to preserve the economic livelihood of the family unit rather than increasing or safeguarding crop production. This response has negative impacts on the overall efficiency and productivity of many small-scale family agricultural operations because it creates a shortage of labor; however, it does allow for non-agricultural income which can provide economic resilience to households otherwise dependent upon a highly variable climate (Mertz et al., 2009).

A lack of financial resources and a lack of information on the objectives and best practices for on-farm responses to climate change have been identified as the primary limitations to response in Africa. In general, a lack of access to credit or financial support systems limits the willingness of growers to attempt to diversify their crop mixes because the perceived risks of altering their methods are too high. The opposite holds true for farmers with greater access to credit or financial support services that allow them to alter their growing methods or crop choices in a more risk averse manner (Hassan et al., 2010; Sani and Chalchisa, 2016). In the case of more technology driven responses, the overall cost of infrastructure, inputs, and equipment can price out farmers (Deressa et al., 2009; Gebrehiwot and Van Der Veen, 2013; Zizinga et al., 2017). In Ethiopia, Kenya, and Uganda, a lack of money to invest, other financial constraints, a shortage of land or water resources—specifically irrigation systems—and limited information on how to implement response strategies are the primary limitations identified by farmers (Bryan et al., 2013, 2009; Deressa et al., 2009; Paavola, 2004; Zizinga et al., 2017). Much like growers in East Africa, Sahelian and sub-Saharan agricultural producers have cited a lack of money and financial support and a general lack of information as the primary impediments to adaptive or mitigative response (Assan et al., 2018; Gandure et al., 2013; Gbetibouo, 2009; Hassan et al., 2010; Mandleni and Anim, 2017; Nyanga et al., 2011; Nyong et al., 2007).

Some limitations are specific to the marginalized groups within the Sahel. Assan et al. (2018) found that in addition to the economic and informational

constraints experienced by most growers in the region, female heads of farms were less likely to respond to climate change than their male counterparts because women are largely excluded from ownership of fertile land or access to a consistent labor force. This has resulted in a higher rate of women choosing to diversify their income to off-farm sources (Assan et al., 2018). The influence of international non-governmental organizations in recent years has led to an increase in the number of female farmers in the region, yet the negative stigma associated with working for a woman and persistent social barriers to land ownership have constrained the ability of women to have full agency over their agricultural decisions (Assan et al., 2018). Across Africa, farmers with more access to extension and outreach services and those with long-term ownership of their land are more likely to adopt adaptive or mitigative measures on their farm (Deressa et al., 2009; Gbetibouo, 2009). In sub-Saharan Africa, issues of long-term land tenure and ownership have limited on-farm response (Bryan et al. 2009), and in East Africa farmers from wealthier households and those who owned larger or privately controlled tracts of land have been shown to be most likely to adapt to climate change (Bryan et al., 2013; Ziervogel et al., 2008). Willingness or ability to adapt is also correlated with the degree of contact growers have with extension or agricultural outreach organizations (Bryan et al., 2013; Deressa et al., 2009; Mesfin and Bekele, 2018). Growers with limited access to extension resources have reported a lack of information as one of their primary constraints to response (Bryan et al., 2013, 2009; Mesfin and Bekele, 2018; Zizinga et al., 2017).

Research limitations

Africa has been the central focus for the majority of the world's empirical research on on-farm responses to climate change, and consequently the research conducted there has fewer limitations than that conducted elsewhere. Though study locations have been broadly distributed across the continent from East to West to sub-Saharan Africa, most have an arid or semi-arid climate, with fewer examples of study sites in the continent's humid, subtropical, or temperate regions. No research has been conducted in north African or central African countries, a surprising gap in the research for two distinct reasons. The agricultural sector in North Africa is growing more rapidly than anywhere else on the continent—roughly 4% between 2000 and 2009—indicating intensification or expansion of production (FAO, 2009). Central Africa has the highest proportion of the population living in rural areas, which heightens individuals' reliance on agricultural production, and should be studied in order to limit the exposure of already vulnerable populations to climatic shifts (FAO, 2009). In addition to a lack of some regional coverage, limited work has been conducted on how female farmers in Africa have responded to climate change. This limitation may be a result of social forces limiting the overall participation of women in agriculture as well as their ability to access support services such as loans, insurance, and long-term leases or land ownership (Assan et al., 2018).

Asia

In Asia as in other parts of the developing world, both individuals and national economies are largely dependent on agriculture, which heightens community and household sensitivities to climate change and makes the need for research on

adaptation or mitigation critical if farmers are going to effectively increase their resilience and safeguard production. Vietnam and Pakistan typify this entanglement of agriculture and household or national livelihoods in Southeast and South Asia, respectively. Vietnam's agricultural sector provides nearly 20% of the national GDP, is responsible for employing over 50% of Vietnam's labor force, and is the source of almost 75% of the population's income (Quang et al., 2018). In Pakistan, roughly two-thirds of the country's population lives in rural areas and relies on agriculture for both their economic livelihood and household subsistence (Abid et al., 2016b). However, agriculture is relatively unproductive. Farmers attain only 32% of potential crop yields, according to a 2013 study, and average wheat yield per hectare is significantly lower than the global mean: 2797 kg/ha compared to 3268 kg/ha in 2013, respectively (Gorst et al., 2018; Prikhodko and Zrilyi, 2013). Consequently, food security is a persistent concern in rural areas (Ali and Erenstein, 2017), and Pakistan's agricultural sector and food security are particularly vulnerable to climatic shifts.

Cereal crop monocultures increase the vulnerability of this rural-agrarian lifestyle, with 80% of Pakistani farmers growing wheat, which supplies 37% of the total daily calories for the country (Abid et al., 2016b; Gorst et al., 2018). Reliance on monoculture places farmers and the rural population at an extremely high risk of food insecurity should crops fail from expected or unexpected climatic shifts. In Sri Lanka, agriculture is heavily skewed towards smallholder ownership of farms; 71% of agricultural land holdings are under one hectare, which increases their vulnerability and lessens their buffering capacity (Esham and Garforth, 2013). The majority of

cropland, 66%, is rainfed (Esham and Garforth, 2013); however, farmers manage over 11,000 small or community level irrigation schemes (de la Poterie et al., 2018). The added complexity of managing an irrigation system as both an agricultural tool and a social organization lessens the adaptive capacity of these farmers and requires collaboration to operate successfully. More than half of South Asia's population is expected to be dependent upon agriculture for their livelihoods through the 21st century despite worsening environmental and climatic conditions (Abid et al., 2019). The impacts of climatic changes on agriculture, farmer's perceptions of changes, their responses to climatic change and limitations they report, as well as research limitations are discussed in detail below.

Climate change impacts on agriculture

Agriculture in South and Southeast Asia is expected to experience worsening agronomic conditions as a result of climate change, though the exact nature of the impacts will vary by climate type. Average annual temperature, variability of precipitation patterns in general, and frequency of extreme storm and precipitation events are all expected to increase (Abid et al., 2019; Parry et al., 2004; Smith et al., 2007).

Changes in average annual temperature will negatively impact agricultural production in much of South Asia. For example, under conservative SRES projections, net cereal production in South Asia will decrease by 4% to 10% by the end of the 21st century (Abid et al., 2019; United Nations IPCC, 2014), while the potential for as much as a 30% decrease in South Asian agricultural yields has been projected under a

SRES scenario—A1F1—which assumes greater average temperature increases across the globe and heightened economic and social inequality as compounding factors (Parry et al., 2004).

The impact of increased average annual temperature will be felt most strongly in arid regions (IPCC, 2007; Knox et al., 2012b). Farmers in locales with an arid climate such as Pakistan face a 3°C increase in average temperature compared to 1961-1990 and more variable precipitation patterns, which will worsen existing water access issues that stem from a unimodal precipitation regime (Abid et al., 2016; Gorst et al., 2018). According to Ali and Erenstein (2017), a 6% decrease in rainfall could lead to an overall 29% increase in net irrigation requirements in Pakistan impacting nearly 1.3 million farming households. When combined, increased average temperature and decreased rainfall during optimal growing times can be expected to exacerbate food insecurity and reduce crop production.

Impacts on agriculture in regions with a tropical moist climate and monsoon seasonality will be different but not necessarily less severe. Monsoon seasonality results in two distinct cropping seasons, the wet season during the monsoon and the dry season between monsoons. With climate change, shifts in the onset and timing of the monsoons may lead to changes in the duration of growing seasons, causing more destructive periods of flooding during the wet season and extended droughts during the dry season that make the traditional dry season cropping period increasingly unproductive (Esham and Garforth, 2013; Knox et al., 2012a; Quang et al., 2018). Despite lengthening inter-monsoonal dry periods, a greater intensity of precipitation

and tropical storm events will likely result in an overall increase in rainfall totals during the shortened summer monsoon season (IPCC, 2007; Knox et al., 2012b). In Vietnam, the frequency of extreme weather events has always been high, with 96 significant floods since 1985, but these storm events are impacting previously unaffected locations or are increasing in intensity (Le Dang et al., 2014). In a study conducted in Ha Tinh province, 78% of farmers reported losses from extreme weather events. Overall crop production is at such high risk from destructive storm events, including typhoons, floods, and droughts, that farmers lose 20% of their annual agricultural income due to extreme weather events associated with climate change (Quang et al., 2018).

Perceptions of climate change

Results from farmer surveys indicate that widespread consensus has emerged among farmers from extremely varied agroecological zones across South and Southeast Asia that average temperature is increasing, particularly during the growing seasons; farmer observations accord with projected and recorded changes (Chengappa et al., 2017; Esham and Garforth, 2013; Gorst et al., 2018; Le Dang et al., 2014; Quang et al., 2018). In Sri Lanka and Pakistan, 79.4% and 87% of surveyed farmers reported an increase in average annual temperature, respectively (Ali and Erenstein, 2017; Esham and Garforth, 2013). A separate study of 442 wheat farmers from 65 villages across Pakistan found that 80% of farmers had observed an increase in average temperature over the previous 10 to 20 years (Abid et al., 2016b). Rice farmers in Vietnam reported an increase in average temperature, particularly during

the dry season, and have observed a growing differential in average temperature between the dry and wet seasons (Le Dang et al., 2014). Coffee producers in India have perceived an increase in average annual temperature in addition to a delay in the onset of the monsoon and increasingly variable patterns in the distribution of rainfall during the growing season (Chengappa et al., 2017).

Perceptions of rainfall patterns and levels across Asia depend on the farmer's agroecological zone. Asian farmers in temperate, tropical, and humid zones with bimodal monsoon cycles have generally reported a change in the onset of the monsoons, a heightened intensity and destructiveness of storm events, flooding, and drought, prolonged dry periods between the wet seasons, and more variable rainfall during the wet season (Chengappa et al., 2017; de la Poterie et al., 2018; Esham and Garforth, 2013; Le Dang et al., 2014; Quang et al., 2018). In Vietnam farmers have noted that precipitation levels have remained unchanged or decreased, but the intensity and variability of rainfall events has increased (Le Dang et al., 2014; Quang et al., 2018). Nearly 86% of Sri Lankan farmers in the Umbulpe Divisional Secretariat division of the Ratnapura district, a predominantly rainfed agricultural region, reported an increase in the variability of rainfall patterns over the last 20 years, which has increased the length of dry periods (Esham and Garforth, 2013).

Farmers in arid agroecological zones with unimodal precipitation regimes are more likely to report decreases in the total rainfall they receive throughout the year and increased drought as a result of temperature-precipitation interactions (Abid et al., 2019, 2016b; Ali and Erenstein, 2017; Gorst et al., 2018). In Pakistan, farmers in arid

regions were more likely to report decreased precipitation and increased incidence of drought than those in humid or semi-humid regions, who reported changes in monsoon seasonality and heightened flooding severity. However, overall, farmers across the country reported an increase in temperature regardless of agroecological region (Abid et al., 2016b; Ali and Erenstein, 2017; Gorst et al., 2018).

Responses to climate change and limitations to response

In South and Southeast Asia, the most common adaptive response strategy is to modify production practices (Abid et al., 2019; Ali and Erenstein, 2017; Chengappa et al., 2017; Esham and Garforth, 2013; Le Dang et al., 2014; Quang et al., 2018).

Farmers diversify crop assemblages to manage risk and switch to earlier-maturing varieties to limit crop loss from extended drought, increased pest pressure, and destructive storm events, particularly in areas with monsoon seasonality (Esham and Garforth, 2013; Le Dang et al., 2014; Quang et al., 2018). In Vietnam, farmers have also increased their use of forecasting tools in order to better manage inputs, irrigation, and harvest schedules (Le Dang et al., 2014; Quang et al., 2018).

Farmers in Sri Lanka have begun selecting short-season crops within the constraints of collectively managed irrigation schemes in an effort to align crop production with water availability and to avoid production during the dry seasons and droughts (Esham and Garforth, 2013). In India, farmers have responded to climate change by intensifying traditional polycultures of coffee plantings by adding citrus fruits, arecanut, banana, and black pepper vines on shade trees in order to protect and simultaneously increase perennial production (Chengappa et al., 2017). Intensification

of coffee agroforestry systems has been accompanied by a switch from arabica to robusta varieties because the latter produce more reliably in shaded polyculture systems—which they feel are a more sustainable alternative to the removal of shade trees to increase coffee production area—as well as its relative resistance to white-stem borer infestations, which have worsened as a result of heightened precipitation variability and increased average temperature (Chengappa et al., 2017).

These same farmers have adopted water management strategies characterized by efforts to maintain sufficient on-farm water during the inter-monsoonal periods when rainfall is scarce, including digging more storage tanks (81.8% of farmers surveyed), deepening boreholes, and increasing the use of irrigation systems such as drip tape (Chengappa et al., 2017). Changes to input management and timing paired with diversification are the most widely reported responses in Pakistan as well. In studies conducted by Ali and Erenstein (2017) and Abid et al., (2019), between one-quarter and one-third of study participants indicated that they had changed their crop varieties, making this the most popular on-farm response by Pakistani producers. Because of a drier growing environment, when selecting crops or varieties, farmers place greater weight on heat tolerance and drought resistance than do growers in monsoonal regions, who select based on crop season length (Abid et al., 2016b; Ali and Erenstein, 2017).

In surveys on climate change response, farmers have reported altering the timing and nature of chemical controls and nutrient inputs for varying reasons. In Vietnam, farmers have modified the timing of fertilizer and other chemical input

applications to reduce leaching losses and to better synchronize applications with emerging precipitation and pest emergence patterns (Le Dang et al., 2014). In Pakistan, food security concerns and yield targets have motivated farmers to alter their fertilization practices. Wheat farmers in particular increasingly use urea, diammonium phosphate, nitrophos, and single superphosphate in their operations in an effort to increase efficiency, boost local production, and combat food insecurity (Abid et al., 2016b).

Rates of on-farm adaptation or mitigation in South and Southeast Asia are generally low despite evidence that response can be beneficial to farmers. In Pakistan, farmers who chose to adapt their on-farm practices experienced 8-13% higher levels of food security than those who did not, yet less than one-quarter of farmers had implemented climate change-responsive practices (Ali and Erenstein, 2017). While 87% of surveyed wheat farmers in Pakistan recognized changes in climate, and 75% planned some form of response, only 37% of farmers implemented their response plans (Abid et al., 2016b). Similarly, 66% of Indian coffee growers surveyed indicated that they do not see an urgent need to alter their practices despite perceiving distinct changes and variability in climatic conditions as a threat to the long-term viability of their agricultural operations (Chengappa et al., 2017). In contrast, Esham and Garfoth (2013) reported that 85% of surveyed Sri Lankan farmers who perceived changes in climate had made some form of on-farm response.

The most commonly identified limitation to response by South Asian agricultural producers is a lack of access to extension services or information on the

objectives and best practices for on-farm response (Abid et al., 2016b; Ali and Erenstein, 2017; Chengappa et al., 2017; Esham and Garforth, 2013; Le Dang et al., 2014; Quang et al., 2018). Studies of Vietnamese farmers showed that increased access to information is a driver for agricultural response, whereas lack of long-term land tenure, fear of maladaptation, and lack of knowledge or understanding are the most common limitations to response (Le Dang et al., 2014; Quang et al., 2018). Pakistani farmers reported similar limitations; the most significant determinants of on-farm response in the country are education or farming experience, access to extension services or information, and access to weather forecasting that can be utilized in decision making (Abid et al., 2016b; Ali and Erenstein, 2017; Gorst et al., 2018). While access to information and support systems are limitations to response in Sri Lanka as well, participation in collectively managed irrigation schemes also limits response. In these schemes, shared reliance on a single source of irrigation water leads to considerations of equal resource allocation between producers. This has resulted in widespread participation in strictly enforced management plans that emphasize synchronization of production schedules, crop assemblages, agro-chemical usage, and irrigation frequency (de la Poterie et al., 2018). Legally or socially binding agreements often limit the agency of individual farmers over crop diversity or farm management decisions (de la Poterie et al., 2018). Synchronization—and homogeneity—of crops and practices purportedly reduces overall burden on the collective system while also providing some agronomic benefits, such as reduced pest pressure and more efficient input use (de la Poterie et al., 2018). Group management of water resources and

socially driven monocultures limit the individual adaptive capacity of farmers but provide those with limited resources with resilience building benefits in some cases (de la Poterie et al., 2018).

Research limitations

The majority of research on climate change and agriculture in Asia consists of attempts to model the overall level of climatic change in the region, to develop yield predictions, or to conduct vulnerability assessments of specific sectors or locales. Fewer studies have employed empirical methods from the social sciences such as on-farm observation, interviews, or surveys to examine the drivers of on-farm climate change adaptation and mitigation. The latter research has been conducted in a varied set of South and Southeast Asian climate zones ranging from temperate and tropical areas with monsoonal climates to arid regions in the west, such as Pakistan. Despite this variation, existing research is marked by a striking lack of geographic coverage. No empirical research on on-farm response based in West Asia, East Asia, or the steppe region was identified in searches of the peer reviewed literature for this review. Most notably, no such research in the Russian Federation or China was identified but rather a high number of projection or modeling based studies. Research from these countries may not have been found in the course of this review because it was limited to the English-language literature. Aside from a limited geographic scope, research has been limited by an almost exclusive focus on small grain or cereal crop production. In most of the studies included in the above review, farmers are producing wheat, rice, other cereals, or unspecified crops, leaving fruit and vegetable crop production

relatively unstudied in the context of climate change. Increasing the diversity of crops and production systems studied and expanding the geographic scope of research would benefit on-farm response in Asia as a whole.

Central America and Mexico

Empirical research on agricultural response to climate change in Mexico and Central America has largely focused on smallholder farmers who grow coffee, basic grains (maize and beans), or a combination of both. Coffee is typically grown for sale and export, while maize and beans are largely subsistence crops (Harvey et al., 2018; Tucker et al., 2010). Roughly 2.3 million smallholder farmers in Central America farm land with low fertility, have limited access to economic resources, and experience high levels of food insecurity, forcing them to largely rely on the basic grains they produce for subsistence (Harvey et al., 2018). Approximately 2.8 million farmers in Mexico grow maize (Eakin et al., 2015), while an estimated 4 million in Mexico and Central America rely on coffee production for their livelihoods (Tucker et al., 2010).

Climate change impacts on agriculture

Climate change projections for Mexico and Central America emphasize the potential for more frequent and intense storm events as a result of the interaction between climate change factors and the exacerbating effects of the El Niño Southern Oscillation (ENSO) on existing environmental and climatic instabilities and trends (Tucker et al., 2010). This region is expected to experience increased average temperatures, heightened rainfall variability and intensity, and warmer Atlantic Ocean temperatures that will increase the chances of hurricanes forming near coastal areas

(Harvey et al., 2018; Tucker et al., 2010). Extreme weather events cause severe damage to grain and coffee production through heavy winds and flooding and disrupt post-harvest processing and transport, which can increase instability in prices (Harvey et al., 2018). Because of the varied agroecological zones and topography of the region, the impacts of storm events on individual farmers varies by landscape context. In 2005, Hurricane Stan, a single storm event, destroyed roughly 20% of the coffee harvest in the Pacific region of Guatemala (Tucker et al., 2010), while farmers in Mexico attributed 90% of their losses to droughts associated with a decline in rainfall during July and August (Eakin, 2000). Major storm or rainfall events have an impact on both livelihoods and subsistence. Of 860 smallholder farmers surveyed across Central America, 32% indicated they were food insecure following an extreme weather event (Harvey et al., 2018).

The risk of losses due to singular events is coupled with other devastating climate change factors that have longer lasting consequences for growers and their farms. Mexico's landscape is roughly 46% arid land requiring irrigation for crop production, but the majority of farms utilize rainfed systems (Eakin, 2000). A regional warming and drying trend is expected to expand the percentage of land classified as arid or semi-arid, which will further worsen existing production constraints (Eakin et al., 2015; Harvey et al., 2018; Tucker et al., 2010). Yields of beans in Central America may drop by as much as 20% by 2025 alongside a potential 15% decrease in maize yields in Nicaragua, Honduras, and El Salvador (Tucker et al., 2010). Some crop suitability models predict that in Nicaragua, Costa Rica, and El Salvador, more than

40% of the land currently in coffee production will no longer be suitable for coffee by 2050 (Tucker et al., 2010). Other long-term climate change factors further threaten agricultural production. The devastating 2012 and 2013 outbreaks of coffee leaf rust—which cost over 264,000 jobs and caused economic losses of \$479.2 million—have been attributed to the increased suitability of the regional environment for the rust pathogen (Tucker et al., 2010).

Perceptions of climate change

Mexican and Central American farmers have demonstrated extremely high levels of climate change awareness in recent surveys. In a survey of coffee and grain producers in Costa Rica, Honduras, and Guatemala, 95% of respondents reported climatic shifts and associated impacts, including increased temperatures, greater variability in rainfall patterns and intensity, more extreme weather events, increased pest pressure, and price instability (Harvey et al., 2018). The perceived changes reported in farmer surveys varies widely, which has been attributed to the region's landscape and environmental diversity (Harvey et al., 2018; Tucker et al., 2010).

Despite widespread recognition of climate change Mexico and Central America, growers in Honduras, Mexico, and Guatemala reported that market instability, specifically low prices, represents a greater threat to their production and livelihoods (Tucker et al., 2010). This has been attributed to a longstanding relationship between agricultural producers and variable climatic conditions in the region, which has produced a culture of ongoing on-farm response or coping (Tucker et al., 2010).

Responses to climate change and limitations to response

In Harvey et al. (2018), while 95% of growers acknowledged a shift in climatic conditions, only 46% indicated they had made changes to their on-farm production, primarily by intensifying plantings, planting more trees as windbreaks and for shading, increasing the use of chemical fertilizers and pest controls, and adopting soil and water conservation practices. Tucker et al. (2010) identified additional responses among farmers in Honduras, Guatemala, and Mexico, including increased intensification of both coffee and maize plantings, a strong reliance on migration as a means of household economic diversification, and, due to greater concern for economic shocks or stressors than climate change risks, actions to safeguard profitability, e.g., by reducing labor costs associated with on-farm weeding and hired harvesters (Tucker et al., 2010). Like Harvey et al. (2018), Tucker et al. (2010) found more widespread recognition of climate change than adoption of climate change-specific on-farm responses.

Low access to agricultural resources such as chemical inputs and management tools and a lack of agriculturally viable land limit the ability of growers in Honduras, Mexico, and Guatemala to adapt to climate change (Tucker et al., 2010). Despite risk from variability in the regional coffee market, the high investment costs associated with replacing coffee plantations with other crops or clearing forested and fallow land in order to further intensify production has limited the willingness of many Mexican and Central American growers to diversify crops or production systems (Tucker et al., 2010).

Research limitations

Empirical research on on-farm response in Central America and Mexico has been extremely homogeneous with respect to farmer populations and crops, with an exclusive focus on smallholder farms that is motivated by their particularly high level of exposure to climate risk (Harvey et al., 2018) and an absence of research on larger farms or non-subsistence farming. Additionally, existing research has focused entirely on coffee and/or grain production. There is substantial room for research on how farmers engaged in fruit and vegetable production in Central America and Mexico have perceived and responded to climate change on their farms.

3.2. Developed countries

While in developing countries, empirical research on agricultural responses to climate change has been diversified in terms of cropping systems, locations, and scales, research in countries with developed economies and more industrialized systems of production has been more homogeneous. Much of the latter research has focused on large-scale growers of grains or other commodity crops in the United States and Canada because of the economic importance of these systems and the vast areas of arable land dedicated to them. While the majority of these growers recognize that climate change is occurring, perception rates are, overall, markedly lower than in the developing world. This may be a result of skepticism about the causes or severity of climate change or a politicization of the subject. Regional or social context influences the ways in which this skepticism is manifested. In Canada, growers widely believe that climate change is a slowly occurring trend in warming that does not have

immediate on-farm repercussions and consequently is not a serious source of risk to their operations (Bradshaw et al., 2004; Reid et al., 2007). In the United States, heavy politicization of information related to the climate and the environment has resulted in strong associations between farmer demographics and belief in climate change (Arbuckle et al., 2015; Chatrchyan et al., 2017; Liu et al., 2014). Generally, “Republican, conservative, and male rural residents” are less inclined to believe that climate change is occurring, is caused by anthropogenic factors, or is a source of risk that requires response (Chatrchyan et al., 2017). However, growers in much of the developed world are aware of specific climate change-related impacts on their farms such as drought, frost, extreme weather, or limited water availability and are willing to respond to those impacts on an incremental basis.

Farmers strongly prefer multifunctional responses that are technologically based or reduce on-farm costs. They have widely adopted conservation tillage, a practice which limits soil erosion (an effect of climate change), coupled with increased herbicide use that enables them to reduce labor costs and other expenses. While this solution is often framed as being mitigative in nature in the research literature because of its greenhouse gas sequestration capabilities, growers have demonstrated an aversion to strategies explicitly labeled as mitigative and have instead favored those which provide direct economic or agronomic benefits to their farm. Farmers also appear to prefer technological responses rather than those which alter on-farm practices or significantly alter the farm’s system of production (Gardezi and Arbuckle, 2018).

Canada

Research on growers' on-farm responses to and perceptions of climate change in Canada after 2000 has been limited to two studies. Bradshaw et al. (2004) examined crop diversification as a response option in the western prairie provinces, while Reid et al. (2007) explored how the agricultural sector in Perth County, Ontario has responded to climate change.

While much of the Global South is expected to experience negative agricultural impacts as a result of climate change, projections for Canada indicate benefits in some areas coupled with potential negative impacts in others (Reid et al., 2007). In many cases, the potential benefits to producers from climatic shifts are also intrinsically associated with harmful agronomic factors. The extension of the growing season and increased average temperatures in British Columbia, Ontario, and the prairies has the potential to increase yields of fruit crops, sorghum and corn, and wheat yields in their respective regions (Reid et al., 2007). However, these beneficial shifts in climate may also expose crops to heightened pest and disease pressure, soil moisture deficits, and drought stress in dry periods (Reid et al., 2007). Should Canadian agricultural producers make adaptive or mitigative on-farm changes, they could simultaneously benefit from positive climate trends and minimize their exposure to new risks.

Canadian agriculture has traditionally been dominated by specialized or monoculture production of cereal crops under conventional tillage regimes and summer fallow (Bradshaw et al., 2004). The western prairie provinces are located

primarily in a semi-arid agroecological zone that has traditionally had its productive capacity limited by inconsistent water availability that is projected to worsen with time (Bradshaw et al., 2004). Ontario's Perth County is located in a region with "reasonably wet summers and cold, snowy winters" characterized by a high degree of variability in average temperature throughout the year; 90% of the land located in Perth County is deemed prime agricultural land by the Canada Land Inventory (Reid et al., 2007).

In both study areas, researchers determined that climate change is not considered a serious source of risk to agricultural production by the vast majority of producers (Bradshaw et al., 2004; Reid et al., 2007). In Perth County, only six of 25 farmers interviewed identified weather as a perceived risk to their farm, and only two of those six identified climate change specifically (Reid et al., 2007). When asked to discuss specific future climatic risks or opportunities such as droughts or increased temperatures, growers demonstrated they are aware of shifts in specific phenomena but are more prone to identify them as individual environmental factors than as climate change at large (Reid et al., 2007). When growers were asked about climate change specifically, 62% responded that it is a long-term trend associated with global warming, whereas only 17% identified a direct connection between climate change and factors such as drought or extreme weather (Reid et al., 2007). Overall, 21% of growers in Perth County stated they were skeptical of climate change, and 42% were not concerned with it at all – a belief that Reid et al. has suggested may be linked to

the belief that climate change is a gradual and long-term shift in temperature (Reid et al., 2007).

In Perth County, growers were observed undertaking both responsive and planned adaptations on their farms. When growers faced a specific production pressure, they altered their on-farm actions in order to address that issue in the moment. For example, they used low quality crops for livestock feed rather than sending the crops to market, or they increased the usage of pesticides during incidences of pest or disease outbreaks (Reid et al., 2007). Common long-term adaptation strategies included the installation of tile drainage in fields, the usage of GMO crop varieties, and crop insurance (Reid et al., 2007). While many of the responsive measures undertaken by farmers have few constraints to their implementation, the long-term options identified by Reid et al. (2007) each comes with limitations. Tile drain installation is an expensive infrastructure addition to farms and as such many growers must rely on a piecemeal adoption strategy that extends their period of exposure to climatic risks (Reid et al., 2007). In the case of GMO crop varieties that have been cited as having increased yields by their peers, farmers may be reluctant to use them for ideological or moral reasons or prefer alternative pest management or economic incentives to grow non-GMO varieties (Reid et al., 2007). Some producers interviewed by Reid et al. (2007) indicated that the ever-changing nature of regulations and financial support programs available to farmers makes long-term adaptation more difficult to plan and in turn to implement.

Issues stemming from crop insurance or financial support systems for growers are not only detrimental to the ability of individuals to respond but also their willingness to embrace adaptive or mitigative on-farm measures (Bradshaw et al., 2004). Growers in the Canadian prairies, for example, are less inclined to accept the associated economic limitations of diversification for climate change reasons if they are able to safeguard their income through insurance programs (Bradshaw et al., 2004). Diversification is a risk abatement strategy rather than one to maximize profits in any given growing season and limits the positive effects of an economy of scale (Bradshaw et al., 2004). In the case of Canadian cereal producers, their on-farm choices from 1994-2002 indicate that the economic incentives to specialized crop production or a move towards monoculture outweigh the benefits that diversification provides when trying to lessen climatic risk exposure (Bradshaw et al., 2004). A trend towards selecting on-farm practices that maximize profitability is again evident in the shift towards conservation or zero-tillage systems as a result of inexpensive herbicides and the reduction in labor costs rather than for environmental reasons (Bradshaw et al., 2004).

The primary limitations to climate change response identified from the two empirical studies of Canadian producers are insurance programs that decrease the willingness of growers to respond to stimuli, a preference for profit maximizing strategies over risk minimization strategies, and a belief that climate change is not a serious and or pressing issue (Bradshaw et al., 2004; Reid et al., 2007).

Australia

Australia represents one of the few developed countries facing largely negative climate change projections. The average annual temperature of the continent is expected to rise 1.0 to 6.0 °C by 2070, relative to 1990, which will increase the likelihood of heat waves, lessen the number of annual frosts, and lessen water availability in general (Kingwell, 2006). This will occur alongside a decrease in rainfall levels in the south-east and south-west portions of the country, and increases in precipitation in the northern and eastern regions. These increases are expected to be nullified by increased temperatures that will lessen overall water availability (Kingwell, 2006). The frequency of extreme rainfall, winds, flooding, and fires is also expected to increase (Kingwell, 2006).

Research indicates that while 77% of Australians believe climate change is occurring (Wheeler et al., 2013), only 55% of Australian farmers shared that belief in 2008 (Donnelly et al., 2009). Australian growers have also demonstrated a preference “to replace the term ‘climate change’ with ‘changes in mother nature,’ ‘changes in climate’, climate challenges’ or ‘a naturally occurring cycle of climate change’ to further distance and reject the role of human activity on current weather conditions” (Donnelly et al., 2009). One study dedicated to assessing how farmers have adapted to water scarcity in Australia found that farmers who believe climate change is occurring are less likely to partake in response measures that would expand their land under cultivation or irrigation, but they are more likely to engage in crop diversification or improving the efficiency of existing irrigation systems (Wheeler et al., 2013).

The Australian Government Department of Agriculture, Fisheries and Forestry has identified five major adaptation categories based on what growers in the country have reported: conserving, reducing, switching and diversifying, improving efficiency, and innovating (Donnelly et al., 2009). Conserving strives to minimize costs and expenses, reducing seeks to lessen the losses of inputs and release of greenhouse gases by farms, switching and diversifying is characterized by crop diversification or shift in production practices, improving efficiency strives to further intensify production through techniques such as rotation and improved agronomic tools, and innovating is the use of biotechnology, soil conservation practices, and forecasting tools (Donnelly et al., 2009). The report in which these are identified provides limited information about their actual on-farm implementation and associated motivations. Rather, it provides an aggregated profile of growers engaging in climate change response.

An alternative adaptation trend in the Sunraysia region—which has high levels of seasonal and permanent migrants as a result of the productive horticulture industry located there—is the integration of migrant knowledge pertaining to agriculture into existing growing systems (Klocker et al., 2018). Evidence from this region has shown that migration can foster the development of a more diversified crop assemblage and portfolio of agronomic techniques within a given agricultural community (Klocker et al., 2018). However, despite the observed and theoretical benefits of diversifying syndromes of production and crop assemblages in a location, a “racialization of knowledge hierarchies” excludes non-white agricultural knowledge from perceived

legitimacy and lessens the likelihood of its adoption by existing farms (Klocker et al., 2018).

The most central limitations reported by growers to the Australian Government Department of Agriculture, Fisheries and Forestry are a limited capacity to respond and a disbelief in climate change or distrust of the associated facts (Donnelly et al., 2009). Over two-thirds of growers cited an inability to afford on-farm responses as a barrier to implementing adaptation and mitigation strategies (Donnelly et al., 2009). The relationship that growers have to climate change information is another barrier to engaging in on-farm response. There has been an observed trend of skepticism or disbelief in climate change by Australian farmers that limits their willingness to alter their operations—particularly in the short-term (Donnelly et al., 2009). Alternatively, there is evidence that those growers who do recognize and feel concerned by climate change are not willing to expand their operations out of fear that the future will not provide viable agronomic conditions and their losses will increase (Klocker et al., 2018).

USA

In the United States, academics and extension agents have conducted extensive research across the country on farmers' perceptions of climate change and its impacts. One review identified 84 studies conducted between 1997-2015 on climate change perceptions. The plurality of these studies were conducted in the Southeast (23) followed by the Midwest (21), Southwest (16), Northern plains (11), Southern plains (8), Northeast (4), and the Pacific Northwest (1) (Chatrchyan et al., 2017). Despite the

apparent research interest in perceptions of climate change, significantly fewer studies have documented on-farm responses. Those that have have primarily focused on commodity crop producers in the Midwest and Northern Plains corn-belt regions. This production is particularly important in terms of land use and economic value as it provides roughly one-third of the world's corn supply (Arbuckle et al., 2013; Mase et al., 2017). Because of the economic importance of large-scale corn production, these studies have limited their survey populations to farms with over 80 acres of corn and \$100,000 of gross sales as determined by the USDA National Agricultural Statistics Service sample frame. In the case of Arbuckle et al. (2013) this represents 27% of respondents in the Midwest and 78% of their total cropland (Arbuckle et al., 2013). So while a majority of agricultural land under production is being examined, it is being managed by a minority of all agricultural producers, which amplifies the importance of their decision making power.

Climate change projections for the United States are extremely varied in their impact by location, with the, the northeast, south and southwest benefiting the least, and the upper Midwest and coastal Northwest the most (Antle, 2008). Overall the projections indicate a positive trend in agricultural productivity, and on a national level an annual loss of \$250 million to a gain of about \$5 billion is projected (Antle, 2008). While short-term benefits are projected, a continued warming trend is expected to eventually result in yield losses (Walthall et al., 2013). This trend will hold true for several major crops in the United States, and corn productivity in particular will decrease alongside farm profitability in the second half of the 21st century according to

multiple climate projections (Walthall et al., 2013). One of the primary production concerns linked to field crop agriculture is soil erosion, which ultimately reduces soil depth, nutrient levels and structure. Climate change could expose growers in multiple regions of the country to increased erosion—particularly where field cropping is the dominant production system. In the northern United States, a conversion of snowfall days to rainfall days in the spring may result in higher soil erosion rate, whereas increased wind erosion threatens the Great Plains (Walthall et al., 2013).

The high degree of politicization of climate change information and beliefs in the United States influences growers' perceptions and their willingness to discuss climatic shifts through time (Arbuckle et al., 2015; Liu et al., 2014). This has led to the emergence of actors both within and outside the agricultural sector attempting to discredit the occurrence of climate change, its causal sources, and its severity (Arbuckle et al., 2015). The perceived legitimacy of climate change information influences the level of ongoing and future adaptation or mitigation (Arbuckle et al., 2015). Climate change belief is positively associated with willingness to adapt or mitigate, yet those who did not believe in climate change demonstrated a willingness to adapt but not implement mitigative practices (Chatrchyan et al., 2017). Climate change belief varies by region with the highest levels in the Midwest and Northeast compared to the lowest in the Southwestern and South Eastern portions of the country. However, these studies have been conducted with varying methodologies and study populations (Chatrchyan et al., 2017).

In the largest study of U.S. agricultural producers, which surveyed roughly 5,000 corn and soybean producers in the Midwest about their climate change views, 66% of farmers believed climate change is occurring, 31% were uncertain, and 3.5% did not believe it was occurring (Arbuckle et al., 2013). Within this population, 41% of growers believed that climate change both was occurring and was caused primarily by anthropogenic forces, while 59% believed the impacts of climate change were overstated, showed less interest in adaptive responses, and did not support mitigative measures (Arbuckle et al., 2013). The reasons for farmers' uncertainty is often highly variable; a study in Wisconsin that found only 26% of farmers believed climate change had been proven by science versus 39% that believed it was caused by human activities (Chatrchyan et al., 2017). Florida growers expressed similar skepticism about the scientific validity of climate change, with 25% feeling there would never be a complete understanding of how weather and climate are determined (Hansen et al., 2004). Climate change denial or skepticism is generally associated with "Republican, conservative, and male rural residents" (Chatrchyan et al., 2017), though Jackson et al. (2011) found differences in climate change perception between organic and non-organic growers in California (Jackson et al., 2011)

Despite relatively low acceptance that climate change is occurring or a risk to their agricultural operations, American farmers are keenly aware and concerned by specific climate change impacts that may influence their farms (Arbuckle et al., 2013; Chatrchyan et al., 2017). Due to the ecosystem heterogeneity of the United States, the factors that most concern growers are regionally dependent. Growers in the Northeast

and Midwest have cited increased rainfall and increased frequency of storm events as their primary concerns while their peers in the West and Southwestern parts of the country have identified frosts, droughts, and limited water availability as their primary concerns (Chatrchyan et al., 2017).

The way in which United States producers perceive climate change has produced a response culture that favors adaptation over mitigation. Growers are more willing to adapt practices on an incremental and continual basis than to implement mitigation strategies that strive to reduce greenhouse gas emissions (Arbuckle et al., 2015, 2013; Chatrchyan et al., 2017; Mase et al., 2017). Only 23% of Midwestern growers surveyed believed that either they or the government should engage in mitigative actions to reduce greenhouse gas emissions (Arbuckle et al., 2013). This same survey found that 64% of corn farmers in the region are adopting field conservation measures in order to lessen the effects of soil erosion, 59% have purchased crop insurance, and 43% have adopted new technologies on-farm while only 10% of growers have engaged in on-farm diversification (Arbuckle et al., 2013).

The response strategies and beliefs of American growers are largely characterized by the Human Exceptionalism Paradigm which asserts that human beings are a unique species meant to dominate and control their surrounding ecosystems via technology (Gardezi and Arbuckle, 2018). “Techno-optimism,” the “belief in human technological abilities to solve problems of unsustainability while minimizing or denying the need for large-scale social, economic and political transformation,” has been identified as the guiding ideology in the majority of

American growers' decision making (Barry, 2016; Gardezi and Arbuckle, 2018). This has manifested itself in a reliance upon biotechnology or technological advancements as opposed to a broader palette of response options, less support for adaptation and mitigation overall, and a delay in the implementation of non-technological responses on-farm (Gardezi and Arbuckle, 2018).

Climate change adaptation and mitigation has also been limited by a disincentive to response fueled by the purchase of crop insurance (Arbuckle et al., 2015, 2013; Chatrchyan et al., 2017; Mase et al., 2017). Access to crop insurance provides growers with a buffer from the negative financial impacts of crop failures and further discourages growers from implementing alternative adaptation or mitigation strategies on-farm; however, growers have been observed, historically, to miscalculate risk, resulting in “an ineffective and inefficient system” (Chatrchyan et al., 2017). Researchers have concluded that in order to more effectively foster on-farm responses by growers, outreach efforts must promote responses—particularly mitigative measures in regions with high climate change skepticism—on their merit as agronomic tools or best management practices rather than as greenhouse gas management strategies (Arbuckle et al., 2013).

4. Conclusion

The overarching goal of the research discussed in this literature review is to lay the foundation for a more resilient food system in the context of climate change and its projected impacts. Approaches to this challenge have included 1) modelling the impacts of climate change on agricultural production, 2) proposing and/or evaluating

the effectiveness of potential on-farm response options, and 3) documenting climate-adaptive practices currently used by farmers, their motivations for adopting those practices, and limitations to on-farm response. The focus of this review has been the latter two forms of research.

Research on potential response options has investigated a broad spectrum of agricultural practices considered to be adaptive. These can be grouped into four major adaptation strategies: farm management, diversification, water conservation and management, and financial management. *Farm management practices* form the broadest category and include synchronizing the timing of cropping with changing environmental conditions, altering fertilization practices, converting from conventional to organic production systems, and using advanced technology such as genetically modified or improved seeds. *Diversification practices* focus on crop diversification and include modifying the spatial and temporal order of crop production, increasing interspecific crop diversity, and selecting climate change-responsive varieties of crops already being grown. *Water conservation and management practices* investigated in the literature include the use of on-farm catchment systems to aid in the collection of water as well as irrigation systems such as drip tape that increase the efficiency of water use. *Financial management practices* build resilience to climatic change through non-agricultural means including crop insurance, government loans and subsidies, and programs to increase smallholder access to inputs and biotechnology. Research on the potential mitigation methods available to farmers has explored a narrower set of practices: conservation or no-till

field management and the application of biochar. However, because these practices have been found to be yield-limiting or decrease farm profitability, research should be careful in recommending these practices without highlighting their contextual dependence.

Observational research draws on methods from the social sciences, including quantitative surveys, participant observation, qualitative interviews, and case studies, to study farmers' perceptions of climate change, their on-farm response methods, and limitations to response. While research on potential response options has focused primarily on agriculture in the Global North, the majority of observational research has been conducted in the Global South. When examining how farmers perceive climatic changes, the bulk of these studies have concentrated on changes in temperature and precipitation patterns. In almost all of the studies reviewed, a majority of farmers reported perceiving changes to climate on their farms, most frequently changes in average temperature and precipitation levels and patterns. Farmers preferred response strategies requiring changes to management strategies over those requiring investment in new technology or infrastructure. The adaptive practices most commonly adopted include crop diversification, adjustments to cropping times, and agroecological intensification using shade trees and wind breaks. In the developing world, the primary constraints to on-farm response are a lack of access to credit or financial support systems such as crop insurance as well as limited knowledge or access to outreach on the benefits, risks, and effectiveness of response options.

Majorities of farmers in developed countries also reported on-farm changes to climate—most commonly drought, extreme temperature and precipitation events, frost risk, and long-term water availability— including changes in average temperature and precipitation levels and patterns, but at lower rates than their counterparts in the Global South. Farmers in developed countries are generally more skeptical about the causes of climate change or potential severity of its impact and are generally optimistic about the potential for technology to address negative impacts. On-farm responses have been adaptive rather than mitigative, but farmers do adopt mitigative practices, not because they are mitigative but because they have co-benefits such as reduced production costs or improved soil quality. Conservation or no-till field management with increased herbicide use in the most common such response. In general, growers’ perceptions of climate change and crop insurance have most limited adoption of on-farm response methods. Climate skeptics are unlikely to implement climate-wise practices without other motivations such as co-benefits, while crop insurance, by providing an economic buffer to crop failure, creates a disincentive for adaptation. It will be important to find incentives or policy solutions that facilitate mitigative or adaptive action by these growers because of the disproportionate contributions that agriculture in developed countries has to GHG emissions.

This review of the literature identified significant gaps in existing research. Social science-based research on on-farm response is geographically restricted, and thus far has neglected to examine a diversity of production locations in the developed world. Understudied populations, such as farmers in the Northeastern United States,

may have valuable knowledge or climate change concerns that could be shared or addressed through further research. Among developed countries, the literature focuses primarily on production in the U.S. Midwest and Australia. European farmers are largely overlooked; however there has been significant research dedicated to projecting or modeling the impacts climate change will have on the production of specific crops or by region. Globally, the majority of research has centered on field crop production or production in general. Very little has examined climate change in the context of vegetable, fruit, nut, or herb production, particularly in the United States. Finally, farmers' discursive environment, including formal government outreach and other more informal sources of information on climate change and agriculture, has been understudied despite research that has shown that a lack of information is a major barrier to response.

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CHAPTER THREE

The discursive environment of on-farm climate change response in the Northeastern U.S : a content analysis of climate change outreach conducted by Cooperative Extension and a quantitative survey of Cooperative Extension providers

by

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Abstract: Specialty crop producers are particularly vulnerable to the effects of climate change on production, farm resilience, and farmer livelihoods. As the major source of public agricultural outreach in the United States, the United States Department of Agriculture's Cooperative Extension System (CES) could play a major role in shaping producers' perceptions of climate change and helping them to adapt to and mitigate its impacts. This study evaluated the discursive environment on climate change and agriculture in the Northeastern U.S. through a content analysis of the CES websites of ten land grant universities and a quantitative survey of Cooperative Extension (CE) professionals. Results indicate low levels of relevant outreach online and in-person by CE professionals. Online outreach was often conducted in formats that CE professionals reported to be ineffective. The climate factors discussed in online outreach appeared to be well-aligned with CE professionals' perceptions of climate change and producers' reported concerns. There was, however, some discrepancy between the climate responsive practices that have been the focus of scientific research and those recommended by CE professionals. Because a lack of access to outreach has been identified as a limitation to response, an increase and refinement of outreach in could heighten farmers' adaptive or mitigative ability.

Keywords: Climate change; agriculture; adaptation; mitigation; outreach; Cooperative Extension

1. Introduction

Climate change is projected to have mixed impacts on agriculture in the northeastern United States (Wolfe et al., 2018). Though projections vary by model, climate change is expected to worsen or intensify existing environmental stressors while simultaneously facilitating expanded production or the emergence of new markets (Wolfe et al., 2018). Farmers in the Northeast have already begun experiencing increased average annual temperatures, heightened risk from extreme temperature events, more variable precipitation patterns, and a longer frost-free period (Walthall et al., 2013; Wolfe et al., 2018). How farmers respond to these changes will determine how climate change impacts their farms.

Response can be classified as adaptive, mitigative, or both. Adaptive measures seek to moderate harm and to exploit new opportunities, e.g. using drip irrigation to mitigate precipitation variability or shifting planting dates to accommodate changing growing seasons. Mitigative measures, in contrast, are intended to reduce the emissions of or to increase the sinks for greenhouse gases, e.g. through adoption of no-till agriculture or biochar applications. Farmers with access to extension and outreach services are more likely to implement practices of either type on their farms (Ali and Erenstein 2017; Chengappa, Devika, and Rudragouda 2017; Deressa et al. 2009; Esham and Garforth 2013; Gbetibouo 2009; Le Dang et al. 2014; Quang et al. 2018). Those with limited access to extension resources cite a lack of information as one of their primary constraints to response (Bryan et al. 2013, 2009; Mesfin and Bekele 2018; Zizinga et al. 2017). Researchers have concluded that in order to more effectively foster on-farm responses by growers, outreach efforts must promote

responses—particularly mitigative measures in regions with high climate change skepticism—on their merit as agronomic tools or best management practices rather than as greenhouse gas management strategies (Arbuckle et al., 2013).

The United States Department of Agriculture's Cooperative Extension System (CES) is the primary agricultural outreach organization in the U.S. and, potentially, an important climate change resource for farmers. At the federal level, the National Institute of Food and Agriculture guides national agricultural research priorities through the allocation of grant funding and program leadership and also supports the outreach efforts of land grant universities and local cooperative extension offices. The USDA's CES was formed in 1914 under the Smith-Lever Act, with the goal of formalizing adult education and outreach systems (Franz and Townson, 2008). In its early stages, extension outreach consisted of traveling lecture series or demonstrations accompanied by informational pamphlets (Franz and Townson, 2008). With time, the CES evolved into a nationwide network of agents permanently stationed in the communities they serve (Franz and Townson, 2008). CES is currently the largest adult education program in the world, with more than 3,000 offices operating from over 100 land-grant universities or, at the county level, from municipal office buildings (Franz and Townson, 2008).

CES agricultural outreach has been shown to positively impact farmers' practices (Bennett, 1976; Wossen et al., 2017). The medium of outreach delivery influences the distribution, reception and effectiveness of CES messaging (Franz et al.,

2010). Furthermore, the critical evaluation of outreach efforts can enhance the productivity and accessibility of CES communication (Bennett, 1976).

To that end, this study component critically evaluated CES outreach to farmers on climate change in the Northeastern United States through a content analysis of web pages and other on-line extension resources maintained by land grant universities. This is the first study of its kind to be conducted with a focus on agriculture and climate change, and as such will provide a novel characterization of outreach available to farmers. An on-line survey of extension professionals at universities and local CES offices complemented the content analysis. Results of this research can potentially be used by advisors and policymakers to better understand the flow of information on climate change from CES to farmers to more effectively disseminate information on on-farm practices related to climate change adaptation and mitigation.

2. Methods

The Cooperative Extension (CE) web sites of ten land grant universities in the Northeast U.S. were included in the content analysis: the University of Rhode Island (URI), the University of Massachusetts, the University of Connecticut, the University of Maine, the University of Vermont, the University of New Hampshire, the University of Delaware, Rutgers University, Cornell University, and the Pennsylvania State University. Relevant outreach materials posted prior to April 2019 were identified through a systematic review of each web site and through keyword searches using web site search engines. Keywords or phrases searched included: “climate change”, “climate change response”, “adaptation”, “mitigation”, “agriculture climate

change.” Relevant outreach materials were read closely and coded by general subject such as climate change, climate change response, adaptation, or mitigation, and further by the specific adaptation, mitigation, or climate factors addressed by the materials (Patton, 2014). The content of the materials was then examined for congruities, contradictions, and absences. The results of coding were summarized in Microsoft Excel to identify the most commonly discussed topics and forms of communication.

A short online survey in Google Forms was distributed to 50 CE professionals in the same ten states as the land grant universities included in the content analysis and received 21 total responses. Potential respondents were first identified through CE web pages; this list was screened and expanded with the assistance of URI CE staff. A wide range of actors at land grant universities contribute to outreach efforts. To ensure comparability of responses across respondents, the survey sample was limited to CE specialists, educators, extension professors, and other CE professionals who devote a majority of their work to outreach with fruit, vegetable, nut, and herb growers. All study procedures were approved by the University of Rhode Island Institutional Review Board, and informed consent was obtained from all individual participants included in the study. A personalized invitation with a link to the survey was emailed to each sample member, followed by email prompts to nonresponding sample members one and then two weeks after the initial survey invitation. The survey focused on extension professionals’ and their farmer clients’ perceptions and concerns about local climate change and the practices that the former recommend to the latter as

climate change responses. Descriptive statistics for survey responses were generated using Microsoft Excel.

3. Results

3.1 Content analysis

Diverse forms of outreach on on-farm climate change response were identified, including factsheets or production guides, published research trials, farm case studies, newsletters, videos, forecasting and monitoring tools, and postings for on-farm workshops or CE-hosted events. In some cases, these were presented in the form of links to the USDA Northeast Climate Hub website. Factsheets and production guides appeared on the highest percentage (70%) of university web pages, followed by published research trials (50%), weather forecasting and tracking tools (40%), and newsletters (30%). Less than one-third of web pages featured videos (20%) or farm case studies (20%) in their archives. Other forms of outreach included long-form reports conducted in partnership with organizations such as the Sustainable Agriculture Research and Education Program (SARE), reports produced by outside organizations, and paid online courses.

Web pages frequently featured information on the impacts of climate change on the local environment, fisheries, and natural resources but infrequently addressed its impacts on agriculture. Only four institutions and associated centers or programs—the University of Vermont (the UVM Center for Sustainable Agriculture), the University of Maine (the Maine Climate and Agriculture Network), Cornell University (the Cornell Climate Smart Farming Program), and Rutgers University (the

Rutgers Climate Institute)—have web pages specifically dedicated to climate change, agriculture, and regionally-appropriate adaptive or mitigative practices. Other universities, such as the University of New Hampshire, have no online content on climate change and agriculture but have, according to their CE web sites, hosted multiple workshops with growers covering the subject. The University of Connecticut has no written online outreach but does feature a lengthy YouTube video, hosted by the Farm Risk Management and Crop Insurance Program website, which discusses in depth how climate change will impact agriculture in Connecticut. CE web pages of the remaining five universities discuss environmental phenomena and practices relevant to on-farm response, such as drip irrigation and drought, without explicitly linking them to climate change. Instead, they frame these subjects as beneficial agronomic practices or distinct environmental stimuli, with no mention of their relevance to climate change adaptation/mitigation.

Outreach on climate change factors and impacts

CE outreach materials frequently discuss phenomena connected to climate change in the research literature, including increased insect populations and disease prevalence, water stress from precipitation variability, and temperature changes but infrequently do so in the context of climate change. The majority of websites treat insect pests as an independent management subject without reference to climate change. For example, the New England Vegetable Crops Management Guide, the primary platform of the University of Massachusetts for outreach on vegetable crop production, discusses insect pest management in great detail but makes no mention of

the need to adapt management practices to climate change-related increases in pest populations. The few websites that do address pest management in the context of climate change make the connection in terms of direct and specific cause and effect, an approach which underscores the evidence-based nature of CE outreach and reinforces its authority. The Cornell Climate Smart Farming Program, for instance, notes that “[s]pring populations of insect pests will expand, as survivorship rates of marginally over-wintering insect species increase, and migratory insects arrive earlier” and “a longer growing season means more insect generations per season, requiring increased intensity of management” (*How is Climate Change Affecting Your Farm*, 2019).

While all of the CE websites have extensive outreach dedicated to disease management or identification, only URI, Cornell University, and the University of Maine attribute an increase in pathogen and disease pressure to changes in climate even in passing. This may be a result of the complexities associated with modeling the impacts of climate change on pest populations stemming from the highly specific environmental considerations of those projections. Outreach from URI and Cornell alludes to this connection but does not discuss the nuances of this relationship. The sole mention of the topic on the URI website is a September 2018 URI newsletter promoting on-farm disease management strategies such as diversification which vaguely remarks that “disease pathogens evolve and the climate is changing” without elaborating on the mechanism linking the two. Outreach from Cornell University notes that climate change will increase disease pressure on farms but, like the URI

newsletter, does not explain how, exactly, the former influences the latter. Only materials on the University of Maine website provide such explanations. A peer reviewed paper on the site, *Unique challenges and opportunities for northeastern US crop production in a changing climate*, projects an increase in disease prevalence as a result of high intensity rainfall events that stimulate pathogen reproduction (Wolfe et al., 2018). The effectiveness of a scholarly paper as a form of outreach on climate change to farmers is, however, debatable.

Outreach on water availability and precipitation variability or temperature changes more directly ties these environmental phenomena to climate change than does that on insect populations or disease prevalence. Of the seven websites with outreach on water availability as a function increased precipitation variability, five do so with specific attention to the influence of climate change on precipitation patterns. Cornell University, the University of Vermont, and the University of Maine all discuss this connection in factsheets or case studies on their websites specifically dedicated to climate change and agriculture. Outreach on the subject from the University of Connecticut and Rutgers University, on the other hand, is in long-form mediums such as an online video lecture and a report by the New Jersey Climate Adaptation Alliance summarizing climate change's impacts on agriculture. Outreach from all five of these universities includes a detailed description of historical and projected precipitation trends as well as an explanation of their agricultural implications. Websites of the remaining two universities, the University of Rhode Island and the University of

Massachusetts, discuss water availability and precipitation variability either without mention of climate change or in the context of environmental stewardship.

The CE websites of seven of the ten universities consistently characterize increases in average annual temperature and the frequency/severity of extreme temperature events as consequences of climate change and frame them as a sector wide stressor to which all specialty crop producers will need to respond. Outreach specifically focuses on increases to annual average temperature, the increased frequency and severity of extreme heat events, and shifts in the timing of frosts. The impacts that these changes—particularly the first two—will have on agriculture are primarily discussed at the farm scale. A Maine Climate and Agriculture Network factsheet highlights both the positive and negative impacts of temperature changes on farm production, including the potential for season extension, altered crop development rates, and increased crop damage. Outreach on shifts in the timing of first and last frosts under climate change appear to focus on fruit production, with special attention to small-fruit and apple production. The Cornell Climate Smart Farming Program website explains that “spring frosts and freezes are not receding as quickly as [apple] flowering is advancing, resulting in increased freeze risk,” while outreach that the University of Massachusetts conducted from 2015 to 2019 on the impacts of extreme heat events on cranberry production has not yet been posted on the university’s website.

Outreach on climate change responses

Like the research literature, CE outreach characterizes responses as adaptive or mitigative or both. Outreach on adaptive practices most frequently connects lists of projected impacts of various climatic factors on production to menus of on-farm practices purported to aid in the management of those impacts. Mitigative practices, on the other hand, are always discussed in the context of both their agronomic benefits and their ability to reduce emissions or sequester carbon in the soil or plant biomass.

CE websites of eight of the ten land grant universities cover potential adaptive practices for on-farm use specifically to respond to climate change, with each of these eight websites describing, on average, approximately seven unique practices across all outreach materials. The number of methods on a single website ranged from 1 to 23, with a median of five. A total of 39 different adaptation methods were found across all websites (n=10) (TABLE 1). No practices were found on a majority of websites. Conservation or no-till field management, cover cropping, crop diversification and drip irrigation were found on four sites; crop insurance and weather monitoring or forecasting tools on three; and adjusting planting and harvesting schedules, increasing the use of compost or organic matter as fertilizer, crop rotation, cross slope tillage, gullies or water diversion, heaters, increased perennial crop production, swales, and wind machines on two. Each of the remaining 24 practices was found on only a single site.

CE websites propose conservation or no-till field management practices as a strategy to address flooding, drought, variability in water availability, soil compaction, and extreme heat and precipitation events by improving field drainage, soil water

holding capacity, and soil microbial health, increasing soil organic matter content, and lessening soil erosion and compaction. They promote cover cropping as an adaptive response addressing climate change factors such as extreme precipitation events, flooding, an increase in average annual temperature, and soil erosion through increased soil organic matter and soil structure. Crop diversification is recommended as a broad strategy for responding to changes in temperature or precipitation patterns and insect pest or disease pressure that is flexible and can be adjusted to suit the farmer's needs.

Outreach materials promote drip irrigation as a water management tool that can help alleviate the impacts of drought, precipitation variability, increased average annual temperature, extreme temperature events, and frosts. This outreach is primarily conducted through factsheets that present a series of hypothetical climatic stressors and potential response options without a quantification of the potential benefits associated with each option. Only one case study, on the UVM CE website, of Intervale Farm, empirically assesses the agronomic and economic benefits of drip irrigation (K and Hodgson, 2017).

CE websites of seven of the universities promote mitigative on-farm practices, with an exclusive focus on four practices that sequester carbon or increase soil organic matter (in some cases in addition to other mitigative effects): cover cropping, conservation or no-till agriculture, perennial cropping systems, and biochar application. All are framed as having agronomic or climate change-adaptive co-benefits. An April 2017 University of Delaware Weekly Crop Update newsletter

discusses the simultaneously adaptive and mitigative nature of cover cropping, promoting cover crops as a useful agronomic tool to prevent erosion and improve soil health while also helping to “combat and prepare for climate change” via soil carbon sequestration. Similarly, Cornell University’s factsheet, *Soil Carbon Management & Greenhouse Gas Mitigation Opportunities*, highlights the advantages of the carbon storage capacity of conservation or no-till agriculture over conventional tillage along with the agronomic benefits of the former (Woodbury and Wightman, 2017). The same factsheet touts the superior, long-term carbon sequestration potential of perennial crops compared to annual crops (Woodbury and Wightman, 2017). The remaining mitigation practice, biochar application, was discussed with limited frequency. Only two websites referenced it, with limited discussion of its agronomic benefits due to its relatively unknown impacts on production. Outreach from the University of Massachusetts characterizes biochar application as an effective long-term carbon sequestration method but notes a lack of necessary research on its impacts on nutrient uptake, soil chemical and physical properties such as pH and cation exchange capacity, and soil water holding capacity (Cole et al., 2014).

3.2. Agriculture and climate change outreach survey

A total of 21 (42%) of the 50 selected CE professionals completed the survey on climate change outreach. They represented universities and county offices located in Rhode Island, Connecticut, Massachusetts, New Hampshire, Vermont, Maine, New York, and Pennsylvania. While all potential respondents were identified for their

outreach with fruit and vegetable producers, only 81% of survey participants reported having direct engagement with growers in their area.

A total of five respondents had a doctorate at the time of the survey, according to online profiles. The job titles of respondents according to CE staff directories varied by institution; four were identified as “Extension Educators,” while six were identified as “specialists” in specific fields. The remaining 10 respondents were a mix of professors, agricultural or research assistants, and program coordinators. Climate change was specifically referenced in the job title of only one respondent.

Climate change concerns and perceptions

Respondents were asked about both their perceptions of climate change and those of the growers to whom they provide outreach. Overall, CE professionals expressed a relatively high degree of concern about the impact of climate change on agriculture in their region. All respondents were at least somewhat concerned (9.5%) or moderately concerned (42.9%) while a plurality of respondents were extremely concerned (47.6%) about climate change (Table 2). According to respondents’ reports, farmers are comparatively less concerned, and their perceptions of climate change span a broader spectrum of concern (Table 3). One-third of respondents believe that farmers in their region are moderately concerned or somewhat concerned about climate change. Almost one-fourth (23.8%) of respondents classified farmers as being slightly concerned (23.8%), the lowest level of concern. No respondents reported that farmers are not concerned about climate change. Notably, the percentage of farmers

who are thought to be extremely concerned, 9.5%, is much lower than that of cooperative extension agents at 47.6%.

CE professionals were asked to identify an increase, decrease, or no change for each of 13 climatic or environmental factors in their area (Table 4). Of the 21 respondents, 18 (86%) report an increase in storm events (86%) more frequently than any other climatic factor. Only three (14%) reported no change, and none a decrease. A similar though less dramatic distribution of responses was found for extreme temperature events and flooding. For both, 15 respondents (76%) perceived an increase and the remainder perceived no change, with none reporting a decrease in either factor. A slightly higher number of respondents, 16 (80%) perceived an increase in average annual temperature, and three (15%) no change, but one respondent (5%) reported a decrease. A majority of survey respondents also reported increases in growing season length (75%) and flooding (66%).

CE professionals were also asked to indicate how often farmers in their area expressed concern about these same 13 climatic or environmental factors, on a six-point scale from never=1 to very frequently=6. Farmers reportedly most frequently expressed concern about storm events, pathogen populations, and extreme temperature events (median=5, frequently) followed by flooding, drought, and growing season length, water availability, and pest populations (median=4, occasionally). Pollinator populations (median=3, rarely), soil erosion (median=3, rarely) average annual temperature (median=3, rarely), sea level change (median=2, very rarely), and

atmospheric carbon dioxide levels (median=1, never) were apparently of infrequent concern to growers, according to survey respondents.

Respondents reported on how often they discuss climate change with colleagues and with growers. Talking about climate change encourages the dissemination of knowledge about climate change, its impacts, and adaptive and mitigative practices across the community of CE professionals. Outreach publications or one-on-one conversations between CE professionals and growers or other clients further disseminates that knowledge to the public. A total of 11 respondents (53.7%) reported talking about climate change with colleagues very frequently (9.5%) or frequently. One third occasionally have conversations about climate change with colleagues. The remaining three rarely (9.5%) or very rarely (4.8%) do. CE professionals may be slightly more reluctant to discuss climate change with farmers than with colleagues; two (9.5%) very frequently have such conversations farmers, seven (33.3%) frequently, and ten (47.6%) occasionally. Only two respondents (9.5%) reported discussing climate change with growers rarely (4.8%) or never (4.8%).

Outreach typology

Respondents reported engaging in formal outreach on climate change from zero to more than 15 times in the previous year. However, the majority of respondents (71.4%) conducted such outreach a modest one to five times in the previous year, one respondent (4.8%) six to 11 times, and another (4.8%) more than 15 times. Surprisingly, four respondents (19%) reported conducting no outreach climate change. These respondents cited “time constraints and a lack of perceived need,” the climate

change denial of most growers they engage with, or greater concern by growers with immediate production issues.

Respondents draw on a wide range of information sources to create outreach and publications on climate change and its impact on agriculture. Not surprisingly, since one of the goals of the Cooperative Extension System is to help farmers to apply university research to production, the vast majority of respondents (90.5%) consult university researchers or staff in developing outreach, followed by conference presentations and meetings (81%), CE colleagues or USDA staff (76.2%), websites (76.2%), and academic publications or research (66.7%). Over half of respondents relied on either their past personal experience (57.1%) or prior CE research and publications (57.1%). The remaining sources of information, which were consulted by a minority of respondents, comprise materials such as magazines and journals (38.1%), published books (19%), multimedia sources like YouTube or Facebook (19%), and the Northeast Regional Climate Center (4.8%).

Respondents were asked about the effectiveness of different outreach mediums and the impact they believe outreach can have on helping farmers adapt to or mitigate climate change. The effectiveness of these mediums was assessed on a five-point scale from not at all effective=1 to extremely effective=5. Hosting on-farm workshops or case studies (median=5, extremely) and personal communications (median=5, extremely) are both believed to be extremely effective forms of outreach, by 61.9% and 52.3% of respondents respectively. These were followed by CE-hosted workshops (median=4, moderately), factsheets and production guides (median=4,

moderately), forecasting and monitoring tools (median=4, moderately). Videos, newsletters, and published research trials were all found to be somewhat effective. Published research trials, newsletters, and publicly available forecasting and monitoring tools were all deemed to be not at all effective by at least one respondent. When asked to what extent they believe outreach on climate change adaptation or mitigation would benefit farmers in their state, the majority of respondents (52.4%) felt it would have some impact. The remaining respondents either felt outreach would benefit farmers to a great extent (38.1%) or very little (9.5%).

From a list of 30 on-farm climate change adaptive or mitigative practices identified from the literature (Lawandy 2019), survey respondents selected those they promote to growers specifically as climate change responses. Of these practices, mulching (84.2%) and no-till field preparation (78.9%) were the most commonly recommended, followed by the use of pest resistant or tolerant varieties (63.2%), drip irrigation (63.2%), high tunnels (57.9%), adjusting planting schedules and harvesting times (57.9%), drought tolerant varieties (52.6%), heat tolerant varieties (52.6%), biocontrol for insect pests (52.6%), and habitat or pollinator strips (52.6%). The most infrequently recommended practices were hydroponics (5.3%), aquaponics (5.3%), biochar (5.3%), soil remineralization (5.3%), and compost tea (0%) (Table 5).

4. Discussion

Overall, this study—the first of its kind evaluation of the discursive environment on climate change and specialty crop production fostered by USDA Cooperative Extension outreach—found relatively low levels of online outreach and

outreach conducted by Cooperative Extension (CE) professionals in the U.S. Northeast. Levels of climate change outreach published online by CE professionals in the Northeastern U.S. are largely consistent with survey respondents' self-reported frequency of outreach. Only 40% of CE offices had a web page dedicated to climate change. Most (71.4%) of CE professionals participating in the study reported conducting outreach on the subject only one to five times in the previous year, four reported conducting no response, and only two CE professionals reported conducting outreach 6-10 or 15+ times per year. The levels of outreach available online may reflect the commitment of individual CE offices or land grant universities to education on climate change. One would expect this level of commitment to influence the amount of outreach conducted by affiliated CE professionals. In some instances this was true; however, the respondents who had conducted no outreach in the previous year were affiliated with universities with online outreach on climate change ranging from the highest levels to none at all.

The low levels of online outreach do not correspond with the levels of concern reported by survey respondents, a plurality of whom are extremely concerned about climate change's impacts on agriculture in their region. CE professionals cited a perceived lack of need or a belief that farmers are climate change deniers as reasons for not conducting climate change outreach. However, studies of farmers' perceptions of climate change have found that, in general, farmers believe climate change is occurring (Arbuckle et al., 2013), and that the Northeast has one of the lowest levels of climate change denial among farmers in the United States (Chatrchyan et al., 2017).

The apprehension or heistance of CE professionals, and possibly CE offices, to conduct outreach on climate change response based on the perception that growers are climate change deniers is very likely contributing to response limitations among farmers.

The forms of outreach most commonly found on CE websites and those that CE professionals find to be most effective diverge. Case studies were the only online form that a majority of respondents (61.9%) to the survey of CE professionals deemed to be extremely effective, yet only 20% of websites featured them as part of their climate change outreach. Just over half (52.3%) of survey participants ranked personal communication as an extremely effective outreach tool, which, depending on how frequently it is conducted, could help to explain the low levels of online outreach. CE centers may prioritize one-on-one interactions with farmers over the production of online climate change-related materials. Despite overall ratings of somewhat effective—based on the median of CE professionals’ responses—which were the lowest ratings of outreach mediums scored, published research trials and newsletters were among the most common forms of online outreach and appeared on 50% and 30% of websites, respectively. Under resourced CE offices may opt to post online materials that require fewer staff resources. However, inadequate access to outreach services and a lack of information were found to be primary limitations to on-farm climate change response around the world (Lawandy, 2019). Outreach in ineffective formats may therefore may be limiting the ability or willingness of farmers in the Northeastern United States to respond to climate change.

CE outreach efforts—both online materials and CE professionals’ activities—on climate change and its impacts on agriculture largely reflect both professionals’ perceptions of climate change in their area and the climate-related topics about which their farmer-clients have most frequently expressed concern. Those concerns most frequently included storm or extreme temperature events and increasing pathogen populations and occasionally flooding, drought, growing season length, average annual temperature, and insect pest populations. Online CE outreach commonly addressed overlapping topics—extreme temperature events, water availability, growing season length, and drought—in the context of climate change; however, outreach on insect pest and pathogen populations, while extensive, was largely devoid of discussions of the impacts of climate change on pest populations or their management. Though CE appears to be responsive to local perceptions and interests, to be providing farmers with the information they want and need in order to adapt to and mitigate climate change, CE could take a more proactive role in educating farmers on emerging trends in climate change, agriculture, and farm resilience.

CE websites and professionals often recommend the same strategies and practices specifically for responding to climate change. Conservation or no-till agriculture and crop diversification were described as climate change responses by the largest number of websites (n=4) of any practice and were also recommended to farmers as climate responsive by a majority of respondents to the survey of CE professionals (78.9% and 52.6% respectively). In some cases, websites and CE professionals promote different practices to farmers as solutions to the same climate

change-related problems. For example, both no-till field management and cover cropping are promoted as ways to increase and maintain soil moisture levels, allowing farmers to adapt to precipitation variability. In other cases, CE websites and professionals, recognizing that multiple climate change factors impact farms at the same time, prioritize practices that address multiple needs. The use of drip irrigation, for example, is commonly recommended as a multifunctional response to drought, precipitation variability, increased average annual temperature, extreme temperature events, and frost that also increases yields. By promoting multifunctional practices, CE outreach can help farmers to justify response costs— a major limitation to response adoption (Lawandy, 2019)—and encourage the implementation of adaptive and mitigative practices. Both websites and CE professionals prioritize adaptive over mitigative practices, with the exception of conservation or no-till field management, a practice which is widely classified as both adaptive and mitigative. While a relatively wide array of adaptive practices have been scientifically validated, mitigative practices for agriculture have not. No-till and biochar, the mitigation strategies most commonly discussed in the scientific literature, have limited yield benefits to growers in temperate climates like the U.S. Northeast, according to the literature (Lawandy, 2019). As a translator and disseminator of evidence-based research, CE may, understandably, be reluctant to promote practices lacking evidence of their effectiveness. In addition, U.S. farmers in general are skeptical about the causes or severity of climate change and have been slow to adopt mitigative practices solely because they reduce greenhouse gas emissions (Arbuckle et al., 2015, 2013;

Chatrchyan et al., 2017; Mase et al., 2017). In the absence of economic co-benefits from yield increases, they also have no incentive to adopt such practices, which have costs. CE outreach efforts that promote mitigative measures by placing increased emphasis on their agronomic or economic value as opposed to their mitigative capacity are thus rational and may represent the best outreach strategy in the short term. At the same time, CE has the opportunity and social capital to provide leadership on climate change and agriculture and to promote mitigative practices which, though they may not have immediate benefits, will benefit farmers and farming in the long run.

Recommendations

This research starts to fill a gap in the existing research on climate change and specialty crop production in the Northeastern U.S. By combining content analysis of Cooperative Extension (CE) websites at regional land grant universities with a survey of affiliated CE professionals, it offers deeper insight into the agricultural outreach available to specialty crop producers and identifies areas for improving the content and effectiveness of outreach efforts. Currently, there is a disconnect between the level of concern held by CE professionals and the level of climate change outreach available online or through CE professionals in the field. Two of the major limitations to farmers' adopting adaptive or mitigative practices are lack of access to outreach services and a lack of knowledge about the intent and functionality of potential responses (Lawandy, 2019). In order to increase the rate of on-farm response to

climate change and reduce knowledge-based barriers, the Cooperative Extension System must expand outreach efforts online and by CE professionals.

Outreach, whether online or in person, must also be re-oriented to place more emphasis on those formats deemed to be most effective by CE professionals, which were underrepresented in online outreach. Increased dissemination of information through case studies published online or on-farm workshops as opposed to newsletters and factsheets would increase the effectiveness of climate change outreach based on the opinions of survey participants. There should be efforts to increase engagement with on-farm workshops in order to extend their impact within the agricultural community. Farmer-to-farmer networks can also serve as an effective means of sharing outreach between individuals (Roesch-McNally et al., 2017)

While a majority (52.6%) of CE professionals reported that personal communication is an extremely effective outreach tool, it strains—at a time of fiscal constraint in the Cooperative Extension System—CE resources, and its potential audience is, by its nature, limited.

Mitigation practices warrant greater attention in CES outreach. Only no-till is recommended as an on-farm response by a majority of the professionals surveyed. While this practice may not increase on-farm yields, it still presents a means by which growers can improve the resilience of their farm to climatic factors while mitigating further climatic change. Agroforestry is another practice that could help to mitigate the effects of climate change and which could be particularly relevant to the temperate Northeastern U.S., but there is limited research on the subject. When promoting

mitigative measures in the future, CES should attempt to increase their focus on the agronomic benefits of mitigative practices rather than the climate change mitigation potential or yield effects of those practices.

While the results of this study may help to inform and shape future outreach in the Northeastern United States and beyond, study findings are limited in their scope and generalizability. Both the content analysis and the survey were restricted to the universities in the Northeastern United States. Additionally, only 21 respondents representing nine schools were surveyed about their climate change response outreach. The study focused on food-producing specialty crop production. Consequently, the survey was distributed only to CE professionals who work with fruit and vegetable crops; those who specialize in field crop, livestock, or nursery production were not included. The agricultural sector of the United States—and the entire food system—would benefit from an expansion of research on climate change and plant production beyond its current narrow focus on commodity crop production in a limited geographical area.

- In order to increase the rate of on-farm response to climate change and reduce knowledge-based barriers, the Cooperative Extension System must expand outreach efforts online and by CE professionals.
- There should be efforts to increase engagement with on-farm workshops in order to extend their impact within the agricultural community.

- Farmer-to-farmer networks may present a useful alternative channel for outreach or information sharing, and represent a potential source of knowledge to inform CE outreach.
- When promoting mitigative measures in the future, CES should attempt to increase their focus on the agronomic benefits of mitigative practices rather than the climate change mitigation potential or yield effects of those practices.

6. Tables

Table 1: On-farm adaptation methods featured in cooperative extension outreach

Climate Change Adaptation	Number of Cooperative Extension Websites (n=10)
Cover crops	4 (40%)
Crop diversification	4 (40%)
Drip irrigation	4 (40%)
Conservation/no-till	4 (40%)
Crop insurance	3 (30%)
Weather forecasting tools	3 (30%)
Adjusting cropping schedules	2 (20%)
Compost/organic matter additions	2 (20%)
Crop rotation	2 (20%)
Cross slope tillage	2 (20%)
Gullies	2 (20%)
Heaters	2 (20%)
Perennial crops	2 (20%)
Swales	2 (20%)
Wind machines	2 (20%)
Agroecological boundaries	1 (10%)
Buffers	1 (10%)
Ditches	1 (10%)
Diversify off-farm revenues	1 (10%)
Filter strips	1 (10%)
Frost protectants	1 (10%)
Greenhouses	1 (10%)

Heat stress protectants	1 (10%)
High tunnels	1 (10%)
Hoop houses	1 (10%)
Inlets	1 (10%)
Intercropping	1 (10%)
Lease/buy new land	1 (10%)
Leveling	1 (10%)
Mulch	1 (10%)
Pest/disease monitoring plan	1 (10%)
Plasticulture	1 (10%)
Raised beds	1 (10%)
Row cover	1 (10%)
Strip cropping	1 (10%)
Subsurface drains	1 (10%)
Terraces	1 (10%)
Tile drains	1 (10%)
Water collection	1 (10%)

Table 2: Cooperative extension professional's level of climate change concern

Level of Concern	Percentage of Cooperative Extension Professionals (n=21)
Not at all concerned	0 (0%)
Slightly concerned	0 (0%)
Somewhat concerned	2 (9.5%)
Moderately concerned	9 (42.9%)
Extremely concerned	10 (47.6%)

Table 3: Farmer's perceived level of climate change concern

Level of Concern	Percentage of Cooperative Extension Professionals (n=21)
Not at all concerned	0 (0%)
Slightly concerned	5 (23.8%)
Somewhat concerned	7 (33.3%)
Moderately concerned	7 (33.3%)
Extremely concerned	2 (9.5%)

Table 4: Cooperative extension professional's perceptions of climate change

Perceived Change in the Past 10 Years			
Climate Change Factor	Increase n (%)	Decrease n (%)	Stayed about the same n (%)
Extreme temperature events (n=21)	16 (76.2%)	0 (0%)	5 (23.8%)
Growing season length (n=20)	15 (75%)	1 (5%)	4 (20%)
Avg. annual temperature (n=20)	16 (80%)	1 (5%)	3 (15%)
Drought (n=21)	14 (66.7%)	2 (9.5%)	5 (23.8%)
Flooding (n=21)	16 (76.2%)	0 (0%)	5 (23.8%)
Storm events (n=21)	18 (85.7%)	0 (0%)	3 (14.3%)
Soil erosion (n=20)	11 (55%)	2 (10%)	7 (35%)
Pollinator populations (n=17)	0 (0%)	7 (41.2%)	10 (58.8%)
Water availability (n=17)	3 (17.7%)	4 (23.5%)	10 (58.8%)
Pest populations (n=19)	12 (63.2%)	0 (0%)	10 (36.8%)
Pathogen and disease populations (n=17)	12 (70.5%)	0 (0%)	5 (29.5%)
Sea level change (n=13)	8 (61.5%)	0 (0%)	5 (38.4%)
Atmospheric CO ₂ levels (n=14)	10 (71.5%)	1 (7%)	3 (21.5%)

Table 5: On-farm practices promoted by cooperative extension professionals as being climate change responsive (n=21)

On-Farm Practice	Recommended by CE Professionals n (%)
Drip irrigation	12 (63.2%)
Rainwater collection/ponds/water storage	6 (31.6%)
Swales	6 (31.6%)
Mulching	16 (84.2%)
Row covers	9 (47.4%)
High tunnels	11 (57.9%)
Greenhouses	3 (21.1%)
Hydroponics	1 (5.3%)
Aquaponics	1 (5.3%)
Drought tolerant varieties	10 (52.6%)
Pest resistant/tolerant varieties (Diversification)	12 (63.2%)
Heat tolerant varieties (Diversification)	10 (52.6%)
Adjusting cropping schedules	11 (57.9%)
Increased pesticide applications	5 (26.3%)
Farmscaping/agroecological boundaries	3 (15.8%)
Trap crops	7 (36.8%)
Insect-repelling plants	1 (5.3%)
Biocontrol for pests	10 (52.6%)
Habitat/pollinator strips	10 (52.6%)
Supplementation of naturally-occurring pollinators	4 (21.1%)
No-till	15 (78.9%)
Lessened use of fossil fuel burning equipment	3 (15.8%)
Conventional to organic conversion	3 (15.8%)
Biochar	1 (5.3%)

Fertigation	7 (36.8%)
Biofertilization	4 (21.1%)
Compost tea	0 (0%)
Soil remineralization	1 (5.3%)
Ley farming (Rotation of vegetable crops with a grazed pasture phase)	2 (10.5%)
Crop rotation with an ungrazed fallow phase	7 (36.8%)

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CHAPTER FOUR

Food-producing specialty crop growers in the U.S. Northeast and climate change: perceptions, responses, motivations, and limitations

by

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Abstract: Food-producing specialty crop production is particularly vulnerable to the vicissitudes of climate change, yet little research has focused on specialty crop growers and their responses to climate change. To address this gap, a mixed methods study in the U.S state of Rhode Island collected quantitative data from 35 food-producing specialty crop growers on their perceptions of and on-farm responses to climate change. Semi-structured interviews were conducted with ten quantitative survey respondents to explore their responses in greater depth. A majority of growers perceived an increase in the frequency and intensity of extreme temperature events and storm events, which is consistent with historical data. However, in general, farmers perceived complex shifts in their production environment rather than observable trends in specific climatic factors. Interview participants expressed a strong preference for climate responsive practices with agronomic or economic co-benefits. The results of this study suggest that increased record keeping and use of monitoring tools may increase the accuracy and consistency of farmer's climate change perceptions, while an added emphasis on multi-use practices or technologies would facilitate heightened rates of on-farm response.

Keywords: Climate change, agriculture, adaptation, mitigation, specialty crop, food system

1. Introduction

Agriculture and climate change are intrinsically linked, with each influencing the other. Agricultural productivity is contingent upon climatic conditions, while farmers' practices have direct impacts on climate and the environment. Farmers in the Northeastern United States are projected to experience increased climatic vulnerability. Climate change could undermine regional food security efforts such as New England's 50 by 60TM plan, which sets the ambitious goal of meeting 50% of food needs regionally and sustainably by 2060. While 2060 is 40 years away, research to identify viable on-farm responses to changing climatic factors must be conducted now. That research must be accompanied by efforts to encourage farmers to adopt climate change-responsive practices in order to build on-farm resilience, to safeguard production, and to reduce greenhouse gas emissions from agriculture, a relatively emissions-intensive sector of the U.S. economy (Desai and Harvey, 2017). Climate change projections for the Northeast indicate the frequency of high rainfall events and extreme temperature events such as heat waves or cold-snaps will increase, along with insect, weed, and disease pressure, the risk of crop losses from short-term summer droughts, and crop damage from frost due to warmer winter and early spring temperatures which promote leaf-out and bud formation in many perennial fruit crops, leaving them exposed to a longer period of frost risk (Walthall et al., 2013; Wolfe et al., 2018).

Farmers have agency in the context of climate change. They can implement a wide range of responsive practices. While many of these practices overlap in their

intent or address multiple climatic factors, they can generally be classified as either adaptive or mitigative based primarily on their long- or short-term focus and their implications for the global climate. Adaptive practices are reactive in nature and are motivated by either an immediate perceived threat to production or an opportunity to capitalize on environmental change. The goal of mitigation, on the other hand, is to actively shape the environment and climate at large, over the long term. Adaptive measures aim to lessen the negative impacts and increase the benefits associated with on-farm climate change, while mitigative measures seek to use processes like soil carbon sequestration to lessen the impacts of previous GHG emissions and to limit agriculture's future contributions to emissions.

While the majority of farmers' decisions center on their on-farm practices, including crop choice, they make significant choices not directly related to production—generally financial decisions—to improve the resilience of their farms. Actions like purchasing crop insurance, diversifying non-food revenue streams, or installing solar panels provide growers with a financial safety net should they suffer a major crop loss, but do not directly alter their production methods (Assan et al., 2018; Bryan et al., 2009; Bryant et al., 2000; Hassan et al., 2010; Wienhold et al., 2018; Zizinga et al., 2017). Other options, such as removing land from production, leasing land to others, or diversifying sales channels, provide many of the same financial benefits but alter the typology or character of the farm. Removing land from cultivation and leasing land to others directly reduces farm size and changes land management strategies while providing a decreased cost of operation for the farm and

increasing guaranteed revenues, in the case of leased land. Diversifying sales channels provides growers with heightened resilience to market fluctuations and changing demand.

To better understand farmers' climate change-related decision making, growers of specialty crops in Rhode Island—a small state in the Northeastern U.S. and a part of New England's 50 by 60 plan for increasing regional food sovereignty—were surveyed and a purposive subsample interviewed. Rhode Island is a relatively unique location for this research. It has a diverse population of producers—including conventional and organic farms plus farms that are not organic certified but follow sustainable practices—within a small geographic area where they face similar socioeconomic and biophysical conditions of production. Due to the high density of producers in Rhode Island relative to its size there heightened potential for farmers to engage with the local food system. The relative homogeneity of the study area provides a background for identifying other factors that influence farmers' decisions about on-farm climate change response. Consequently, findings from Rhode Island could be generalized and applied to other states in the region.

Data collection was restricted to growers of crops directly consumed by humans as food, including vegetables, fruit, nuts, and herbs. The specific goals of the study were: 1) to characterize the agricultural practices of specialty crop growers, particularly as they relate to climate change; 2) to explore growers' perceptions of climate change and its impacts on agriculture; and 3) to assess the resilience of farms

based on their adoption of climate-wise practices, independent of whether those practices were consciously adopted for their adaptive or mitigative functions.

2. Methods

Study site and population

Rhode Island, a small coastal state in southern New England, has a humid climate characterized by equal levels of precipitation throughout the year, highly variable temperatures both within a single day and over the course of a year, large differences from year to year in the nature of each season, and diverse weather patterns within short durations of time resulting from the prevailing westerly winds (Overview of Climate in Rhode Island, 2019).

The state's frost-free growing period ranges from 150 to 180 days, with some areas limited to 130 to 145 days and others having 200 or more frost-free days ("Overview of Climate in Rhode Island", 2019). The average annual rainfall is 42 to 46 inches with 22 to 24 inches falling during the frost-free period (State of Rhode Island: Department of Environmental Management). The state encompasses USDA hardiness zones 6a (-20.6°C to -23.3°C) , 6b (-23.3°C to -26.1°C), and 7a (-17.8°C to -20.6°C) (USDA Plant Hardiness Zone Map, 2012).

The state's total land area is 1033.81 square miles with a population estimated to be 1,057,315 people as of July 2018 (U.S. Census Bureau QuickFacts: Rhode Island, 2018). The state has 1,043 farms (277 vegetable farms and 94 orchards) in Rhode Island with roughly 56,864 acres of farm land and an average farm size of 55 acres (USDA, 2017).

Data collection

The study employed a sequential mixed-methods research design. Growers initially completed an online, quantitative survey to identify topics, themes, or ideas warranting further exploration through qualitative interviews. Semi-structured interviews were then conducted with a subsample of survey respondents to explore in greater depth the areas covered by the quantitative survey. The study comprised the following series of interrelated tasks that can be generalized and used in varying production locations or with different populations in future research.

Task 1: Compile grower list (January 2018 - July 2018). A master list of the state's fruit, nut, vegetable, and herb growers was compiled and de-duplicated using data provided by Farm Fresh Rhode Island and the University of Rhode Island Cooperative Extension Program.

Task 2: Conduct pre-survey interviews (August 2018 - September 2018). A small yet diverse group of key informants comprising University of Rhode Island professors, Cooperative Extension professionals, and farmers selected from the list of eligible growers were informally interviewed about key topics or technical agricultural terms. Their responses and knowledge informed the vocabulary and nomenclature used and topics covered in the quantitative survey and qualitative interview. This strategy reduced the risk of miscommunication or misunderstanding. The spectrum of tillage practices in particular required definition and classification because farmers may refer to the same practices by different names, referring, for example to no-till as "carbon

farming" or "soil carbon sequestration." Where deemed appropriate, definitions of terms were included in survey and interview instruments.

Task 3: Survey growers (January 2019 - August 2019). The quantitative survey was distributed to all growers (n = 357) identified in Task 1. Questions were derived from pre-survey interviews, a review of the literature on climate-wise agricultural practices (Lawandy, 2019), and existing farmer surveys. The survey was divided into nine parts. The first part focused on farm typology, followed by sections on climate change perceptions, level of intensification, crop diversity, tillage and weeding regimes, agricultural practices, non-agricultural practices, nutrient sources, and finally demographic data (Table 1). The climate change factors and response practices were identified through a review of the literature (Lawandy, 2019). Practices promoted in the literature as climate-wise, adaptive, or mitigative—30 in total—were included in survey questions about on-farm climate change responses.

The survey was formatted in the online survey software Qualtrics (Appendix A). A link to the survey was mailed to all eligible growers (n=357) in late January 2019. After two weeks, a postcard was mailed to nonresponding growers prompting them to complete the survey. After four weeks, nonresponding growers were called or left voicemails urging them to complete the survey either online or over the telephone. An abridged paper version of the survey, estimated to take 15 to 20 minutes to complete, was developed in early summer 2019 to address problems of nonresponse. It was distributed through in-person visits to farmers markets around the state and through farm visits.

Task 4: Conduct semi-structured interviews (January 2019 - September 2019).

Semi-structured interviews were conducted with nine current Rhode Island growers who had completed the quantitative survey. A tenth interview was conducted with a producer who completed the quantitative survey and had recently relocated their farm from Rhode Island right across the state line to Massachusetts. Ideally, interviews were conducted at the participant's farm and were recorded. Some participants preferred to be interviewed over the telephone due to time constraints. The semi-structured interview questions were designed to gain deeper insight into participants' climate change perceptions, motivations, and decision making processes (Appendix B).

Information collected in the quantitative survey informed lines of questioning in the interview. Their answers to questions on climate change perceptions, crop assemblages, tillage and weeding regimes, and climate change-responsive practices determined which topics were further investigated in interviews. The interview had seven sections (Table 2). Topics included crop selection and diversification, field preparation methods, current and desired on-farm climate change-responsive practices, sources of information on climate change and on-farm practices, on-farm decision making, and perceptions of climate change. While many of these topics were addressed in the quantitative survey, the semi-structured interview format allowed for their discussion to be more personal, descriptive, and flexible (Patton, 2014).

Data analysis

Data were exported from Qualtrics and imported into Microsoft Excel where all identifying information was removed from the data file except for a respondent identification code. Statistical analysis of survey data was conducted using a combination of Microsoft Excel, R-studio, and Qualtrics StatsIQ. Other inferential analyses were conducted, including Pearson's product moment correlations and Tukey's HSD tests for differences between means using the Real Statistics Resource Pack software (Release 6.2).

The semi-structured interviews were recorded and then transcribed in Microsoft Word and coded. Coding was done by identifying relevant descriptors, trends, and keywords in order to identify emergent themes on on-farm climate change response in Rhode Island (Patton, 2014). Manual coding using keyword searches, classification of quotes by theme, and a categorization of responses was conducted using both Microsoft Word and Microsoft Excel.

3. Results

3.1 List compilation

After an initial round of vetting and de-duplication, the combined lists from Farm Fresh Rhode Island and URI Cooperative Extension were reduced to 357 fruit, vegetable, nut, and or herb producing operations. During data collection, 83 ineligible or inactive growers were identified, further reducing the eligible population to 274 growers.

3.2. Quantitative survey

Farmer and farm characteristics

A total of 35 growers completed the quantitative survey; 28 completed the survey online and 7 completed the abridged paper questionnaire. Table 3 summarizes the socio-demographic characteristics of participants. The large majority were white (97%) and born in the United States (96%). One grower was of South Asian origin. Gender identification and religious affiliation demonstrated greater diversity. Just over one-third of respondents identified as female (36%) while the remainder (64%) identified as male. The predominant religious affiliations of participants were no religion (8 of 22), Protestant (4 of 22), and atheist or agnostic (3). A total of five additional affiliations were represented at frequencies of one or two.

Farmer experience

The average age of respondents was 55.5 years with a range of 25 to 80 (median=62.5, SD=15.6). Farm or ranch work was the primary occupation of 88% of survey participants. The total number of years that respondents had spent farming was 23.25 on average and ranged from 3 to 60 years (median=18, SD=19.1). However, the average number of years spent as the primary operator of the current farm (11.68) or of any farm (11.97) was markedly lower, indicating that many had less on-farm decision making experience than overall agricultural experience and were not first-time farmers prior to becoming a principal operator. Roughly 35% of respondents were raised on a farm or ranch while 42% have completed an agricultural internship or apprenticeship. Despite 86% of survey participants possessing an Associate's degree or higher none possessed a degree in an agricultural field. This demonstrated a high

level of diversity in both the age and experience of farmers who participated in this survey.

Farm typology

The farms of survey participants were considerably smaller than the Rhode Island average, 21.1 versus 55 acres (USDA, 2017). Farm size ranged from 0.05 acre to 148 acres (median=6, SD=33.7). Small farms are overrepresented in the sample and large farms are underrepresented compared to the state population (51.4% vs. 35.8% for small farms (1-9 acres) and 11.4% vs. 21.6% for large farms (over 50 acres) (USDA, 2017). The percentage of mid-sized farms (10-49 acres) was similar in both the sample and statewide, at 37.1% and 36.1%, respectively (USDA, 2017). The majority of farms consisted of a single parcel (89%); however, some comprised up to 6. Most principal operators (63%) owned a portion of their farmland, with the majority of owners having purchased their land as opposed to inheriting it (86% vs. 14%). The remaining farms were operated by a tenant, on at least partially leased land (29%), or by a hired manager (8%).

These farms represented a wide range of production schemes, from USDA certified organic to conventional systems using synthetic inputs. The most common was organic but not certified (37%) followed by conventional (29%) and USDA certified organic (24%). Conventional to organic transition and other growing systems constituted the remaining farms (10%). The average acreage in organic but not certified production was 4.25 acres with a range of 0.05 acre to 20 acres (median=2, SD=5.9). USDA certified organic farms were slightly smaller and averaged 2.82 acres

while ranging from 0.05 to 9 acres (median=1.3, SD=3.2). Conventional farms, however, were larger than their organic counterparts, with an average size of 10.14 acres and a broad range from 1 to 50 acres (median=4, SD=15.8).

Participating farms producing vegetable crops grew 18 different varieties on average with a range of 0 to 42 (median=22, SD=13.9) (Table 4). Farms growing fruit or nut crops produced an average of 2 different fruit or nut crops with a range of 1 to 8 (median=2, SD=2.4). In general, farms were well diversified with just under one-fifth (19.3%) of vegetable producers not growing any fruit or nut crops and only 10.3% of fruit growers not producing any vegetables. Just under two-thirds of respondents (65.71%) grew herbs on their farm, though data on specific herb crops were not captured. Only 30% of farmers surveyed raised livestock alongside crops.

Farmers were also asked to identify their most profitable crops as well as their most land intensive crops, those to which they dedicated the most land. The crops most frequently identified as being most profitable were: tomatoes (17%), mixed salad greens (9%), lettuce [leaf, head, Romaine] (5%), potatoes (5%), and pumpkins (5%). An additional 28 other crops were identified as being one of farms' three most profitable crops (Table 4). On average, growers dedicated just under a quarter of an acre to tomatoes (0.23 acres) or lettuce (0.20 acre) and slightly more than that to mixed salad greens (0.29 acres).

The crops to which growers dedicated the most land on their farms were slightly different than those which they identified as being most profitable. They most frequently reported tomatoes (14%), apples (6%), kale (6%), potatoes (6%), and mixed

salad greens (6%) as their most land-intensive crops, along with 24 other crops (Table 4). Other crops commonly reported as being among the most land intensive were lettuce (5%), pumpkins (5%), winter squash (5%), and strawberries (5%). While sweet corn, pumpkins, broccoli, strawberries, winter squash, and garlic were identified as being among the most land intensive crops of fewer farms than kale or tomatoes, they were on average planted over a greater area. This contrast is most obvious in the case of sweet corn, which was planted on an average of 3.5 acres, or pumpkins, which were grown on an average of 2.81 acres, versus 0.23 acre for tomato and 0.46 acre for kale. Despite apples being the fruit crop most frequently selected by farmers as their most land intensive, average area devoted to grapes outstripped that for apples by far, 25.75 acres versus 6.4 acres, respectively.

The majority of farmers reported that most of their 2018 sales were direct-to-consumer through farmers markets, roadside or farm stands, CSA distributions, pick-your-own, or on-site tasting rooms. Farmers markets were the sales channel most frequently identified by growers and were the only channel in which a majority of growers (57%) had engaged in 2018. Roadside or farm stands and CSA distributions were each used by roughly one-third of participants. Approximately 18% of farmers engaged in some form of wholesaling to retail grocers, processors, or distributors, but only one relied exclusively on wholesaling. A small portion of farms sold directly to restaurants (12%) or donated production (3%). None of the farms sold produce directly to institutions such as schools, prisons, hospitals, or other organizations that provide regular meals to a specific community.

Climate change perceptions

Participants were asked to identify trends in 13 climatic factors on their farms over the previous 10 years or the duration of their tenure as primary operator if under 10. The majority of respondents reported that these factors had stayed about the same except for extreme temperature (heat waves and cold snaps) and storm events. An increase in extreme temperature events was reported by 66% of respondents while 60% perceived an increase in storm events. Respondents' perceptions are consistent with historical data for Providence, RI. The number of days in which the maximum temperature was greater than or equal to 32.2°C has exceeded long-term averages since the 1990s, with the greatest number of such days annually occurring between 2010 and 2014 (Runkle et al., 2017). A majority of the farmers who perceived a change in the annual number of extreme temperature events indicated that this has negatively impacted their crop yields (56%), harvesting schedule (52%), and crop quality (52%). Smaller percentages of growers indicated negative impacts on the varieties they can grow (22%), crop prices (17%), input costs (13%), farm value (9%), and land or field quality (9%). Some respondents did report benefits to crop yields (30%), quality (9%), pricing (13%), harvest schedule (26%), and the varieties they can grow (17%). A majority (83%) of farmers who perceived an increase in extreme temperature events have altered their growing practices in response.

Historical data also suggest an increase in storm events. In the most recent ten year recording period for which data are available, 2005-2014, state-level annual precipitation levels were above average, and a record number of precipitation events

with greater than 2 inches of rainfall were recorded (Runkle et al., 2017). In 2018, 63.49 inches of precipitation were recorded for the state, well above the average of 47.18 inches. Farmers who perceived an increase in extreme storm events reported negative impacts on crop yields (59%) and quality (55%). These farmers also reported negative consequences for their harvesting schedule (27%) and the varieties they can grow (22%). Some farmers who perceived an increase in storm events reported benefits to crop yields (9%), quality (18%%), and pricing (14%), harvest schedule (14%), farm value (5%), input costs (5%), land and field quality (14%), and the varieties they can grow (9%). (This finding warrants exploration in future research, to determine whether it is real or due to response error.) More than half (59%) of the farmers who perceived an increase in storm events have altered their on-farm practices in response.

Other climate factors that were identified by a large proportion of growers as having changed on their farm were average annual temperature (43%), drought (43%), flooding (37%), and pathogen/disease populations (34%) (Table 5). Growers experiencing a change in the frequency of these climatic factors most commonly reported negative impacts on crop yield and quality. Of the growers reporting a change in drought frequency, 61.1% and 55.5% reported that it had a negative impact on crop yields and quality, respectively. Of those reporting a change in pathogen populations, slightly smaller percentages, 60.0% and 53.3%, observed negative impacts on yields and quality, respectively.

An increase in average annual temperature was more commonly associated with positive on-farm effects than any other commonly identified climatic factor. Just under half the farmers who identified a change in average yearly temperature reported positive impacts on their harvest schedule (44%) and the varieties they can grow (44%). An increase in growing season length, reported by 12 farmers, had the highest positive associations of any climatic factor identified as having changed. Of these 12 farmers, 58% felt it had a positive impact on their crop yields while 50% believed it had benefited their harvest schedule. Though farmers generally reported that the majority of climate change-related factors had stayed the same on their farm over the previous ten years, the majority of survey respondents (62%) still indicated that they were somewhat concerned (6%), concerned (20%), or very concerned (37%) about how climate change will impact their farm. Roughly three-quarters of farmers (74%) reported discussing climate change with their friends, family, or other growers at least occasionally. Those who discuss climate change somewhat often (43%) or often (29%) were the greatest proportion of respondents. Only 9% of respondents reported never discussing climate change.

Tillage and weed management regimes

Data were collected on the field preparation methods and weed management regimes for 76 crops that farmers identified as their most land intensive—respondents who completed the online survey reported on their three most land intensive crops while those who completed the abridged paper version did so for only their single most land intensive crop. A slight majority (51%) of these crops were prepared using

full-field systems, defined as systems in which 100% of the soil surface is disturbed and <15% of the soil surface is covered by crop residues. Of full-field tillage crops (n=36), the majority were plowed to a shallow depth (61%); deep tillage (28%) and subsurface tillage (11%) were far less common. No-till field preparation (<10% of the soil surface is disturbed and >70% covered by crop residues) was practiced on 32% of participating farms' most land intensive crops. Crops prepared using restrictive/reduced tillage methods (n=13), in which planting strips are tilled and 15-30% of the soil surface is covered by crop residues, were most commonly tilled to a shallow depth (61%) while a minority were deep tilled (39%).

Farmers reported at least partially managing weeds by manual cultivation in 67% of their most land intensive crops, which is 50% more than any other individual method. Other weed control strategies that rely on soil disturbance, such as machine cultivation (16%), sterile seedbed methods using repeated shallow cultivation prior to planting (9%), and tillage (7%), were not as common. In total, weeds were managed through soil disturbance for 99% of the crops for which data were collected. Weed suppressive strategies were also used, in the aggregate, on 74% of the most land intensive crops. Methods leveraging biological competition such as cover cropping, living mulch, and biointensive planting were applied to 30% of crops, combined, while artificial covers such as tarps, black plastic, landscape fabric, or pre-planting soil solarization were used on 28%. Mulching with leaves (8%), straw (7%), or compost (1%) was used on a total of 16% of crops. Post-emergence weed control methods that do not disturb the soil were less prevalent than those relying on soil disturbance or

weed suppression. The use of herbicides (12%) was the most common; burning or flame weeding (9%) and mowing or trimming (3%) were not conducted as frequently.

Current and prospective adaptive or mitigative agricultural practices

Of the 30 adaptive or mitigative practices listed on the quantitative survey, respondents most frequently selected crop diversification through different forms of responsive crop selection as a current on-farm practice (Table 6). The majority of farmers reported planting pest resistant or tolerant varieties (57%) compared to just over one-third who selected crops purported to be drought tolerant (34%) or tolerant to extreme heat or cold (34%) as part of their diversification efforts. The most commonly reported single practice was the use of row covers (60%), which has two potential functions, protecting plants from insect damage and extending the growing season. A relatively large proportion of respondents selected as current practices those increasing the presence or diversity of pollinators: supplemental pollinators such as honeybees (49%) and habitat or pollinator strips (31%). Other popular on-farm practices were soil remineralization (26%), reduced use of fossil-fuel burning equipment (26%), and fertigation (26%). Farmers reported using an additional 9 of the other 30 climate adaptive or mitigative practices identified through a review of the literature and offered as response options (Lawandy, 2019), bringing the total number of practices used in 2018 to 18. On average, farms followed 4.8 of these practices, with a range of 0 to 13 (median=4, SD=3.5).

Farmers were asked to select from this same list of practices the ones they would most like to adopt (Table 7). High tunnels (34%) were the only practice in

which more than one-third of respondents demonstrated interest. Mulching (31%), the installation of habitat or pollinator strips (26%), and adjusting planting and harvest schedules (26%) were all selected by more than one-quarter of respondents. Farmers also expressed an interest in the potential use of rainwater catchment systems or water storage methods (23%), drip irrigation (23%), no-till soil preparation (20%), biocontrol for pests (20%), lessening their use of fossil fuels (20%), and diversifying their crop selection to include more drought (20%) or pest (20%) tolerant varieties. In total, the farmers surveyed reported they were considering 26 different climate adaptive or mitigative practices for future farm use. The average and median number of practices under consideration per farm was 4, with a range of 0 to 10 (SD=3.1).

Non-agricultural practices to build resilience

Farmers identified the non-agricultural actions they had undertaken to increase their farm's resilience in the previous five years as well as the options they would like to adopt in the next five. Of the 35 respondents, 12 (34%) had not made any non-agricultural changes to their farm operation and 13 (37%) indicated that they had no plans to engage in future non-agricultural actions to build resilience. The most common actions respondents had already taken were the diversification of sales channels (56%), addition of non-food revenue streams through the addition of services or activities such as weddings and events, hayrides, corn mazes, or a brewery (22%), and purchase of crop insurance (22%). The installation of solar panels (13%) and the removal of land from cultivation (13%) were less common choices but were still

undertaken by multiple respondents. In only a single instance each did a farmer convert land to sod or turf (4%) or lease land to others (4%).

The most frequently selected nonagricultural changes that farmers would like to make in the next five years were largely the same as those that other farmers reported that they had already made, with one exception, the installation of solar panels. While a relatively small percentage of farms had installed solar panels in the previous five years, 69% of respondents reported a desire to install them in the next five, making this the most frequently selected prospective response. The diversification of sales channels (44%) and non-food revenue streams (13%) were the next most frequently selected responses. All other options were selected by one or fewer respondents with no respondents expressing interest in converting land to sod or turf or removing land from cultivation.

Farmer/farm characteristics and perceptions of climate change and adoption of climate-wise responses

Statistically significant negative correlations were found between farmer age and number of current ($\rho = -0.44$, $p < 0.01$) and prospective ($\rho = -0.51$, $p < 0.01$) climate-change responsive practices (Table 8). A somewhat weaker negative correlation was also identified between years as principal operator and the number of climate-wise practices that the farmer would like to adopt in the future ($\rho = -0.35$, $p < 0.05$). No other statistically significant correlations were found between continuous farmer- or farm-level variables and the number of current or prospective practices.

Comparison of the mean number of current or prospective climate-wise practices by categorical farmer- or farm-level variables identified only a single significant difference, by production system. Respondents managing organic-only production systems had adopted and expressed a desire to adopt in the future a higher number of climate-wise practices than those managing conventional-only or mixed systems (6.2 and 5.8, respectively, for organic only versus 2.3 and 1.8 for conventional and 3.4 and 2.4 for mixed, $p < 0.05$). Means were not significantly different between conventional and mixed systems. Comparison of the mean number of climatic changes perceived/responded to by categorical farmer- or farm-level variables revealed only a single significant difference, by gender. Respondents identifying as female perceived and responded to, on average, a significantly greater number of climatic changes than did those identifying as men (6.2 and 4.9 versus 4.9 and 2.7, respectively, $p < 0.05$; Table 9).

3.2. Qualitative interviews

A subsample of ten growers who had completed the quantitative survey participated in a semi-structured interview that explored their on-farm practices and perceptions of climate change with greater depth. Interview participants represented a diverse, purposive sampling of farmers by sociodemographic characteristics, farming experience, and relationship to the land they farmed (Table 10). The ages of participants ranged from 25 to 80 years old, with an average and median age of 48 (SD=16.6). They had, on average, spent 9 years as the principal operator of any farm, with a range of one to 22 years (median=7.5, SD=6.3). Participants were nearly evenly

split in terms of their relationship to the land they farmed, with five owning their land, four being tenants on leased land, and one being a hired manager. Most of the farms are located in urbanized areas surrounding Providence and the southeastern coastal portion of the state stretching from North Kingstown to Cranston. No survey respondents located in the inland western or northwestern parts of the state agreed to participate in an interview.

Climate change perceptions and impacts

All of the participants expressed some concern about climate change either on their farm or at a global level. For many farmers, the most alarming aspect of climate change was not a specific factor or event, but rather the uncertainty associated with the pace and intensity of change. All of the farmers believed that climate change was occurring. While all felt climate change would eventually impact their farms or the global environment, they did not seem to have a strong understanding of how this will occur. Respondent 8 indicated they are “nervous [but they] don't know the answer to ‘How will things change?’.” This sentiment was echoed by Respondent 7 who said that there is “so much mystery out there about how things will look” and that they’re fearful of not knowing “what climate change will bring in terms of changes to the farm.” Farmers also expressed concern about when these impacts will be felt on their farms and how quickly. When asked about their primary concerns about climate change, Respondent 6 stated, “It worries me. I don't really know how soon [climate change] is happening.” Similarly, Respondent 8 commented, “If it occurs as fast as they think it will, then it’s very frightening.” Other farmers’ primary environmental

concerns lay not with climate change's impacts on production, but rather with broader issues that may ultimately contribute to environmental degradation. For example, Respondent 5 "believe[d] that climate change is happening" but was "more concerned with recycling and things like that." Similarly, despite being framed within a discussion of on-farm climate change, Respondent 3's primary concern focused on reduction of litter such as cigarettes and plastic bottles. When asked about their climate change concerns, Respondent 10 remarked, "I'm more concerned with weather than climate, day-to-day stuff...and I think all the other farmers I talk to are too."

Participants reported frequently discussing climate change with their peers. All believed that their views on climate change were shared by other farmers, particularly those with whom they frequently interact or who manage production systems similar to their own. However, Respondent 3 felt "that most people, myself included, are in denial about that" despite previously indicating they had perceived changes in climate on their farm. This was the only assertion by a participant that farmers are in denial about the impacts of climate change. Farmers perceived heightened variability in temperature and precipitation patterns—most notably in the form of heat waves and cold snaps—along with an increase in the frequency and severity of storm events as having the greatest impact on their farm in the previous ten years. For two farmers, a perceived increase in sudden heat waves in June and July has made planting spring brassica crops too risky because they had suffered increased crop losses from bolting. An increase in the severity and frequency of cold snaps and hard frosts, both early and

late in the season, had reduced the number of grape varieties one grape grower felt safe cultivating. This same grower, speaking on behalf of his agricultural peers around the state, noted a specific reduction in plantings of Cabernet grapes in the state.

Several farmers commented on the destructive impacts an increase in the frequency and severity of storm events had had on their farms. Respondent 4 stated, “Winds are stronger and it demolishes trees around the farm now”, while Respondent 6 noted that they’ve “had a lot more winds and even a few twisters down here, which we’ve never had before.” Respondent 1 claimed, “Wacky stuff happens in the summer. We have thunderstorms here, hail, flash floods, and wind storms, all out of nowhere.” Roughly one-third of participants reported a change in the insect populations on their farm, specifically a decrease in pollinator populations. Respondent 10 also felt there “has definitely been an increase in insect pests and fungal pathogens on the farm the past few years.”

Farmers were hesitant or unwilling to discuss many of the climate change factors they had identified as increasing or decreasing on the quantitative survey. An inability or dismissal of the opportunity to expand upon these factors and their impacts was sometimes followed by a statement to the effect that they don’t keep detailed records from year to year and thus have difficulty in accurately tracking changes. Other farmers denied that their farms had been impacted at all by the previously reported changes in climatic factors, with many saying they could not recall or accurately distinguish changes. Increases in average annual temperature or soil erosion were the factors that farmers had the most difficulty tracking or perceiving despite

indicating on the survey that they had noticed an increase in these phenomena on their farms.

Rather than describing their experiences with specific climatic factors on their farms, many participants preferred to discuss overall trends in climate or environment or more complex phenomena than a change in a single factor. Multiple farmers described a more drawn out transition from winter to spring characterized by slower warming, excessively wet soils, and, consequently, an increase in flooding. Respondent 2 felt their fields were “waterlogged in the spring, when they haven't been before,” while Respondent 9 experienced difficulty accessing fields due to mud and flooded roadways on their farm. Excessively wet soil was also mentioned by Respondent 8 who described springs as having “less frost, but everything is wet for longer.” Farmers also perceived a greater variability in temperature within a single growing season. Respondent 1 “felt like June, July, and August was a bell curve and in August things would tail off, but now it's all over the place. It gets warm then cold, then warm. I don't know.” Similarly, Respondent 8 believed “climate is warming but not evenly. There are dips now that are more significant than the past. It's more harsh and more random.”

Crop and varietal selection

Farmers primarily selected crops based on their marketability, consumer demand, or specific requests from consumers and not based on their resilience to climate change. Growers making a large percentage of their sales at farmers markets tended to select crops based on their color, shape, taste, or size. This was particularly

true for crops such as tomatoes, summer squash, and salad greens. Respondent 4 and Respondent 1 both stated that they could plant more disease resistant tomato varieties but preferred to grow heirlooms because customers find them more attractive. The marketability of the farmers market stand as a whole was important for Respondent 3, who chose tomato, eggplant, and summer squash varieties “by what will make a nice display at the farmers market” because “how the stand looks to customers really matters.” Similar selection criteria were applied to salad greens; farmers have opted to grow a diversified selection based on leaf shape, color, and taste. The goal of “having a nice blend of reds and greens” was what dictated how Respondent 9 selected salad green varieties.

Farmers also made a concerted effort to diversify the selection offered in their community supported agriculture (CSA) programs; however, their efforts were largely guided by what they perceived to be customer requirements. For example, despite having persistent issues with insect damage on their brassica crops, Respondent 2 continued to grow kale “because the CSA members sort of expect it to be in there.” CSA customer requests also prompted farmers to select crop types or varieties that were uncommon or that they had not previously grown. Respondent 2 had increased production of bitter melon as a result of requests from CSA members, while Respondent 1 had altered their mix of melon varieties over the previous two years as a result of feedback and requests from members. Customer-driven crop and varietal selection sometimes came with tradeoffs. Respondent 1 observed that many of the melon varieties specifically requested by their CSA members were less resistant to

powdery and downy mildew and were generally less productive than varieties they had grown in the past.

Farmers wholesaling or selling directly to restaurants selected crop varieties based on special requests. Respondent 1 grew “a specialty bean, which was a request from a chef. He buys the whole crop because he can’t get it anywhere else but I don’t think we would grow it otherwise.” Respondent 10, on the other hand, reduced their production of leeks because demand from wholesale purchasers had decreased and the market had become less profitable. Unlike growers of annual vegetable crops, growers of apples and grapes were highly constrained in their ability to change the varieties they were producing because of the longer life cycles and perennial nature of their crops. In the case of vineyards, selection was dominated by the grapes required to produce specific wines or blended wines. One grape grower reported that the number of grape varieties that they could grow was limited by a lack of cold tolerant varieties suited to their microclimate. Grafting more desirable wine grape varieties onto hardier rootstocks was one way that growers could diversify their varietal palette.

Pathogen resistance or tolerance was of secondary consideration for almost all of the farmers interviewed. Farmers gleaned information about the disease resistance or tolerance of crop varieties from anecdotal evidence, personal experience, and varietal descriptions on seedhouse websites. Respondent 1 expressed a preference for beets with green vegetation over those with red vegetation because they had observed superior resistance to cercospora leaf spot in the former; the same farmer was a fan of the ‘Sugar Cube’ variety of cantaloupe “which has an insane disease package.” For

Respondent 10, fungal pathogens were a primary production challenge; consequently, for them, “fungal resistance is key. If it doesn't have listed resistances on the seed websites, I usually won't buy it.” In some circumstances, climate and environment had an impact on not just which varieties but also which crops were grown. Both Respondents 4 and 5 noted that they no longer planted brassica crops in the spring because they were too prone to bolting and early season insect pressure.

Many farmers operating at smaller scales were forced to consider the labor requirements of their crop choices, especially the frequency of harvests and the time required to harvest. Crops that were labor intensive to harvest, require large planting areas, e.g. sweet corn and pumpkins, or require consistent in-season maintenance were often avoided by smaller farms unless demand for the product was high or sales were guaranteed. Generally, crops with smaller fruit such as cherry tomatoes and green beans that must be picked frequently or don't hold well in the field were reported to be the most labor intensive. Respondent 4 noted that they “don't grow cherry tomatoes anymore because they split so fast. I don't have enough time to harvest them every day in the summer.” Respondent 1 similarly remarked that while all of their “beans have grown well, the issue we run into is the picking and processing” and that “for green [they] tend to grow Roma types because Romas are a little more forgiving. If we grew Provider or something like that we would be picking them every single day. A Roma can hang on and work into a 3 or even 4 day picking cycle and it grows well for us.”

Few farmers actively selected crop types or varieties based on perceived changes in climate. When they did, it was generally a crop's seasonality that influenced its selection. This was most clearly evidenced by Respondent 1's remark that, while he has, in the past, tried "Crimson Sweet but it needs to be a really really hot summer to make that work" and was now "looking for shorter season stuff that [they] can harvest with fewer hot days so they don't stay in the field as long and run the risk of going down to mildew or something like that." Some farmers opted to plant crop varieties recommended for early or late season production to increase farm profitability and resilience during periods of relative scarcity. This was most common for tomatoes. Some farmers reported planting early or late season varieties to avoid the saturated mid-season market. Respondent 7 said they "prefer to grow early ripening cherry tomato varieties because [they] like to have the first field ripe tomatoes in the state." Respondent 5, on the other hand, planted late season varieties for high tunnel production in the fall, when prices are higher than in July or August. Farmers also expressed an interest in planting more heat tolerant varieties of greens, citing increased crop losses from heat wave-induced bolting in recent years.

Tillage and weed management regimes

Participants reported both economic and environmental motivations for using no-till field preparation methods, most frequently reductions in operating costs and soil disturbance. Respondent 2 said that one reason they used no-till field preparation was that they "don't have to own or maintain anything expensive like a tractor." A desire to "limit soil disturbance as much as possible" motivated Respondent 9 to

practice no-till agriculture. Farmers reported benefits to soil microbial diversity and abundance, resilience to precipitation variability, and reduced pest populations. After transitioning to no-till, Respondent 6 reported “seeing an amazing diversity of life in the soil...with more fungi than [they] used to see when looking under the microscope.” Respondent 3 reported similar results and also felt their soil’s water-holding capacity had increased after switching to no-till. Respondent 3 noted that since the change their “farm irrigates less and doesn't have to worry about drought as much anymore.” The drawbacks that participants associated with no-till were the labor of using a broadfork to crack the soil surface prior to planting and increased weed pressure. Respondent 6 remarked, “Keeping up on weeds is really important now; we have more than we used to. I can't spray though because we're organic no-till.” Participants not currently using no-till expressed interest in it but were uncertain about its effectiveness. Respondent 1 commented, “No-till is really interesting, but I don't know if I have the intestinal fortitude for that though. I would have to really look into it and try it in a test plot before switching the farm over. Plus, then we would have to buy a tractor with a crimper or go the glyphosate route.” Similarly, Respondent 5 said, “I heard no-till is good for your soil but I don't know enough about it.”

Participants using reduced or restrictive tillage methods did not elaborate on their motivations for their tillage regime. Respondent 4 gave no more explanation than, “That's just how I learned to farm...that's the only way I can break up my soil.” Equipment dictated the depth of tillage in these systems. Respondent 1, for

example, “just till[s] as deep as the rototiller goes.” Reported benefits of reduced or restrictive tillage systems were reduced erosion, decreased pest populations, increased drainage, reduced ponding, decreased irrigation, and increased soil fertility. On Respondent 8’s farm, the use of restrictive tillage had “added a lot of organic matter and structure to the soil” which they felt had reduced their irrigation and fertilizer costs. Some farmers did express concern that soil disturbance from reduced or restrictive tillage might still negatively impact soil microbial health. Respondent 4 had reservations about reduced tillage, saying, “I don’t really know if im doing more harm than good, or if I’m going to kill my microbes.” Similarly, Respondent 10 believed that there could be a “potential loss of soil life with tilling” and as a result tried to limit the depth of soil disturbance.

When asked to discuss their weed management practices, farmers focused on their experiences with different mulching systems or methods. Participants perceived leaf mulch and plastic mulch to be the most successful weed control methods, in addition to having production benefits such as increased cold protection and erosion control. Leaf mulch was touted as a more sustainable option by both the growers who did and didn’t use it on their farms; however, it was perceived and found to be more laborious than other weed suppression methods. Respondent 3 noted that leaf mulch helps to “build soil health as it breaks down, but it takes a lot of time and labor,” a sentiment echoed by Respondent 8 ,who stated that their use of leaf mulch required “lots of work up front, but there is less weed pressure season-long so it’s worth it.” While participants felt that plastic mulch was an effective weed control method and

easy to use, particularly with the help of a four-wheel or walk-behind tractor, many were uneasy with the level of plastic waste associated with this practice, prompting some participants to alter or consider altering their practices. Respondent 6 opted to use leaf mulch because they felt that “plastic was effective but it didn’t feel right to throw it away at the end of every season.” Others, like Respondent 1, mentioned an interest in decreasing their plastic waste on-farm but had been limited by the fact that “biodegradable [plastic] options aren't available in smaller rolls that make economic sense for the farm.” Roughly one-third of farmers discussed using tarps or soil solarization to reduce weed pressure. Respondent 3 felt that clear plastic tarps to solarize soil “helps] to cut back on the weed seed bank in the soil...and maybe decreas[es] the insect pests.” Respondent 9 deployed opaque tarps for soil occultation which “reduced the amount of weeding required on the farm year after year.” (In soil occultation, tarps create a warm, moist environment that encourages the germination of weeds, which then die due to lack of light.) Farmers did not expound upon whether soil solarization or tarping had any environmental benefits or drawbacks but did report a high cost of investment as one limitation to their use. One site specific concern came from Respondent 8, who thinks tarps could help with weed management but was unsure how they could effectively be used in their space-limited setting.

On-farm practices

Of the climate-wise agricultural practices that they had reported—in the quantitative survey—currently using, interview participants were most voluble on the topics of row covers and pollinator strips. Row covers allowed growers to plant earlier

in the spring and to continue harvesting or planting later into the fall. Some growers like Respondent 9 used them both in the field and “in high tunnels as a double layer of protection for greens and roots in the winter.” Participants also used row covers for pest protection on a wide variety of crops, particularly brassicas. Farmers mentioned flea beetles, cabbage looper moth larvae, and imported cabbageworm as insect pests they sought to deter using row covers. Respondent 1 had success with row covers as a pest protection strategy—but one with tradeoffs—stating “there are things we haven’t had to spray because it was under row cover, but it does raise the temperature so we’ve had some things bolt.” On the other hand, multiple growers reported they had success in reducing bolting in many crops by shielding them from intense sunlight and temperatures with row covers. Respondent 3 found that “since [they] started using row covers on greens we’ve had a lot less bolting...maybe because there is more shade and they aren’t in direct heat all day.” While farmers reported a number of benefits from the use of row covers, the majority also felt that there was a substantial downside associated with the labor requirements of installing and maintaining them. Respondent 8 felt that despite their effectiveness at building on-farm resilience, “Row covers are impossible to manage. You constantly have to put them back over your beds when they blow away or pull them back to harvest and weed, and it really only lasts one season before you have to replace it.”

All but one interview participant elaborated on the use of pollinator strips on their farm. Participants described managed cut flower plantings, agroecological boundaries containing native plants, fallow fields, managed plantings of native plants,

or some combination of these. Participants reported an increase in the populations of pollinators such as native bees or Monarch butterflies and beneficial insects including hover flies that aided in the management of pests like aphids or cabbageworm.

According to Respondent 6, after establishing a planting of cut flowers for sale as well as a managed stand of native plants, their farm had “been full of dozens of insect species that we’ve never seen before.” Respondent 8 had created agroecological boundaries on their farm, including a structurally diverse assemblage of plants such as shade trees, fruit bearing bushes and shrubs, and native plants like milkweed. The boundaries increased the associated biodiversity of their farm and reduced active pest management throughout the season. Respondent 8 reported that “the milkweed has brought in a lot of butterflies and other pollinators and the shade trees and berries give the resident birds somewhere to live and they eat a lot of the pests and contribute to our soil fertility with their droppings.” Farmers who planted cut flowers to increase pollinators on their farms found benefits both in terms of pollination services to their crops and farm profitability. Respondent 1 initially planted a combination of native and cut flowers for pollination services but subsequently “developed a good cut flower business that has actually made a lot of money so far,” leading them to consider expanding the practice in coming years. After allowing a fallow field to be reclaimed by native plants, Respondent 9 observed an increase in native bee populations.

Participants reported no negative consequences of pollinator strips. Only two farmers discussed increasing the presence of pollinators on farm through the use of in situ beehives. Both of these participants felt that this practice simultaneously increased the

environmental sustainability of their farm and its economic resilience. Respondent 1 initially began beekeeping in order to increase their pollinator populations but was soon able to monetize the honey produced by their hives. They found that “the money is good, people will pay a lot for local honey, but the intangible aspect [they] value the most is the pollination.”

In terms of future adoption of on-farm, climate-wise practices, participants expressed the most interest in high tunnels, followed by drip irrigation, water collection and management systems, and adjustments to planting and harvest schedules. All of the participants who indicated they would like to install high tunnels believed it would increase the resilience of their farm to climatic or environmental factors by limiting their exposure to environmental stressors and extending the length of the growing season. Respondent 2 “would like to extend the growing season a little bit more, either starting earlier or going later in a high tunnel.” Respondent 3 echoed this sentiment: “It would add some protection from the elements and definitely allow us to grow later into the year.” Almost all of the participants who expressed interest in high tunnels also voiced concern about their cost or the uncertain land tenure of their farm. Like many of their peers, Respondent 4 felt “right now it's too big of an investment. I would like to do it, but it costs too much.” Respondents 1 and 3 both indicated that they were unsure about whether it is an economically viable decision because they lease land and are unsure how long they will be farming at their current site.

Participants also commonly reported an interest in either adopting drip irrigation or increasing its use. Respondent 2 mentioned, “Time is one of [my] biggest constraints, so having an irrigation system would save a lot of watering.” Similarly, Respondent 6 believed that by expanding drip irrigation on their farm they would “cut back on the time spent watering” and that “it uses less water which is good for the environment...the downside is that it is a lot of plastic.” Other participants were concerned that drip irrigation would be too expensive, require too much labor to establish, or limit their ability to grow successional rotations. Participants were also interested in adopting water collection and management systems. Respondent 4 envisioned using rainwater collection barrels to irrigate vegetable crops more sustainably and in turn reducing their water bill. Respondent 2 “would like to be able to use runoff from the house and barn to water some dwarf fruit trees.” Participants cited only benefits of water collection, with none discerning any drawbacks of the practice.

In response to perceived cooler, wetter, and more drawn out springs, some participants indicated they would like to adjust their farm production schedule. Respondent 6 would like to “do more fall crops, because the spring is wetter and [they] can't get into the fields until later.” Respondent 5 had the same motivation for wanting to “start growing fall crops, to make up for lost sales in the spring.” Respondent 5, though, worried that shifting production later into the fall would mean “no time off” and “growing four seasons, it’s too much without a break.”

Non-agricultural practices

In terms of the non-agricultural, resilience-building practices that they had adopted in the previous five years, participants most frequently discussed diversification of sales channels, diversification of non-food revenue streams, and installation of solar panels. They diversified sales channels through new or increased sales in direct-to-consumer markets and attempts to increase wholesaling. Respondent 1 accomplished this by “starting as almost all CSA and a small amount of wholesale, which has grown significantly, and now some farmers markets.” They found that this diversity of sales was a necessity: “We have to have that. Last year, a restaurant we work with changed chefs and adding the farmers markets helped get past that.” Respondent 1 reported synergy between different marketing channels, noting that “people [they] meet at the farmers market” have contributed to a significant increase in their CSA membership, more so than sponsored Facebook posts. Although they voiced concerns about an expansion into pick-your-own berries, and stated that “after the GAP (Good Agricultural Practices) and FSMA (Food Safety Modernization Act) training [they] will never do pick-your-own.” Respondent 5 diversified sales channels in order to increase profitability and to sell bumper crops rather than as a way of to reduce risk. They were “selling raspberries at farmers markets because [they] have so many right now and it’s some extra cash,” while also looking into “things like Farm Fresh or the New England Agricultural Exchange for when we have excess we can’t sell at the stand.”

Participants had diversified non-food revenue streams through the sale of agricultural related goods or knowledge. Two respondents had begun teaching

gardening classes. One respondent did this in a non-profit capacity, believing it increased the exposure of their farm to the surrounding community, while the other did so for a fee that helped support the farm. These same respondents also engaged in the sale of goods such as compost and greenhouse-grown transplants in order to boost farm income from sources less vulnerable to the vicissitudes of the outdoor environment, like field production. Respondent 6 remarked that the diversification of non-food revenues is “nice, because in case something fails in the field you have a backup.”

Only three growers had installed solar panels on their farms, which they found provided a source of non-food income, increased farm sustainability, and built the resilience of their operations to environmental stressors. Participants cited a desire for a more sustainable power source and independence from the electrical grid as their primary motivations for installing solar panels. Respondent 6’s panels “power the entire farm which has really reduced overhead costs... It really fits our model of sustainability, and it made economic sense.” However, Respondent 6 would like to increase the infrastructure of their system to include backup batteries because “it would be more resilient if we weren’t connected to the grid and didn’t have outages still.” Respondent 7 found that the installation of panels with an array of batteries provided their operation with increased resilience to extreme weather events that might knock out power and safeguarded their postharvest storage and production.

The resilience-building non-agricultural practices that participants would most like to adopt are the diversification of sales channels, diversification of their non-food

revenue streams, and installation of solar panels. Participants in the first group were most intrigued by the idea of expanding their wholesale business. Respondent 3 “wants to increase wholesaling to avoid having to provide consistent product all season long in a CSA” and believed that “selling some things in bulk seems like a good way to hedge our bets for resilience.” Respondent 5 expressed interest in using this strategy as a means for increasing total sales as opposed to diversifying markets. This respondent expressed interest in building relationships with wholesalers in order to have a market for excess crops they were unable to sell at their roadside stand.

Farmers had considered diversifying their non-food revenue streams through the sale of value added goods and cut flowers. Two participants would like to begin producing value-added goods such as pickles or popcorn; however, both noted concerns about meeting the food safety standards for a processor. Respondent 4 “would love to sell pickles but would need a commercial grade kitchen and a license” so they had not pursued it yet. The participants who mentioned that they had been considering the sale of cut flowers as part of their farm’s business plan had already begun establishing relationships with purchasers and identifying which varieties they would like to grow. Respondent 9 would like to expand cut flower production to the point where they are “ideally working with local grocery stores and retail chains on a consistent basis.”

While the farmers interviewed that already have solar panels on their farm use them to power their entire operation, those who would like to add them had more modest goals. Respondent 9 believed the installation of panels would increase the

overall sustainability of their farm. With this in mind, they had applied for grant funding to install solar panels “for a well pump, but will probably find other uses after that like charging their tillage batteries or heating high tunnels.” Similarly, Respondent 2 would like to look into the possibility of installing solar panels should they eventually install a greenhouse or high tunnel on their farm. Cost, however, was a concern of these participants and a possible limitation to adoption.

4. Discussion

Findings from this research shed light on how food-producing specialty crop growers in Rhode Island perceive and respond to changes in climate. They also illuminate some of the factors motivating and limiting response and suggest directions for future research on this understudied population and production sector, in the context of climate change. The generalizability of the results of the research are, however, limited by small sample sizes and, of course, the intentional geographic restriction of the study to Rhode Island, arguing for the evaluation of these results through larger, more geographically expansive studies.

Overall, statistical analysis of the data revealed few significant relationships between hypothetical explanatory variables, such as farmer and farm characteristics, and perceptions or responses to climate change. Males who were the primary operator of their farm were found to perceive and to respond to, on average, fewer climate change factors than their female counterparts. Research on farmers’ climate change perceptions and rates of response by gender identification has been extremely limited; a single study, from Ghana, found lower rates of perception and response among

female farmers, in contrast to the results of this study (Assan et al., 2018). This difference may be due to greater social restrictions on women in Ghana, which constrain their access to resources and information. Future research should investigate, with larger samples, whether the difference between genders identified in this study is real and, if so, explore possible reasons for the relationship.

Significant negative correlations were found between farmer age and years as principal operator and the number of climate-wise practices that farmers currently used or would like to adopt in the next five years. Older, more experienced farmers may rely more heavily on their past experience and engage with new agricultural knowledge less frequently than younger farmers seeking to define their practices in the early years of farm management. On-farm and regional food system resilience could be improved by increasing the social self-organization of farmer networks, including building intergenerational networks, in order to enhance reflective and shared learning behaviors across generations (Cabel and Oelofse, 2012).

Farm size and income were not significantly correlated in this study with the number of climate responsive practices in use or being considered for future use. Previous research conducted in East Africa, in contrast, found that wealthier farmers or those with larger tracts of land were more likely to adapt to climate change (Bryan et al., 2013; Ziervogel et al., 2008). This however, may be an imperfect comparison due to the differing agricultural histories of these regions and the differences in farm scale. In Rhode Island, smaller farms may be more agile and their principal operators, with smaller investments in equipment and other infrastructure and because of

differing levels of dependence on their farm related income, especially in the case of lifestyle farmers, may be more open to taking risks and experimenting with novel practices. This hypothesis warrants further exploration in future research.

Organic-only producers were found to follow a greater number of resilience-building, climate-wise practices on their farms than conventional-only or mixed system producers. Moreover, despite already following a greater number of these practices, organic-only growers were interested in adopting a significantly higher number of new climate-wise practices in the next five years than were farmers managing mixed or conventional-only systems. As alternative agricultural producers, organic-only farmers are undoubtedly predisposed to experimenting with novel practices. Conventional-only and mixed growers, on the other hand, may show less inclination to adopt such practices because they are able to draw on a larger repertoire of more reliable and effective chemical controls than organic growers. These controls potentially provide a technological buffer to climate change. In order to overcome a sense of “techno-optimism” among conventional and mixed producers (Gardezi and Arbuckle, 2018), research and outreach should focus on identifying and promoting climate responsive practices that meet these production standards or practices that are functional alternatives to their current practices.

Rhode Island specialty crop growers operate at a broad range of scales and employ diverse production systems and business models. Acreage of participating farms varied widely, from 0.05 to 148 acres, reflecting differing levels of business investment, site-specific land availability, and farmer engagement. While all of the

farms in the study grew fruit or vegetables commercially, they varied in terms of their business model and included traditional commercial farms, market gardens involved in direct-to-consumer sales, and not-for-profit farms. The landscape context of farms also varied, spanning the urban to rural continuum. Though access to land is a recognized limitation to agriculture across Rhode Island—the state has the highest farmland value in the country—it is an even greater constraint in urbanized environments, limiting farm/market garden size and contributing to the diversity in farm acreage reported in this study (USDA, 2018).

Study results suggest that climate change may not be a pressing concern for most growers in Rhode Island. A similar lack of immediate concern for the impacts of climate change was found to be common and response-limiting in previous studies of producers in developed countries such as Australia, Canada, and the United States (Lawandy, 2019). However, a large majority of farmers in Rhode Island are discussing climate change with their colleagues and peers and are still concerned about the impacts of climate change on their production, suggesting that they may be receptive to outreach on adaptive and mitigative strategies and practices.

Farmers in this study reported discerning more complex trends in climate change, such as shifts in the nature of seasons, as opposed to specific climatic factors. This differs from previous research on farmers in developing countries, whose climate perceptions have widely been characterized by an emphasis on changes in specific factors rather than general shifts (Lawandy, 2019). A majority of farmers in this study reported no change on their farms in the frequency or intensity of all climatic factors

except extreme temperature and storm events. Changes in temperature and precipitation patterns were the most commonly perceived by farmers in previous observational research (Lawandy, 2019), indicating that these may be the most apparent climate change factors, the most readily observed and interpreted by farmers. When interviewed about the factors that they had claimed had changed on the quantitative survey, farmers often recanted those claims, citing an inability to discern changes without maintaining detailed yearly weather and crop records. Farmers may have been reluctant to discuss these changes—particularly with a researcher associated with an institution like the University of Rhode Island—because they could not empirically prove their claims. Enhanced record keeping, crop data collection, or the use of monitoring tools on farms might reveal changing climate patterns to farmers beyond the extreme temperature and storm events they already observe, motivate them to respond to climate change, and help them tailor responses to impacts specific to their farms.

Respondents to the quantitative survey reported mixed impacts of climate change on their farms, with most climate change factors having both positive and negative impacts. Majorities of farmers reported negative impacts to crop yields and quality from a change in the frequency of extreme temperature events, storm events, drought, and pathogen populations. Farmers reported positive impacts to harvest schedules (44%) and the diversity of crop varieties farms can grow (44%) from an increase in average annual temperature. By adopting more climate responsive practices, farmers may be better able to lessen the negative impacts of climate change

on their farm while maximizing their benefits from productivity enhancing changes to the environment.

Though farmers may not be able to discern on-farm changes in climate and consequently may not be tailoring their production practices to respond specifically to climate change, many—particularly organic-only growers in this study—still followed and expressed a desire to adopt climate-wise methods that build on farm resilience. Farmers were more likely to currently follow or to express a desire to adopt in the future those practices with multiple functions. This is consistent with previous research which found a preference for technology driven and cost reducing practices among farmers in developed countries (Gardezi and Arbuckle, 2018). While farmers in this study, per qualitative interviews, largely began implementing a particular climate-responsive practice to address a specific climatic factor or stressor, they often chose to intensify or to continue to follow the practice for reasons not related to climate change. Some farmers, for example, initially adopted beekeeping because of a perceived decline in pollination services to their crops but continued keeping bees because they found them to be a profitable source of income. These multifunctional climate-response practices represent a form of functional diversity, which is associated with agroecosystem resilience (Cabel and Oelofse, 2012).

Follow-up interviews with farmers revealed that crop variety selection was driven by economic considerations with only secondary consideration for environmental or climatic factors. The selection of tomato varieties is a strong example of this, with many farmers opting to grow heirloom or eye-catching varieties

despite acknowledging they may be less adapted to their climate or resistant to pests and pathogens. When discussing climate-responsive practices that they would like to adopt in the future, farmers articulated a mix of motivating factors including climate/environment, labor, and overhead costs. Each of these motivations was referenced in discussions about drip irrigation; it helps growers adapt to precipitation variability, reduces the time they spend watering crops, and, in some circumstances, could reduce their water bill and in turn operating costs. Future outreach on the subject should emphasize the multifunctional nature of climate responsive practices, as well as practices that address the motivations or climate change factors that most compel on-farm response.

The primary limitations to adopting climate responsive on-farm practices cited by farmers in this study were cost, lack of information, labor, land tenure, and environmental concerns. These differ from the limitations to response reported in other research conducted in developed countries: crop insurance or financial support systems and a general disbelief or distrust of the scientific facts on climate change (Lawandy, 2019). The limitations reported by farmers in Rhode Island more closely mirror those of farmers in developing countries and stress a lack of access to outreach or a lack of financial resources required to respond (Lawandy, 2019). In many cases, these constraints or limitations are substantial enough to prevent farmers from adopting new on-farm practices. In particular, the installation of high tunnels, which could extend the growing season and increase farm productivity, has been constrained by their upfront investment cost and their permanence relative to land tenure

agreements. Tradeoffs between agronomic benefits and increased labor are particularly important to small-scale growers who operate with limited hired help or mechanization. Increasing the reusability of agricultural technologies like drip tape or plastic mulch would reduce environmental degradation and the costs associated with repeated purchasing, and in turn facilitate on-farm response. Attempts should be made to increase the publicly available outreach on climate responsive practices in response to farmers' reported lack of access to information as a limitation.

In this study, farmers' primary motivation for non-agricultural response was economic. Farmers have found that by diversifying their sales channels and non-food revenue streams and by installing solar panels they have been able to lessen the impacts of climate change on their farms by increasing their economic resilience. These practices are indicators of resilience building behaviors by farmers that leverage and increase the local interconnectedness of producers and consumers, build human capital, and enhance their farm's functional and response diversity (Cabel and Oelofse, 2012). However, more widespread use of these practices has been limited by cost and fear of added regulatory requirements. This is consistent with results from Reid et al. (2007) who found that farmers were hesitant to make long-term adaptations to their farm in response to climate change because they were concerned about ever-changing regulatory requirements or standards. Future research and outreach should emphasize how farmers can take advantage of grants or other external funding in order to reduce the cost of resilience building measures like high tunnels and solar panels. Additionally, the USDA and other agricultural stakeholders should make efforts to

clarify the regulations surrounding non-agricultural practices like the production of value added goods that strengthen farms' economic resilience.

This study had some limitations that should be addressed in future research. The actual population of eligible growers in the state may be larger.. Institutional lists such as those used in this study often underrepresent urban market gardeners and other growers who may make significant contributions to local food economies (Taylor and Lovell, 2012; Young, 2015). Attempts were made to address this potential source of undercoverage through the distribution of paper surveys at farmers markets frequented by urban growers and collaboration with the Southside Community Land Trust, the state's largest urban agriculture service provider. Even when urban growers were identified and included in the population frame, language barriers sometimes prevented their participation in the study. Representation of these diverse growers in the study would have afforded a broader look into production practices, climate change perceptions, and response methods.

The response rate for the quantitative survey was 12.7% despite the launch of the survey during the off-season and aggressive nonresponse follow-up. Results may be biased due to low response. The research literature suggests that low response rates are not uncommon in surveys of farmers and often lower than what was attained in this study. A study on the barriers and motivations to adopting multifunctional perennial cropping systems in Illinois, for example, had a response rate of 7.6% (Mattia, Lovell, and Davis 2018), while another study on the likelihood of Australian farmers to adopt carbon farming practices had a response rate of only 6.8% (Dumbrell,

Kragt, and Gibson 2016). Previous research on increasing survey participation within the farming community has attributed low response rates to the period in which the survey is sent, the form and amount of compensation, the source or organization distributing the survey, and and perceived length (Pennings et al., 2002)

5. Conclusions

The influence of climate change on agricultural production is projected to continue and worsen in the future, putting specialty crop production and, in turn, regional food systems at risk. This study begins to fill a significant gap in the scholarly literature—an almost complete lack of research on climate change and fruit, vegetable, nut, and herb production in the U.S. Northeast. By illuminating how these specialty crop growers perceive and respond to climate change, the study lays the foundation for outreach to growers on climate-wise practices by agricultural service providers such as the USDA Cooperative Extension System.

Future research and outreach should have the goal of maximizing levels of on-farm response by emphasizing the multifunctional nature of practices that build resilience to climate change. Ultimately, the primary determinant of adoption of these practices is their impact on the economic sustainability of the farm. To be successful, efforts to increase the climate resilience of agricultural production must reflect this. Incremental and even transformational adaptation to and mitigation of climate change through the alteration of on-farm agricultural practices, both now and in the future, will be required to strengthen regional food systems and build resilience within the agricultural sector.

6. Tables

Table 1. Quantitative survey topics

Survey section	Topics
Farm typology	<ul style="list-style-type: none"> • Farm size • Production systems • Relationship to land • Crop types grown
Climate change	<ul style="list-style-type: none"> • Trends in climate change factors • Influence on growing practices • Level of concern • Frequency of discussion
Level of intensification	<ul style="list-style-type: none"> • Production systems • Chemical controls • Irrigation • Mulching
Crop diversity	<ul style="list-style-type: none"> • All crops grown • Most profitable crops • Most land intensive crops
Tillage and weeding regimes	<ul style="list-style-type: none"> • Tillage system • Tillage depth • Weed management
Climate responsive agricultural practices	<ul style="list-style-type: none"> • Practices used on farm • Practices farmers are interested in adopting
Climate responsive non-agricultural practices	<ul style="list-style-type: none"> • Practices used on farm • Practices farmers are interested in adopting
Nutrient sources	<ul style="list-style-type: none"> • Types of nutrients used • Sources of nutrients
Demographic data	<ul style="list-style-type: none"> • Age • Gender • Level of education • Marital status • Farming experience • Farm income

Table 2: Qualitative interview topics

Interview section	Topics
Crop Selection	<ul style="list-style-type: none"> • Specific crop varieties grown • Crop selection criteria and motivations • Climate change impacts on crops • Crops that have been successful/ failed
Field Preparation	<ul style="list-style-type: none"> • Tillage system • Tillage depth • Weed management practices • On-farm impacts • Benefits/drawbacks • Motivations for use • Limitations to use • Environmental implications
Climate Responsive Agricultural Practices	<ul style="list-style-type: none"> • Practices used on farm • Practices farmers are interested in adopting • On-farm impacts • Benefits/drawbacks • Motivations for use • Limitations to use • Environmental implications
Climate Responsive Non-Agricultural Practices	<ul style="list-style-type: none"> • Practices used on farm • Practices farmers are interested in adopting • On-farm impacts • Benefits/drawbacks • Motivations for use • Limitations to use • Environmental implications
Sources of Information	<ul style="list-style-type: none"> • Sources of information used to learn about climate change or agricultural practices
Decision Making	<ul style="list-style-type: none"> • Influence of different factors on decision making
Climate Change	<ul style="list-style-type: none"> • Trends in climate change factors • Influence on growing practices • Level of concern • Frequency of discussion

Table 3: Sociodemographic characteristics of quantitative survey respondents

Socio-demographic characteristic			
Age (n=35)	Mean/ Median	Range	SD
Age	55.5/62.5	25-80	15.6
Gender (n=34)	n (%)		
Male	22 (64.70%)		
Female	12 (35.30%)		
Race (n=28)	n (%)		
White	27 (96.43%)		
Asian Indian	28 (3.57%)		
Religious affiliation (n=25)	n (%)		
No religion	10 (40%)		
Protestant	4 (16%)		
Agnostic	2 (8%)		
Roman Catholic	2 (8%)		
Other	2 (8%)		
Jewish	2 (8%)		
Muslim	1 (4%)		
Atheist	1 (4%)		
Buddhist	1 (4%)		
Marital status (n=26)	n (%)		
Now Married	19 (73.08%)		
Never Married	6 (23.08%)		
Divorced	1 (3.85%)		
Pre-tax farm net income (n=27)	n (%)		
Less than \$1,000	5 (18.52%)		
\$1,000 to \$2,499	1 (3.70%)		
\$2,500 to \$4,999	2 (7.41%)		
\$5,000 to \$9,999	3 (11.11%)		
\$10,000 to \$24,999	1 (3.70%)		
\$25,000 to \$49,999	10 (37.04%)		
\$50,000 to \$99,999	0 (0%)		

\$100,000 to \$249,999	4 (14.81%)
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Table 4: Crop diversity, profitability, and intensification

Crop Diversity			
Crop	All farms n (%)	Most Profitable n (%)	Most land intensive n (%)
Apples	9 (25.71%)	2 (5.71%)	5 (14.29%)
Apricots	1 (2.86%)	0 (0%)	0 (0%)
Artichokes	1 (2.86%)	0 (0%)	0 (0%)
Asparagus	12 (34.29%)	0 (0%)	0 (0%)
Beans	22 (62.86%)	0 (0%)	1 (2.86%)
Beets	19 (54.29%)	0 (0%)	1 (2.86%)
Blackberries	5 (14.26%)	1 (2.86%)	0 (0%)
Blueberries	12 (34.28%)	1 (2.86%)	2 (5.71%)
Broccoli	16 (45.71%)	0 (0%)	1 (2.86%)
Brussels sprouts	8 (22.86%)	0 (0%)	0 (0%)
Cabbage	14 (40%)	0 (0%)	0 (0%)
Carrots	17 (48.57%)	1 (2.86%)	2 (5.71%)
Cauliflower	7 (20%)	0 (0%)	0 (0%)
Celery	8 (22.86%)	0 (0%)	0 (0%)
Cherries	3 (8.57%)	0 (0%)	0 (0%)
Collards	10 (28.57%)	0 (0%)	0 (0%)
Cucumbers	26 (74.29%)	2 (5.71%)	3 (8.57%)
Currants	1 (2.86%)	0 (0%)	0 (0%)
Eggplant	20 (57.14%)	1 (2.86%)	1 (2.86%)
Garlic	22 (62.86%)	2 (5.71%)	3 (8.57%)
Ginger root	4 (11.43%)	2 (5.71%)	0 (0%)
Gooseberry	1 (2.86%)	0 (0%)	0 (0%)
Grapes	6 (17.14%)	2 (5.71%)	2 (5.71%)
Herbs	23 (65.71%)	3 (8.57%)	3 (8.57%)
Horseradish	4 (11.43%)	0 (0%)	0 (0%)
Kale	21 (60%)	3 (8.57%)	5 (14.29%)
Kiwi	1 (2.86%)	0 (0%)	0 (0%)
Kohlrabi	9 (25.71%)	0 (0%)	0 (0%)
Lettuce	18 (51.43%)	4 (11.43%)	4 (11.43%)
Melons	24 (68.57%)	0 (0%)	1 (2.86%)
Microgreens	6 (17.14%)	2 (5.71%)	0 (0%)
Mixed salad greens	18 (51.43%)	7 (20%)	5 (14.29%)
Mushroom	3 (8.57%)	1 (2.86%)	1 (2.86%)
Mustard greens	15 (42.86%)	0 (0%)	0 (0%)
Nectarine	3 (8.57%)	0 (0%)	0 (0%)
Okra	3 (8.57%)	0 (0%)	0 (0%)
Onions (dry)	14 (40%)	0 (0%)	2 (5.71%)
Onions (green)	19 (54.29%)	2 (5.71%)	0 (0%)
Other	7 (20%)	1 (2.86%)	2 (5.71%)
Parsley	22 (62.86%)	2 (5.71%)	0 (0%)
Paw-paws	2 (5.71%)	1 (2.86%)	1 (2.86%)
Peaches	9 (25.71%)	2 (5.71%)	1 (2.86%)
Pears	6 (17.14%)	1 (2.86%)	1 (2.86%)
Peas (all types)	25 (71.43%)	1 (2.86%)	0 (0%)

Peppers	2 (65.71%)	1 (2.86%)	0 (0%)
Plums	3 (8.57%)	1 (2.86%)	0 (0%)
Potatoes	18 (51.43%)	4 (11.43%)	5 (14.29%)
Pumpkins	18 (51.43%)	4 (11.43%)	4 (11.43%)
Radishes	18 (51.43%)	0 (0%)	0 (0%)
Raspberries	12 (34.28%)	1 (2.86%)	1 (2.86%)
Rhubarb	14 (40%)	1 (2.86%)	1 (2.86%)
Spinach	14 (40%)	2 (5.71%)	1 (2.86%)
Squash (summer)	23 (65.71%)	3 (8.57%)	3 (8.57%)
Squash (winter)	21 (60%)	0 (0%)	4 (11.43%)
Strawberries	11 (31.43%)	3 (8.57%)	4 (11.43%)
Sweet corn	9 (25.71%)	3 (8.57%)	3 (8.57%)
Sweet potatoes	16 (45.71%)	0 (0%)	0 (0%)
Swiss chard	19 (54.29%)	0 (0%)	1 (2.86%)
Tomatoes	25 (71.43%)	14 (40%)	12 (34.29%)
Turnips	13 (37.14%)	0 (0%)	0 (0%)
Watercress	2 (5.71%)	0 (0%)	0 (0%)

Table 5: Farmers' perceptions of climate change

Climate change factor	Increase n (%)	Decrease n (%)	Stayed about the same n (%)
Extreme temperature events (n=35)	23 (65.71%)	0 (0.00%)	12 (34.29%)
Growing season length (n=35)	11 (31.43%)	1 (2.86%)	23 (65.71%)
Avg. annual temperature (n=35)	15 (42.86%)	1 (2.86%)	19 (54.29%)
Drought (n=35)	15 (42.86%)	3 (8.57%)	17 (48.57%)
Flooding (n=35)	13 (37.14%)	0 (0.00%)	22 (62.86%)
Storm events (n=35)	21 (60.00%)	1 (2.86%)	13 (37.14%)
Soil erosion (n=35)	4 (11.43%)	3 (8.57%)	28 (80.00%)
Pollinator populations (n=35)	5 (14.29%)	10 (28.57%)	20 (57.14%)
Water availability (n=35)	4 (11.43%)	2 (5.71%)	29 (82.86%)
Pest populations (n=35)	10 (28.57%)	3 (8.57%)	22 (62.86%)
Pathogen/ disease populations (n=35)	12 (34.29%)	3 (8.57%)	22 (54.29%)
Sea level change (n=35)	4 (11.43%)	1 (2.86%)	29 (82.86%)
Atmospheric CO ₂ levels (n=35)	5 (14.29%)	2 (5.71%)	27 (77.14%)

Table 6: On-farm climate change response practices currently used by respondents

On-farm practice	Farms (n=35)
Row covers	21 (60.00%)
Pest resistant/tolerant varieties	20 (57.14%)
Supplementation of naturally-occurring pollinators	17 (48.57%)
Drought tolerant varieties	12 (34.29%)
Heat tolerant varieties	12 (34.29%)
Habitat/pollinator strips	11 (31.43%)
Crop rotation with an ungrazed fallow phase	10 (28.57%)
Fertigation	9 (25.71%)
Reduction in fossil fuel-using equipment	9 (25.71%)
Soil remineralization	9 (25.71%)
Farmscaping/agroecological boundaries	7 (20.00%)
Insect repelling plants	7 (20.00%)
Biocontrol for pests	6 (17.14%)
Compost tea	6 (17.14%)
Trap crops	5 (14.29%)
Swales	3 (8.57%)
Bio-char	2 (5.71%)
Bio-fertilization	2 (5.71%)

Table 7: On-farm practices farmers would like to adopt

On-farm practice	Farms (n=35)
High tunnels	12 (34.29%)
Mulching	11(31.43%)
Adjusting cropping schedules	9 (25.71%)
Habitat/pollinator strips	9 (25.71%)
Drip irrigation	8 (22.86%)
Rainwater collection/ponds/water storage	8 (22.86%)
Biocontrol for pests	7 (20%)
Drought tolerant varieties	7 (20%)
Lessened use of fossil fuel burning equipment	7 (20%)
No-till	7 (20%)
Pest resistant/tolerant varieties	7 (20%)
Compost tea	6 (17.14%)
Heat tolerant varieties	6 (17.14%)
Soil remineralization	6 (17.14%)
Biofertilization	5 (14.29%)
Insect-repelling plants	5 (14.29%)
Row covers	5 (14.29%)
Greenhouses	4 (11.43%)
Supplementation of naturally-occurring pollinators	4 (11.43%)
Trap crops	4 (11.43%)
Biochar	3 (8.57%)
Crop rotation with an ungrazed fallow phase	3 (8.57%)
Farmscaping/agroecological boundaries	2 (5.71%)
Fertigation	2 (5.71%)
Aquaponics	1 (2.86%)
Ley farming (Rotation of vegetable crops with a grazed pasture phase)	1 (2.86%)

Table 8: Pearson's correlation coefficients for farmer and farm characteristics and climate change factors, responses, and practices

	Number of climate factors perceived	Number of climate factors responded to	Number of current climate-wise practices	Number of prospective climate-wise practices
Farmer age	-0.08	0.23	-0.44**	-0.51**
Years as principal operator of current farm	-0.05	-0.15	-0.24	-0.35*
Number of times engaged with ag organizations	0.25	0.23	0.06	-0.23
Farm size	0.19	0.06	-0.01	-0.33
Farm income	-0.18	-0.10	-0.07	-0.09

*correlation significant at $p < 0.05$ (2-tailed);

**correlation significant at $p < 0.01$ (2-tailed);

Table 9: Comparisons of mean number of climate change factors perceived and responded to and mean number of current and future climate-wise practices by farmer and farm characteristics

	Mean number of climate factors perceived	Mean number of climate factors responded to	Mean number of current climate-wise practices	Mean number of future climate-wise practices
Gender				
Female	6.2a	4.9a	6.4	4.8
Male	4.0b	2.7b	4.0	4.0
Highest level of education				
< Bachelor's	6.2	4.0	5.0	2.0
Bachelors	4.9	3.3	5.5	4.9
> Bachelor's	4.3	3.4	4.4	4.5
Production system				
Conventional	3.9	2.6	2.3b	1.8b
Organic only	5.1	4.0	6.2a	5.8a
Mixed	5.0	3.0	3.4ab	2.4b
Land tenure				
Owned	5.0	3.6	4.4	3.5
Rented	4.4	3.8	5.2	5.0
Manager	4.7	3.3	7.7	6.0

Means followed by different letters are considered significantly different at $p < 0.05$.

Table 10: Interview respondent key

ID #	Age	Gender	Production system	Relationship to their farmland	Net income of farm before taxes
1	53	Male	Organic not certified	Tenant	\$25,000 to \$49,999
2	31	Female	Organic not certified	Tenant	\$25,000 to \$49,999
3	46	Female	USDA certified organic	Owner	Less than \$1,000
4	58	Female	Organic not certified	Owner	Less than \$1,000
5	65	Female	Organic not certified	Owner	\$5,000 to \$9,999
6	38	Female	Organic not certified	Owner	\$100,000 to \$249,999
7	50	Male	Organic not certified	Hired manager	\$100,000 to \$249,999
8	80	Male	Conventional	Owner	\$25,000 to \$49,999
9	37	Male	Organic not certified	Tenant	\$25,000 to \$49,999
10	25	Male	Organic not certified	Tenant	\$25,000 to \$49,999

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CHAPTER FIVE

CONCLUSIONS

Climate change is projected to have profound effects on agricultural productivity in the United States (Walthall et al., 2013). Changes to the on-farm environment are projected to have mixed impacts nationwide, with some regions harmed while others stand to benefit, despite exacerbated vulnerability to environmental stressors (Antle, 2008; Parry et al., 2004). The Northeastern United States may experience both negative and positive impacts from changes in climatic factors (Wolfe et al., 2017), which may undermine or enhance the productivity and resilience of regional food systems and food sovereignty efforts such as New England's 50 by 60TM plan. The nature and severity of climate change's impacts will in part depend on how farmers perceive environmental change and alter their practices to adapt to new production conditions. Understanding farmers' perceptions, motivations, and on-farm adaptive and mitigative strategies is essential to safeguarding agricultural production and building on-farm resilience.

Despite the greater vulnerability of food-producing specialty crop production to climate change, very little research had been conducted on this production sector in New England, the United States, or internationally prior to this mixed-methods study examining Cooperative Extension outreach in the Northeastern U.S. and Rhode Island farmers' perceptions and responses to climate change. The study found that farmers in Rhode Island have primarily perceived general trends in climate change, such as cooler, wetter springs, and changes in specific factors that they are able to keep track

of without the use of record keeping, such as increases in extreme precipitation or storm events. Farmers' perceptions largely match those of Cooperative Extension professionals and what they report farmers have expressed concern about, indicating that these climatic factors may be impacting farms throughout the region. When choosing on-farm responses, farmers in Rhode Island were found to have a preference for practices that are multifunctional and allow them to accomplish a combination of climate response, agronomic, and economic goals. Current CES outreach also tends to favor climate responsive practices that serve multiple purposes on-farm. By illuminating the climate change perceptions and response practices of farmers in Rhode Island and characterizing Cooperative Extension outreach, results from this study can potentially contribute to efforts to build the resilience and productive capacity of local food systems. Future research on agricultural responses to climate change should investigate the perceptions and practices of a diverse demographic array of producers, regions outside of the Northeastern United States, and production systems to gain a more comprehensive understanding of how farmers perceive and respond to climate change. This should be accompanied by efforts on behalf of the CES to increase the availability and effectiveness of their publicly available outreach in order to better facilitate on-farm response.

CHAPTER SIX

APPENDICES

APPENDIX A: FULL LENGTH QUANTITATIVE SURVEY

Low Risk Survey Consent Form for Research

You are being asked to take part in a research study, "Growing Food Sovereignty in Rhode Island." The principal investigator for the study is Dr. John Taylor in the Department of Plant Sciences and Entomology at the University of Rhode Island. The purpose of the study is to develop a fuller understanding of the production practices of vegetable and fruit growers in the state of Rhode Island, as a foundation for growing the local food system. Please read the following before agreeing to be in the study. If you agree to participate, it will take you approximately 45 minutes to complete this survey. Questions will be asked about the crops you grow, your agricultural practices, and your background. There are no known risks or benefits to participating in the study. Study participants will be entered in a drawing to win one of five \$100 Visa gift cards.

Your responses will be strictly confidential. The responses may be used in research papers, policy papers, academic presentations, or other reports on the state food system. Your identifying information will be separated from your responses after the interview, and responses will be identified only by a study ID number. The file linking your name and ID number will be kept on Dr. Taylor's password-protected computers in his office and lab. Only those who work with this study or are performing their job duties for the University of Rhode Island will be allowed access to your information. You will never be identified by name in any reports, articles, presentations, or other documents based on study results. Your responses will be combined without any identifying information with the actions and words of other participants or will be identified by a false name.

The decision to participate in this study is entirely up to you. You may refuse to take part in the study at any time without affecting your relationship with the investigators of this study or the University of Rhode Island (URI). Your decision will not result in any loss of benefits to which you are otherwise entitled. You have the right not to answer any single question, as well as to withdraw completely from the survey at any point during the process; additionally, you have the right to request that the researchers not use any of your responses.

You have the right to ask questions about this research study and to have those questions answered by me before, during or after the research. If you have questions about the study, at any time feel free to contact Dr. Taylor at (401) 874-9027.

Additionally, you may contact the URI Institutional Review Board (IRB) if you have questions regarding your rights as a research participant. Also contact the IRB if you have questions, complaints or concerns which you do not feel you can discuss with the investigator. The University of Rhode Island IRB may be reached by phone at (401) 874-4328 or by e-mail at researchintegrity@etal.uri.edu. You may also contact the URI Vice President for Research and Economic Development by phone at (401) 874-4576

Consent

If you would like to keep a copy of this document for your records, please print or save this page now. You may also contact the researcher to request a copy.

By typing your name below, you indicate that you have read and understood the above and volunteer to participate in this study.

Typed Name of Participant

FUTURE FOLLOW-UP SURVEYS

Type your initials below to indicate that you agree to be re-contacted about participation in future follow-up surveys. Otherwise leave this space blank.

Initials

Click on the link below to continue to the survey.

<LINK>

A. Please confirm that you are at least 18 years old.

☐ Yes, I am at least 18 years old.

☐ No, I am not at least 18 years old. --> Unfortunately only growers 18 years of age or older are eligible to participate

B. May we contact you to conduct an in-person follow-up interview to learn more about your farm and production practices?

☐ Yes

☐ No

FARM OWNERSHIP AND CHARACTERISTICS

- 1. Are you the principal operator of this farm (the person with primary responsibility for making decisions about the farm)?**
 - a. Yes**
 - b. No -- SKIP TO Q6**
- 2. What is your name?**
- 3. What is the name, address, and email address of your farm?**
- 4. How long have you been the principal operator of this farm?--> GO TO Q7**
- 5. How long have you been farming in any capacity?**
- 6. What is the name, address, telephone number, and email address of the principal operator?—>Unfortunately for this survey we're interviewing only principal operators of farms. Thank you for your help today and interest in the study.**
- 7. What is your relationship to the land you farm? (Select all that apply.)**
 - a. Owner**
 - b. Leased Land**
 - c. Manager**
 - d. Other (Specify)**
- 8. How many acres are owned? (ASK IF Q4a IS SELECTED.)**
- 9. How many acres are leased? (ASK IF Q4b IS SELECTED.)**
- 10. How did you acquire this farm? (ASK IF 4a IS SELECTED.)**
 - a. Inherited (from previous farmer as sole legatee)**
 - b. Inherited (from previous farmer, jointly with siblings/relatives)**
 - c. Purchased**
 - d. Rent**
 - e. Other (specify):**
- 11. What is the main address of the farm?**
- 12. Does the farm consist of multiple parcels?**

- a. Yes -- PROCEED TO Q13
- b. No -- SKIP TO Q15

13. How many parcels does the farm consist of?

14. Where are they located?

- a. Parcel 1 address:
- b. Parcel 2 address:
- c. Parcel 3 address:

15. What is the total area operated by the farm business?

16. What is the total area in annual fruit/vegetable production, in open field, indoors, greenhouses, or tunnels?

17. What is the total area in perennial production (perennial fruit trees or small fruits, vegetables, herbs, flowers or vines)?

18. Which of the following crops do you grow? (Mark all that apply.)

- a. Specialty/vegetable crops
- b. Corn (silage) or cereal grains
- c. Potatoes
- d. Tree fruit
- e. Small fruits (strawberries, raspberries, blackberries, grapes, etc.)
- f. Herbs
- g. Cut flowers
- h. Other (specify):

19. Do you raise livestock?

- a. Yes
- b. No

20. Please select from the following list all of the specialty crops you grew in 2018. (This list is based on the 2012 USDA Census of Agriculture list of specialty crops)

a. Artichokes -
exclude
Jerusalem	e. Beets	l. Cantaloupes and
muskmelons
b. Asparagus	f. Broccoli	m. Carrots
c. Bearing age
Beans	g. Brussels sprouts	n. Cauliflower
d. Lima Beans,
snap (bush and
pole)	h. Cabbage,	o. Celery
	i. Chinese (nappa,
bok choy, etc.)	p. Chicory
	j. Cabbage, head	q. Collards
	k. Cabbage, mustard	r. Cucumbers and
pickles

s. Daikon	hh. Onions, green	ss. Spinach
t. Eggplant	ii. Parsley	tt. Squash, summer
u. Escarole and endive	jj. Peas, Chinese (sugar, snow)	uu. Squash, winter
v. Garlic	kk. Peas, green	vv. Sweet corn
w. Ginger root	ll. Peas, southern (cowpeas) - blackeyed, crowder, etc	ww. Sweet potatoes
x. Ginseng		xx. Taro
y. Herbs, fresh cut		yy. Tomatoes in the open
z. Honeydew melons	mm. Peppers, bell - exclude pimientos	zz. Turnip greens
aa. Horseradish	nn. Peppers, other than bell - include chile	aaa. Turnips
bb. Kale Lettuce, head		bbb. Watercress
cc. Lettuce, leaf		ccc. Watermelon
dd. Lettuce, Romaine	oo. Potatoes	s
ee. Mustard greens	pp. Pumpkins	ddd. Other veg
ff. Okra	qq. Radishes	
gg. Onions, dry	rr. Rhubarb	

21. Please select from the following list all of the fruit and nut crops you grew in 2018.

a. Chestnuts	o. Mulberry
b. Hazelnuts	p. Gooseberry
c. Walnuts	q. Apples
d. Blueberries	r. Grapes
e. Blackberries	s. Peaches
f. Boysenberries	t. Pears
g. Loganberries	u. Plums
h. Black raspberries	v. Nectarine
i. Red raspberries	w. Apricots
j. Raspberries	x. Cherries
k. Cranberries	y. Paw-Paws
l. Strawberries	z. Hardy Kiwi
m. Currants	aa. Other (specify):
n. Goji Berries	

22. What percentage of this farm's fruit/vegetable production area is in:

- USDA Certified Organic production?
- Organic but not certified production?
- Conventional (synthetic fertilizers/pesticides/herbicides) production?
- Conventional to organic transition?
- Permaculture?
- Other (specify)?

23. In 2018, did you participate in programs or events sponsored by any of the following organizations?

- a. USDA sponsored Cooperative Extension Agencies
- b. RI DEM - Division of Agriculture
- c. USDA Farm Service Agency
- d. Northeast Organic Farming Association
- e. SARE (Sustainable Agriculture Research and Education Program)
- f. New England Vegetable and Berry Association
- g. Farm Bureau Federation
- h. New England Vegetable and Fruit Conference
- i. New England Farmers Union
- j. New England Small Farm Institute
- k. New Entry Sustainable Farming Project
- l. Northeast Sustainable Agriculture Working Group
- m. Other (specify):

ASK THE FOLLOWING FOR EACH ORGANIZATION IDENTIFIED IN Q23.

24. In how many programs or events sponsored by (ORGANIZATION NAME) did you participate in 2018?

25. How many total employees did your farm have in August 2018?

26. How many total volunteers did your farm have in August 2018?

CLIMATE CHANGE FACTORS

Environmental Factor	Over the past 10 years (IF FARMING FOR LESS THAN 10 YRS: since you started farming) has/have _____ increased, decreased , or stayed about the	Has the change in _____ influenced your growing practices?	Which of following have been positively impacted by the change in _____?	Which of following have been negatively impacted by the change in _____?

	same on your farm?			
27. Extreme temperature events (heat waves, cold snaps, etc)	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
28. Growing season length	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
29. Average yearly temperature	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices

30. Drought	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
31. Flooding	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
32. Storm events (high winds, extreme rain, etc)	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices

33. Soil erosion	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
34. Pollinator populations	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
35. Water availability	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices

36. Pest populations (insect, animal)	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
37. Pathogen and disease populations	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
38. Sea level changes	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices

39. Atmospheric carbon dioxide levels	Increased Decreased Stayed about the same	Yes No	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices	A. Crop yields B. Crop quality C. Varieties I can grow D. Input costs (fertilizers, pesticides, etc) E. Land/field quality F. Farm value G. Harvesting schedule H. Crop prices
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LEVEL OF INTENSIFICATION

40. In 2018, what percentage of your fruit/vegetable production area was, at any time, in....

<u>Production method</u>	<u>Percentage of farm area</u>
a. Permanent Raised Beds	
b. Annual Raised Beds	
c. Low tunnels	
d. High Tunnels (Unheated)	
e. Greenhouses (Heated)	
f. Hydroponics (Indoor)	
g. Hydroponics (Outdoor)	
h. Aquaponics (Indoor)	
i. Aquaponics (Outdoor):	

41. Do you use supplemental lighting for greenhouse production? (ASK ONLY IF 40E > 0 ELSE SKIP TO Q45)

- a. Yes
- b. No —>SKIP TO Q43

42. For what percentage of the total greenhouse production area do you use supplemental lighting?

43. Do you use carbon dioxide enrichment for greenhouse production?

- a. Yes
- b. No —>SKIP TO Q45

44. For what percentage of the total greenhouse production area do you use carbon dioxide enrichment?

45. In 2018, at any time, what percentage of the farm's fruit/vegetable production area was mulched with the following materials?

Mulching material	% production area
a. Disposable black plastic	
b. Biodegradable black plastic	
c. Reusable landscape fabric	
d. Clear plastic	
e. Colored plastic, e.g., red, silver, (not black or clear)	
f. Hay/Straw	
g. Wood chips	
h. Living mulch	
i. Yard waste (grass clippings, leaves, etc.)	
j. Opaque (e.g., black) tarps	
k. Compost	

46. In 2018, at any time, what percentage of the farm's fruit/vegetable production area was sprayed with any of the following:

Management tool	% production area
a. Synthetic insecticides	
a. Insecticides (OMRI Certified)	
a. Synthetic herbicides	
a. Herbicides (OMRI Certified)	
a. Synthetic fungicides	
a. Fungicides (OMRI Certified)	

- 47. At any time in 2018, did you irrigate any of your fruit/vegetable production area?**
- a. Yes
 - b. No-->SKIP TO Q50
- 48. In 2018, what percentage of the farm's fruit/vegetable production area was irrigated with the following forms of irrigation at any time?**
- a. Drip irrigation
 - b. Sprinkler
 - c. Subsurface irrigation
 - d. Other (specify):
- 49. What were your sources of irrigation water in 2018? (Mark all that apply,)**
- a. Harvested rainwater
 - b. Municipal water
 - c. Surface water (pond, stream, etc.)
 - d. Subsurface water (well, spring)
 - e. No irrigation, completely rain-fed
 - f. Other: _____
- 50. In 2018, at any time, what percentage of the farm's fruit/vegetable production area was succession cropped or relay cropped? (Succession cropping, also known as double-cropping, is the planting of one crop immediately following another, in the same plot. In relay cropping, the second crop is planted before the first is harvested.)**
- 51. Please list below the crop combinations you planted in succession.**
- 52. At any time in the past year what percentage of the farm's fruit/vegetable area was planted in polyculture (also known as intercropping or companion planting)? (In polyculture, two or more crops are grown together for an extended period of time.)**
- 53. Please list below the crop combinations you grew in polyculture.**
- 54. In 2018, at any time, what percentage of the farm's fruit/vegetable production area was part of a crop rotation?**
- 55. In 2018, at any time, what percentage of the farm's fruit/vegetable production area was planted with cover crops (spring, summer, or over-wintering)?**
- 56. In 2018, at any time, what percentage of the farm's fruit/vegetable production area was harvested using machinery?**

FIELD PREPARATION: Please provide answers based on the 2018 growing season.

57. Please select from the following list your farm's three most profitable specialty crops in 2018?
58. What was the production area of [CROP NAME]? (Please provide an estimate in acres or square feet.)
59. Please select from the following list the three specialty crops to which you dedicated the most production area in 2018.
60. What was the production area of [CROP NAME]? (Please provide an estimate in acres or square feet.)

FOR EACH CROP SELECTED IN Q59 THE FOLLOWING NINE QUESTIONS WILL BE ASKED.

61. Which of the following best describes how you prepared the field for this crop in 2018?
- a. Full-field System (100% of the soil surface is disturbed and <15% of the soil surface is covered by crop residues)
 - b. Restrictive/Reduced System (Strips where planting occurs are tilled and 15-30% of the soil surface is covered by crop residues)
 - c. No-Till (<10% of the soil surface is disturbed and >70% covered by crop residues)
 - d. There was no field preparation for this crop in 2018 (e.g., for a perennial crop in permanent cover)
62. Which of the following best describes the depth to which you tilled the soil for this crop in 2018? (ASK ONLY IF 61c/d IS NOT SELECTED.)
- a. Shallow tillage (top 6" of soil)
 - b. Deep Tillage (6" to 18")
 - c. Subsurface Tillage (18" or deeper)
63. How did you control weeds for this crop? (Mark all that apply)
- a. Cover crops
 - b. Herbicides
 - c. Herbicide resistant varieties
 - d. Tilling
 - e. Mowing
 - f. Mulching with organic or inorganic materials
 - g. Living mulch

- h. Rotational Grazing/ Animals
- i. Burning/Flame Weeding
- j. Manual cultivation (hoe, hand weeding)
- k. Machine cultivation
- l. Soil solarization
- m. Sterile seedbed methods (repeated shallow cultivation prior to planting)
- n. Tarps
- o. No weed control methods were used in 2018.
- p. Other (specify):

64. Did you plant cover crops *before* growing this crop?

- a. Yes
- b. No—> GO TO Q67

65. What kinds of cover crops?

66. How was the cover crop killed/terminated? (Mark all that apply.)

- a. Winter/frost killed
- b. Roller-crimper
- c. Mowed
- d. Plowed under
- e. Herbicide

67. Did you plant cover crops *after* this crop?

- a. Yes
- b. No-->GO TO Q70

68. What kinds of cover crops?

69. How was the cover crop killed/terminated? (Mark all that apply.)

- a. Winter/Frost killed
- b. Roller-crimper
- c. Mowed
- d. Plowed under
- e. Herbicide

AGRICULTURAL PRACTICES: FARM LEVEL RESPONSES

70. Which of the following practices/methods do you use on your farm?

- a. Swales
- b. Drought resistant varieties
- c. Row covers
- d. Heat tolerant varieties
- e. Disease or insect resistant/tolerant varieties
- f. Farmscaping/agroecological boundaries

- g. Trap crops
- h. Repellent plants
- i. Biocontrol for pests
- j. Bio-char
- k. Reduction in fossil fuel-using equipment
- l. Fertigation
- m. Bio-fertilization
- n. Compost tea
- o. Soil remineralization
- p. Habitat/Pollinator strips
- q. Ley farming (Rotation of vegetable crops with a grazed pasture phase)
- r. Crop rotation with an ungrazed fallow phase
- s. Supplementation of naturally-occurring pollinators, e.g., use of honey bee hives to pollinate crops

71. Which of the following practices/methods *would you like to adopt/increase* on your farm?

- a. Drip irrigation
- b. Swales
- c. Black plastic/mulching
- d. Crop diversification (drought resistant varieties)
- e. Row covers
- f. Planting schedule shifts
- g. Crop diversification (heat tolerant)
- h. High tunnels
- i. Greenhouses
- j. Row covers
- k. Crop diversification (disease/insect resistant/tolerant, GMO)
- l. High tunnels
- m. Increased pesticide applications
- n. Farmscaping/agroecological boundaries
- o. Trap crops
- p. Repellent plants
- q. Biocontrol for pests
- r. Biochar
- s. No-Till
- t. Lessened use of fossil fuel burning tools
- u. Conventional to organic conversion
- v. Fertigation
- w. Biofertilization
- x. Compost tea
- y. Soil remineralization
- z. Hydroponics
- aa. Habitat/pollinator strips
- bb. Rainwater collection/ponds/water storage

- cc. Ley farming (Rotation of vegetable crops with a grazed pasture phase)
- dd. Crop rotation with an ungrazed fallow phase
- ee. Supplementation of naturally-occurring pollinators, e.g., use of honey bee hives to pollinate crops

NON-AGRICULTURAL RESPONSES

72. Please select all of the following non-agricultural changes you have made on your farm in the last 5 years:

- a. Installation of solar panels
- b. Removal of land from cultivation
- c. Purchase of crop insurance
- d. Diversification of sales channels (EX. Direct-To-Consumer: *CSA/Farmer's Markets, Wholesale: via distributor or direct to retailer, Institutional Sales: Prisons, Schools, Hospitals*)
- e. Diversification of non-food revenue streams (Brewery, Corn Maze, Haunted Hay Rides, Weddings/Events, etc)
- f. Leasing land to others

73. Please select all of the following non-agricultural changes you want to make on your farm in the future:

- a. Installation of solar panels
- b. Removal of land from cultivation
- c. Purchase of crop insurance
- d. Diversification of sales channels (EX. Direct-To-Consumer: *CSA/Farmer's Markets, Wholesale: via distributor or direct to retailer, Institutional Sales: Prisons, Schools, Hospitals*)
- e. Diversification of non-food revenue streams (Brewery, Corn Maze, Haunted Hay Rides, Weddings/Events, etc)
- f. Leasing land to others

NUTRIENT SOURCES

74. In 2018, what percentage of your fruit/vegetable production area was fertilized with...

- a. Compost
- b. Bulk animal manure
- c. Dried animal manure
- d. Green manure
- e. Nitrogen fixing cover crops
- f. Fresh or dried seaweed

- g. Solid synthetic chemical fertilizers (e.g., urea, superphosphate, combination fertilizers)
- h. Solid organic fertilizers (e.g., Pro-Gro, Nature's Turf)
- i. Soil-applied liquid synthetic chemical fertilizers (e.g., urea, superphosphate, combination fertilizers)
- j. Soil-applied liquid organic fertilizers (e.g., fish emulsion, Neptune's Harvest)
- k. Compost tea
- l. Foliar synthetic chemical fertilizers
- m. Foliar organic fertilizers
- n. Biofertilizers
- o. Biochar
- p. Rock dust (Mineral fertilizer)
- q. Other (specify):

75. What was the source of the fresh manure? (Mark all that apply) (ASK ONLY IF Q74b > 0)

- a. On farm
- b. Off farm

76. What was the source of your compost? (Mark all that apply) (ASK ONLY IF Q74a > 0)

- a. On farm
- b. Off farm

77. Where did you obtain your compost? (ASK ONLY IF Q76b IS SELECTED.)

- a. Johnston (RIRRC) certified-organic compost
- b. Earthcare Farms
- c. Rhody Gold
- d. Rhodeside Revival
- e. Other (specify):

78. When deciding how much fertilizer, manure, or other nutrient sources to apply, do you consult any of the following sources of information? (Mark all that apply.)

- a. Recommendations accompanying soil tests
- b. New England Vegetable Crop Management Guide
- c. Cooperative Extension
- d. Past experience
- e. Colleagues/peers
- f. Published books
- g. Magazines/journals
- h. Websites
- i. Conference Presentations/Meetings

- j. Multimedia sources (youtube, social media, etc)
- k. Other (specify):

79. How often do you test your soil for nutrients?

- a. Never
- b. Every year
- c. Every other year
- d. Less often than every other year

FARMER BACKGROUND

Your responses to the following questions will help us interpret your other responses. Like all of your responses, they are confidential. You may skip any question you do not wish to answer.

80. How old are you?

81. What is your gender?

- a. Male
- b. Female
- c. Other

82. What is your highest level of education?

- a. Less than high school
- b. High school diploma or equivalent
- c. Some college, no degree
- d. Postsecondary non-degree award
- e. Associate's degree
- f. Bachelor's degree
- g. Master's degree
- h. Doctoral or professional degree

83. Do you possess an agriculture-specific degree?

- a. Yes
- b. No

84. Did you complete any agricultural internships/apprenticeships?

- a. Yes
- b. No

85. Did you grow up on a farm?

- a. Yes

b. No

86. Were you born in the United States?

a. Yes -- SKIP TO Q82

b. No

87. How many years have you lived in the United States?

88. Are you of Hispanic, Latino, or Spanish origin?

a. No, not of Hispanic, Latino, or Spanish origin

b. Yes, Mexican, Mexican Am., Chicano

c. Yes, Puerto Rican

d. Yes, Cuban

e. Yes, another Hispanic, Latino, or Spanish origin

89. What is your race? Mark one or more boxes.

a. White

b. Black, African Am., or Negro

c. American Indian or Alaska Native — Print name of enrolled or principal tribe.

d. Asian Indian

e. Chinese

f. Filipino

g. Other Asian — Print race, for example, Hmong, Laotian, Thai, Pakistani, Cambodian, and so on.

h. Japanese

i. Korean

j. Vietnamese

k. Native Hawaiian

l. Guamanian or Chamorro

m. Samoan

n. Other Pacific Islander — Print race, for example, Fij

We are asking the following question because religion or spiritual beliefs may influence how an individual relates to the natural world or environment. As with all questions in this survey, it is voluntary and you may skip it.

90. What is your present religion, if any?

a. Protestant

b. Roman Catholic

c. Mormon

d. Orthodox such as Greek or Russian Orthodox

e. Jewish

f. Muslim

g. Buddhist

- h. Hindu
- i. Atheist
- j. Agnostic
- k. No religion
- l. Other (specify):

91. What is your current marital status?

- a. Now married
- b. Widowed
- c. Divorced
- d. Separated
- e. Never married

92. In 2017, what was the net income of this farm business before taxes?

- a. Less than \$1,000
- b. \$1,000 to \$2,499
- c. \$2,500 to \$4,999
- d. \$5,000 to \$9,999
- e. \$10,000 to \$24,999
- f. \$25,000 to \$49,999
- g. \$50,000 to \$99,999
- h. \$100,000 to \$249,999
- i. \$250,000 to \$499,999
- j. \$500,000 to \$999,999
- k. \$1,000,000 or more

Those are all of the questions we have for you today. Thank you for your time. You'll now be forwarded to a form to fill out to be registered in the drawing to win one of five \$100 Visa gift cards.

APPENDIX B: QUALITATIVE INTERVIEW

Qualitative Interview Schedule of Questions

PLANT DIVERSITY/CROP VARIETIES

1. Let's talk about specific crops you're growing this year...

- a. What varieties of [QUANTITATIVE SURVEY RESPONSE] are you growing?
- b. How long have you grown ?
- c. What other varieties have you grown in the past?
- d. How does this variety do for you?
- e. How did you decide to grow this variety?
- f. What do you like about this variety?
- g. How well does this variety grow compared to others you've grown in RI?
- h. What do you like about this variety?
- i. What don't you like about this variety?
- j. How does the environment/climate impact your choice of variety for this crop?
- k. Are there any environmental/climatic factors you wish this variety could withstand better?
- l. Are there any characteristics you wish this variety had?
- m. Could you tell me about how you source your seeds or transplants?
- n. Could you tell me about any sort of on-farm selection or seed saving you practice?

FIELD PREPARATION

2. Tell me about how you prepare your fields.

ASK THE FOLLOWING QUESTIONS FOR EACH TILLAGE PRACTICE IDENTIFIED IN THE QUANTITATIVE SURVEY.

Tillage Percentage

a. What are the advantages of [TILLAGE SYSTEM]?

- i. What are the disadvantages?
- ii. How did you decide to use this method?
- iii. How satisfied are you with this practice?
- iv. What do you think are the environmental benefits or drawbacks of this practice?
- v. What might be some alternatives to this practice?
- vi. What do you think are the advantages of each of those alternatives?
- vii. What are the disadvantages?
- viii. Have you considered switching to an alternative method?

Tillage Depth

B. What are the advantages of [TILLAGE DEPTH]?

- i. What are the disadvantages?
- ii. How did you decide to use this method?
- iii. How satisfied are you with this practice?
- iv. What do you think are the environmental benefits or drawbacks of this practice?
- v. What might be some alternatives to this practice?
- vi. What do you think are the advantages of each of those alternatives?
- vii. What are the disadvantages?
- viii. Have you considered switching to an alternative method?

Weed Control

i. What are the advantages of [WEED CONTROL METHODS]?

- i. What are the disadvantages?
- ii. How did you decide to use this method?
- iii. How satisfied are you with this practice?
- iv. What do you think are the environmental benefits or drawbacks of this practice?
- v. What might be some alternatives to this practice?
- vi. What do you think are the advantages of each of those alternatives?
- vii. What are the disadvantages?
- viii. Have you considered switching to an alternative method?

Cover Crops

j. Could you tell me about your use of cover crops?

- i. What are the advantages
- ii. What are the disadvantages?
- iii. What do you think are the environmental benefits or drawbacks of this practice?
- 1. Could this help reduce greenhouse gas emissions on your farm?
- 2. How do you think this could influence carbon sequestration on your farm?
- iv. How did you decide to use these cover crops? These specific varieties of cover crops?
- v. How did you decide to use this method of termination?
- vi. How satisfied are you with this practice?
- vii. What might be some alternatives to this practice?
- viii. What do you think are the advantages of each of those alternatives?
- ix. What are the disadvantages?
- x. Have you considered switching to an alternative method?

AGRICULTURAL PRACTICES: *FARM LEVEL RESPONSE*

I would like to ask you some questions about each of the farm level practices you identified on the quantitative survey as *being actively used on your farm...*

FOR EACH OF THE PRACTICES SELECTED ON THE QUANTITATIVE SURVEY, ASK QUESTIONS 3A- 3H.

- Swales
- Crop diversification (drought resistant varieties)
- Crop diversification (heat tolerant)

- Crop diversification (disease/insect resistant/tolerant)
- Crop Diversification (GMO)
- Row covers
- Farmscaping/ agroecological boundaries
- Trap cropping
- Bio-char
- Reduction in fossil fuel using equipment
- Fertigation
- Bio-fertilization
- Compost Tea
- Soil Remineralization
- Habitat/Pollinator Strips
- Ley Farming (Rotation of grasses/legumes with grains, includes grazed pasture phase)
- Crop Rotation with Fallow Phase

3. How do you think [QUANTITATIVE SURVEY RESPONSE] impacts your farm?

- a. What do you think are the benefits of this to your farm?
- b. What do you think are the drawbacks for your farm?
- c. How does this practice impact your farm's long-term resilience? ("Resilience is the capacity of a system to absorb disturbance and still retain its basic function and structure")
- d. What do you think are the environmental benefits or drawbacks of this practice?
 - i. Could this help reduce greenhouse gas emissions on your farm?
 - ii. How do you think this could influence carbon sequestration on your farm?
- e. Would you recommend this to other growers in the state? Why or why not?
- f. How did you decide to use this method?
- g. How satisfied are you with this practice?
- h. How does [QUANTITATIVE SURVEY RESPONSE] impact your other growing practices?

I would like to ask you some questions about each of the farm level practices you identified on the quantitative survey as *something you would like to adopt on your farm...*

FOR EACH OF THE PRACTICES SELECTED ON THE QUANTITATIVE SURVEY, ASK QUESTIONS 4A- 4G.

- Drip irrigation
- Swales

- Black plastic/mulching
- Crop diversification (drought resistant varieties)
- Crop diversification (heat tolerant)
- Crop diversification (disease/insect resistant/tolerant)
- Crop Diversification (GMO)
- Row covers
- High tunnels
- Greenhouses
- Row covers
- High tunnels
- Increased pesticide applications
- Farmscaping/agroecological boundaries
- Trap cropping
- Biochar
- No-Till
- Lessened use of fossil fuel burning tools
- Conventional to organic Conversion
- Fertigation
- Biofertilization
- Compost Tea
- Soil Remineralization/ application of rock dust
- Hydroponics
- Habitat/Pollinator Strips
- Rainwater collection/ponds/water storage
- Ley Farming (Rotation of grasses/legumes with grains, includes grazed pasture phase)
- Crop Rotation with Fallow Phase

4. What do you think about [QUANTITATIVE SURVEY RESPONSE]?

- a. How do you think this could impact your farm?
- b. What about this do you think could be beneficial to your farm?
- c. What about this do you think could be the drawbacks for your farm?
- d. Does this impact your farm's long-term resilience? How?
- e. What do you think are the environmental benefits or drawbacks of this practice?
 - i. Could this help reduce greenhouse gas emissions on your farm?
 - ii. How do you think this could influence carbon sequestration on your farm?
- f. Would you recommend this to other growers in the state? Why or why not?
- g. What is stopping you from adopting this practice?

NON-AGRICULTURAL RESPONSES

I would like to ask you some questions about each of the farm level practices you identified on the quantitative survey as *being actively used on your farm...*

FOR EACH OF THE PRACTICES SELECTED ON THE QUANTITATIVE SURVEY, ASK QUESTIONS 5A- 5G.

- Installation of solar panels
- Removing land from cultivation
- Purchasing crop insurance
- Diversified sales channels (Ex.. Direct-To-Consumer: *CSA/Farmer's Markets*, Wholesale: *via distributor or direct to retailer*, Institutional Sales: *Prisons, Schools, Hospitals*)
- Diversified non-food revenue streams (Brewery, Corn Maze, Haunted Hay Rides, Weddings/Events, etc)
- Leasing land to others

5. How do you think [QUANTITATIVE SURVEY RESPONSE] impacts your farm?

- a. What about this do you think is beneficial to your farm?
- b. What about this do you think are the drawbacks to your farm?
- c. How does this impact your farm's long-term resilience?

(ASK ONLY ABOUT "INSTALLATION OF SOLAR PANELS" and "REMOVING LAND FROM CULTIVATION")

- d. What do you think are the environmental benefits or drawbacks of this practice?
 - i. Could this help reduce greenhouse gas emissions on your farm?
 - ii. How do you think this could influence carbon sequestration on your farm?
- e. Would you recommend this to other growers in the state? Why or why not?
- f. How did you decide to use this method?
- g. How satisfied are you with this practice?

I would like to ask you some questions about each of the farm level practices you identified on the quantitative survey as *something you would like to adopt on your farm...*

FOR EACH OF THE PRACTICES SELECTED ON THE QUANTITATIVE SURVEY, ASK QUESTIONS 6A- 6G.

- Installation of solar panels
- Removing land from cultivation
- Purchasing crop insurance
- Diversified sales channels (EX. Direct-To-Consumer: *CSA/Farmer's Markets*, Wholesale: *via distributor or direct to retailer*,
- Institutional sales: *Prisons, Schools, Hospitals*)
- Diversified non-food revenue streams (Brewery, Corn Maze, Haunted Hay Rides, Weddings/Events, etc)
- Leasing land to others

6. What do you think about [QUANTITATIVE SURVEY RESPONSE]?

- a. How do you think this could impact your farm?
- b. What about this do you think could be beneficial to your farm?
- c. What about this do you think could be a drawback to your farm?
- d. Does this impact your farm's long-term resilience? How?

(ASK ONLY ABOUT "INSTALLATION OF SOLAR PANELS" and "REMOVING LAND FROM CULTIVATION")

- e. What do you think are the environmental benefits or drawbacks of this practice?
 - i. Could this help reduce greenhouse gas emissions on your farm?
 - ii. How do you think this could influence carbon sequestration on your farm?
- f. Would you recommend this to other growers in the state? Why or why not?
- g. What is stopping you from adopting this practice?

SOURCES OF INFORMATION

8. Where do you learn new information about agricultural practices? 9. Where do you learn new information regarding the environment or climate? 10. Do you use any of the following to learn about agricultural practices or the environment?

- a. Recommendations accompanying soil tests
- b. New England Vegetable Crop Management Guide
- c. Cooperative Extension
- d. Past experience
- e. Colleagues/ Peers
- f. Published books (Please specify)
- g. Magazines/Journals (Please specify)
- h. Websites (Please specify)
- i. Conference Presentations/ Meetings
- j. Multimedia sources (youtube, social media, etc)
- k. Other (Please specify)

11. How do you judge the trustworthiness or accuracy of information sources?

DECISION MAKING

12. When making choices on your farm what are some things you consider?

Please rank those that apply in order of most important to least important and could you tell me how you decided on their order of importance?

- a. Economic impact

- b. Sustainability (Large-scale environmental impact)
- c. Stewardship (Farm-scale environmental impact, long-term health of your farm)
- d. Past experience/ tradition
- e. Example set by other farmers
- f. Learned technique (apprenticeship/college/internship)
- g. Personal beliefs
- h. Other (Please specify)

CLIMATE CHANGE

13. What do you think about climate change? 14. How do you think climate change might be an issue on your farm?

ASK THE FOLLOWING FOR EACH FACTOR IDENTIFIED IN QX OF THE QUANTITATIVE SURVEY.

15. You identified [QUANTITATIVE SURVEY RESPONSE] as influencing your agricultural practices. Tell me more about [QUANTITATIVE SURVEY RESPONSE].

16. Do you or how often do you discuss climate change or its impacts on your farm with other people?

a. How similar are your views to those of your peers?

17. Could you tell me about your last conversation about climate change?

18. How would you get more information about how to address a situation where you were faced with a new environmental/climate issue on your farm? Whom and/or what would you consult?

APPENDIX C: COOPERATIVE EXTENSION PROFESSIONAL SURVEY (GOOGLE FORMS)

Extension, Agriculture, and Climate Change in the Northeast

Low Risk Survey Consent Form for Research

You are being asked to take part in a survey on extension, agriculture, and climate change. The principal investigator for the study is Dr. John Taylor in the Department of Plant Sciences and Entomology at the University of Rhode Island. The purpose of the survey is to develop a fuller understanding of the outreach that land grant universities in the Northeast are conducting on agriculture and climate change. Please read the following before agreeing to be in the study. If you agree to participate, it will take you approximately 10 minutes to complete this survey. Questions will be asked about the climate and environment in your area, your outreach and publication work, and your perceptions of climate change. There are no known risks or benefits to participating in the study.

Your responses will be strictly confidential. The responses may be used in research papers, policy papers, academic presentations, or other reports on the state food system. Your identifying information will be separated from your responses after the interview, and responses will be identified only by a study ID number. The file linking your name and ID number will be kept on Dr. Taylor's password-protected computers in his office and lab. Only those who work with this study or are performing their job duties for the University of Rhode Island will be allowed access to your information. You will never be identified by name in any reports, articles, presentations, or other documents based on study results. Your responses will be combined without any identifying information with the actions and words of other participants or will be identified by a false name.

The decision to participate in this study is entirely up to you. You may refuse to take part in the study at any time without affecting your relationship with the investigators of this study or the University of Rhode Island (URI). Your decision will not result in any loss of benefits to which you are otherwise entitled. You have the right not to answer any single question, as well as to withdraw completely from the survey at any point during the process; additionally, you have the right to request that the researchers not use any of your responses.

You have the right to ask questions about this research study and to have those questions answered by me before, during or after the research. If you have questions about the study, at any time feel free to contact Dr. Taylor at (401) 874-9027.

Additionally, you may contact the URI Institutional Review Board (IRB) if you have questions regarding your rights as a research participant. Also contact the IRB if you have questions, complaints or concerns which you do not feel you can discuss with the investigator. The University of Rhode Island IRB may be reached by phone at (401) 874-4328 or by e-mail at researchintegrity@etal.uri.edu. You may also contact the URI Vice President for Research and Economic Development by phone at (401) 874-4576

Consent

If you would like to keep a copy of this document for your records, please print or save this page now. You may also contact the researcher to request a copy.

By typing your name below, you indicate that you have read and understood the above and volunteer to participate in this study.

A. Please confirm that you are at least 18 years old by checking the box below.

☐ Yes, I am at least 18 years old.

☐ No, I am not at least 18 years old. --> Unfortunately only growers 18 years of age or

1. Do you work with fruit and vegetable crop producers in your region?

a. Yes

b. No

2. Over the past 10 years, has each of the following increased, decreased, or stayed about the same in your region? Please circle one number on each line.

(If you have been working in the region for less than 10 years, please answer for the period since you started.)

	Increased	Decreased	Stayed about the same
Extreme temperature events (heat waves, cold snaps, etc)	1	2	3
Growing season length	1	2	3
Average yearly temperature	1	2	3
Drought	1	2	3
Flooding	1	2	3
Storm events (high winds, extreme rain, etc)	1	2	3
Soil erosion	1	2	3
Pollinator populations	1	2	3
Water availability	1	2	3
Pest populations (insect/animal)	1	2	3
Pathogen and disease populations	1	2	3

Sea level change	1	2	3
Atmospheric carbon dioxide levels	1	2	3

2. In the past 10 years, have growers in your region expressed concern about any of the following environmental factors? Please circle one number on each line. (If you have been working in the region for less than 10 years, please answer for the period since you started.)

	Never	Very Rarely	Rarely	Occasionally	Frequently	Very Frequently
	1	2	3	4	5	6
Extreme temperature events (heat waves, cold snaps, etc)						
Growing season length	1	2	3	4	5	6
Average yearly temperature	1	2	3	4	5	6
Drought	1	2	3	4	5	6
Flooding	1	2	3	4	5	6
Storm events (high winds, extreme rain, etc)	1	2	3	4	5	6
Soil erosion	1	2	3	4	5	6

Pollinator populations	1	2	3	4	5	6
Water availability	1	2	3	4	5	6
Pest populations (insect/animal)	1	2	3	4	5	6
Pathogen and disease populations	1	2	3	4	5	6
Sea level change	1	2	3	4	5	6
Atmospheric carbon dioxide levels	1	2	3	4	5	6

3. How concerned are growers in your state about climate change?
 - a. Not at all concerned
 - b. Slightly concerned
 - c. Somewhat concerned
 - d. Moderately concerned
 - e. Extremely concerned

4. How concerned are you about the impact of climate change on agriculture in your region?
 - a. Not at all concerned
 - b. Slightly concerned
 - c. Somewhat concerned
 - d. Moderately concerned
 - e. Extremely concerned

5. How often do you discuss climate change with growers in your region?
 - a. Never
 - b. Very Rarely

- c. Rarely
 - d. Occasionally
 - e. Frequently
 - f. Very Frequently
6. How often do you discuss climate change with other extension or USDA professionals?
- a. Never
 - b. Very Rarely
 - c. Rarely
 - d. Occasionally
 - e. Frequently
 - f. Very Frequently
7. What sources of information do you use to inform outreach and publications about climate change and its impact on agriculture?
- a. University researchers and staff
 - b. Prior extension research
 - c. Academic/scientific publications
 - d. Past experience
 - e. Extension or USDA colleagues/peers
 - f. Published books
- _____
- g. Magazines/journals
- _____
- h. Websites _____
 - i. Conference presentations/meetings
 - j. Multimedia sources (youtube, social media, etc)
8. In the last year how many times did you conduct outreach specific to on-farm climate change response or planning?
- a. _____
9. If YES, could you provide some examples of subjects you have addressed in climate change outreach you have conducted in the past year?
- a. _____
- _____

10. If NO, why did you choose to not conduct outreach on this subject?

a. _____

11. How much do you think outreach regarding on-farm climate change response would benefit growers in your area?

- a. To a Great Extent
- b. Somewhat
- c. No Change
- d. Very Little
- e. Not at All

12. Please rank the effectiveness of each of the following forms of outreach.

	Not at all effective	Slightly effective	Somew hat effectiv e	Moderately effective	Extre mely effecti ve
Factsheets and production guides	1	2	3	4	5
Published research trials	1	2	3	4	5
Extension hosted workshops	1	2	3	4	5
On-farm workshops or case studies	1	2	3	4	5
Publicly available forecasting and	1	2	3	4	5

monitoring tools					
Newsletter	1	2	3	4	5
Videos	1	2	3	4	5
Personal communications	1	2	3	4	5

13. Which of the following practices/methods **do you promote specifically as an on-farm climate change response** to growers in your region? (Circle all that apply)

a. Drip irrigation	p. Trap crops
b. Rainwater collection/ponds/water storage	q. Insect-repelling plants
c. Swales	r. Biocontrol for pests
d. Mulching	s. Habitat/pollinator strips
e. Row covers	t. Supplementation of naturally-occurring pollinators, e.g., use of honey bee hives to pollinate crops
f. High tunnels	u. No-till
g. Greenhouses	v. Lessened use of fossil fuel burning equipment
h. Hydroponics	w. Conventional to organic conversion
i. Aquaponics	x. Biochar
j. Drought tolerant varieties	y. Fertigation
k. Pest resistant/tolerant varieties	z. Biofertilization
l. Heat tolerant varieties	aa. Compost tea
m. Adjusting planting schedules for changing environmental conditions	bb. Soil remineralization
n. Increased pesticide applications	cc. Ley farming (Rotation of vegetable crops with a grazed pasture phase)
o. Farmscaping/agroecological boundaries	dd. Crop rotation with an ungrazed fallow phase

Thank you for participating in this survey on cooperative extension, climate change, and agriculture.