A Digital Agricultural Revolution: Ontario Grain Farmer Perceptions of Digital Farming and Big Data

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Digital technologies and big data are revolutionizing agriculture, but the implications for equity and sustainability are uncertain. From big data climate forecasts and massive robotic tractors, to satellite pest control and precision agriculture drones, *digital farming* is taking off in traditional agribusiness and agri-food start-ups and receiving positive attention from governments and the media. Proponents claim that digital farming will improve efficiency, productivity, and profits for farmers and address food system challenges, including food security for a rapidly growing world population. Critics are concerned about the distribution of risks and benefits, particularly between farmers and corporations, as well as the possible adverse effects for justice, quality of life, and the environment. The digital agricultural revolution could either enhance or degrade food systems; however, it is more likely that the implications will be uneven and contradictory. While there is growing attention in the social sciences on the social and political implications of digital farming, there remains a dearth of empirical studies in the emerging discourse.

This thesis considers the following research question: *How do Ontario grain farmers perceive digital farming, and how do their perspectives compare to public debates and academic research?* Given the prevalence of grain operations, high farming population, and leadership in ag-tech innovations, Ontario is an ideal context to study farmer perceptions of digital farming. To answer the research question, an abductive and constructivist study design employs a suite of qualitative methods in line with three objectives. First, a review of academic and grey literature identifies key narratives in digital farming debates, focusing on the views of proponents and critics. Second, a combination of qualitative methods – including an online questionnaire, semi-structured interviews, and fieldwork observations – generates a rich depiction of Ontario grain farmer perceptions of digital farming and the challenges and opportunities it presents. Third, abductive analysis considers the results as a whole to compare farmer perceptions with central themes in emerging discourses. Emphasizing political dimensions and farmer experiences, the discussion centres on the implications of digital farming for power relations, data concerns and knowledge, agricultural labour, and environmental impacts. The thesis offers empirical contributions and proposes directions for theory development in a nascent research community.

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Land acknowledgment and statement of gratitude

Indigenous Peoples have unique and enduring relationships with land and food systems across Turtle Island, since time immemorial. I acknowledge that I live and work on the traditional territory of the Attawandaron (Neutral), Anishnawbe, and Haudenosaunee peoples. The University of Waterloo is situated on the Haldimand Tract (Treaty 4): six miles of land on each side of the Grand River promised to the Six Nations. I acknowledge that I contribute to and benefit from the expulsion, assimilation, and genocide of Indigenous Peoples. I also acknowledge that food and agriculture have played an important role in colonialism across Turtle Island. I make this statement act against the erasure of ongoing colonial legacies and to express gratitude to Indigenous Peoples who live within and care for these territories.

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List of Abbreviations

AAFC	Agriculture and Agri-Food Canada (Government of Canada)
ABCD	Archer Daniels Midland, Bunge, Cargill, and Louis Dreyfus
ACEG	Advisory Council on Economic Growth (Government of Canada)
AFO	Accredited Farming Organization
CAQDAS	Computer Assisted Qualitative Data Analysis Software
ETC Group	Action Group on Erosion, Technology and Concentration
FAO	Food and Agriculture Organization of the United Nations
GFO	Grain Farmers of Ontario
GHG	Greenhouse Gas
GIS	Geographic Imaging System
GM	Genetically Modified, also Genetically Engineered
GPS	Geographic Positioning System
IBM	International Business Machines Corporation
NFU	National Farmers Union of Canada
OAFT	Ontario Agri-Food Technologies
OSCIA	Ontario Soil and Crop Improvement Association
OMAFRA	Ontario Ministry of Agriculture and Rural Affairs
ROI	Return on Investment
RRI	Responsible Research and Innovation
RTK	Real Time Kinetic, auto-steer
STS	Science and Technology Studies or Science, Technology, and Society Studies
TNC	Transnational Corporation
UAV	Unmanned Aerial Vehicle
UN	United Nations
VRA	Variable Rate Application, also Variable Rate Technology
WEF	World Economic Forum

Chapter 1
A Digital Agricultural Revolution

1.1 Problem Context

The future of food faces complex and contradictory problems. Agriculture is threatened by climate change and unsustainable resource use, but the sector is simultaneously a key driver of environmental degradation and a prominent source of anthropogenic greenhouse gas (GHG) emissions (Pretty & Bharucha, 2018). Globally, 821 million people are chronically undernourished, continuing an upward trend of food insecurity in recent years (FAO, 2018b). At the same time, at least one third and perhaps as much as 58% of food produced for human consumption is lost or wasted each year (FAO, 2011; Gooch et al., 2019). Food systems are not meeting the needs of society, while also undermining the ecological systems on which they rely (Garnett, 2013). There are countless possible approaches to addressing these tensions. Yet public debates often turn to technological innovations, most recently big data and digital technologies, to meet the needs of a growing population by increasing agricultural production.

The emergence big data and digital technologies in food systems give rise to a new model of agriculture, *digital farming*, supporting more precise and data-driven agriculture as a potential solution to complex problems in the agri-food system (Wolfert, Ge, Verdouw, & Bogaardt, 2017). From big data climate forecasts and massive robotic tractors, to satellite pest control and precision agriculture drones, digital farming is taking off in traditional agribusiness and agri-food start-ups and receiving positive attention from governments and the media. Still, digital farming remains contentious and implications for equity and sustainability are uncertain. Beyond technological change, digital farming is an ongoing social, cultural, political, and ecological transformation, perhaps even driving a "digital agricultural revolution" akin to previous revolutions in agriculture (Bronson & Knezevic, 2016a; Shepherd, Turner, Small, & Wheeler, 2018; Weersink, Fraser, Pannell, Duncan, & Rotz, 2018, p. 20). Digital farming refers to new technologies in agri-food, but also the corresponding changes to agricultural practices and norms, the political and economic relationships affected by the emergence of digital farming, and the forms of knowledge the technology produces, among other implications across food systems.

Proponents of digital farming make claims that new technologies and big data in the food system will help farmers and solve food system challenges, including food insecurity (Balafoutis et al., 2017; Bayer, 2019b). Unfortunately, this problem-frame typically minimizes or omits social, cultural, political, and ecological dimensions, in favour of productivity and economic growth. In a global food system that produces an abundance of food and leaves billions hungry or unwell (De Schutter, 2011; FAO, 2018b; WHO, 2018), technological innovations alone are unlikely to reconcile the complex problems facing the future of food. Moreover, critics raise concerns for impacts of digital farming on corporate power and farmer autonomy, data access and privacy, agricultural labour, and sustainability (Bronson, 2018; Carbonell, 2016; Carolan, 2018b; Mooney, 2018; Wolfert et al., 2017). Although the benefits of technological innovation for quality of life and productivity are incontrovertible, so too are the consequences, risks, and trade-offs (Jasanoff, 2016). According to Kranzberg's Laws of Technology, "technology is neither good nor bad; nor is it neutral" (1986, p. 545). Thus, the rise of digital farming has neither a positive nor a negative influence on the wicked problems in food systems. Instead, digital farming is a phenomenon embedded in complex systems. Digital farming could enhance or degrade food systems; but it is more likely that implications will be uneven and contradictory.

1.2 Research Question and Objectives

Today, farmers are interacting with digital technology in new and unprecedented ways to consume and produce information, make farm management decisions, and work on the field. Digital farming developers focus on crop farming – especially large industrial, capital-intensive grain operations – due to their production traditions and economies of scale (Bronson & Knezevic, 2019; Mulla & Khosla, 2016; Rotz, Duncan, et al., 2019). Accordingly, this thesis focuses on grain farmers. While there are a growing number of studies on digital farming in the more industrialized world (Carolan, 2018b; Fleming, Jakku, Lim-Camacho, Taylor, & Thorburn, 2018; Regan, 2019), there is little coverage from a Canadian context (Bronson & Knezevic, 2019). In Ontario, agribusiness and agri-food start-ups, with the support of governments across levels, are driving innovation and adoption of digital farming technology, making promises for the benefits of the digital revolution of agriculture. This study will prioritize the voices of farmers and critically analyze the narratives in digital farming debates. Drawing from food studies, political economy, and science and technology studies (STS), I direct this study to an emerging body of literature exploring and responding to the digital agricultural revolution.

This thesis considers the following research question: **How do Ontario grain farmers perceive digital farming, and how do their perspectives compare to public debates and academic research?** To answer this question, three objectives direct the study design:

1. Identify key narratives in digital farming debates, focusing on proponents and critics.
2. Describe the perceptions of farmers regarding challenges and opportunities of digital farming.
3. Compare farmer perceptions with key themes in digital farming debates.

The research question and the corresponding objectives inform methodological decisions. The first research objective calls for a review of academic and grey literature (e.g., government documents, corporate publications), complemented by fieldwork observations, to identify and analyze key narratives. Proponents frame digital farming as a solution to food system challenges, thus the analysis must investigate the narratives and underlying assumption, as problem frames affect perceptions and proposed solutions (Bronson, 2019; Garnett, 2013). The second research objective demands empirical data collection to understand farmer perceptions of digital farming. A combination of qualitative methods – including an online questionnaire, semi-structured interviews, and fieldwork observations – provides a rich depiction of farmer perceptions and strengthens the validity of analysis through multiple means of data collection and analysis (Lynch, 2013; Ritchie, Lewis, McNaughton Nicholls, & Ormston, 2014). The third research objective builds on the preceding data and analysis to consider the research question more holistically, comparing farmer perceptions to themes in the broader debates.

In the past few years, scholars across the social sciences, especially political economy and sociology, have been raising questions and concerns regarding the implications of digital farming. There is a small set of studies exploring matters of governance, power relations, and ethics (Bronson & Knezevic, 2016a; Carbonell, 2016; Carolan, 2018b; Rotz, Duncan, et al., 2019). Of particular relevance to this thesis are the scholars who explore the perceptions and experiences of farmers in the digital agricultural revolution (Carolan, 2016; Eastwood, Klerkx, Ayre, & Dela Rue, 2017; Fleming et al., 2018; Regan, 2019). While theoretical pieces and research agendas are emerging, scholars stress that the empirical research on digital farming remains limited (Carolan, 2018b; Regan, 2019). Furthermore, some of the attention on digital farming and farmer experiences focuses primarily on technologies for dairy farming, rather than crop farming (Driessen & Heutinck, 2015; Eastwood et al., 2017; Holloway & Bear, 2017; Schewe & Stuart, 2015; Vate-U-Lan, Quigley, & Masoyras, 2017). Grounded in transdisciplinary literature, I employ an abductive and constructivist research design to analyze a rich empirical dataset and make recommendations for further research. This thesis explores the deep tensions between Ontario food systems challenges and the digital agricultural revolution, emphasizing political dimensions in the experiences of grain farmers.

1.3 Why Ontario Grain Farmers?

Accounting for more than 25% of Canada's farmland, Ontario is a key agricultural province (Statistics Canada, 2017a). Ontario also has a higher farming population than any other Canadian province or territory; 26.9% of Canadian farmers live in Ontario (Statistics Canada, 2016a). However, there is a trend of concentration and increasingly large farms, demonstrated by the decrease in the number of farms and the increase in active farmland (Statistics Canada, 2017a). Given the farmer population and the prevalence of large grain operations, Ontario is an ideal location for this research. The thesis focuses on food crops that are most prevalent to Ontario's economy: soybeans, corn, and wheat—referred to collectively as grains. While soybeans physiologically resemble pulses, their economic dimensions and farming practices are more closely aligned with those of other grains, as exemplified by the North American Industry Classification System (GFO, 2019a; Statistics Canada, 2018b). Together, soybeans, corn, and wheat cover 74% of Ontario's farmland (OMAFRA, 2017).

The significance of Ontario grain farming extends across global food systems, with historical roots in settler colonialism.[1] In 2016, Canada exported $6 billion of wheat and $2.5 billion of soybeans (Statistics Canada, 2018a). Ontario is the largest producer of soybeans and corn in Canada; by area, 49.6% of soybean farming and 59.8% of corn farming take place in Ontario (Statistics Canada, 2017a). After soybeans and corn, wheat covers the most farmland in Ontario (1.2 million acres); however, in Saskatchewan, Canada's largest wheat producer, wheat accounts for nearly ten times more farmland (OMAFRA, 2017; Statistics Canada, 2017b). In Ontario, 59% of soybean production and 43% of wheat are exported, while 97% of corn is used domestically, predominantly for animal feed or ethanol production (GFO, 2019b).

The prevalence of large grain operations in Ontario is conducive to digital farming adoption. Analysis of the 2016 Census of Agriculture suggests that 32% of Ontario farmers use Global Positioning Systems (GPS) technology, 39% use cellphone applications, and as many as 59% use computers for farm operations (Duncan, 2018). Additionally, there are many farmer-entrepreneur digital farming ventures in Ontario who are recognized at international scales (A&L Canada Laboratories, 2018; Devron UAS, 2019; SoilOptix, 2019). Farmer and civil society organizations in Ontario are also paying attrition to the emergence of digital farming. Organizations like Grain Farmers of Ontario and Ontario Agri-Food Technologies are conducting research and implementing programs to support the adoption of digital technologies and applications of big data in agriculture (GFO, 2019a; OAFT, 2018; Schaer, 2017). Farmers are also organizing and attending conferences of varying scales

[1] I acknowledge that agriculture is an ongoing colonial act (Morrison et al., 2019). To many Indigenous Peoples, including those on whose land I reside, corn is an important cultural food, such as the Three Sisters tradition of inter-cropping corn, squash, and beans (Wabano, 2014). A Food Secure Canada report authored by Indigenous Peoples explains, "traditional harvesting and management strategies and practices adapted over millennia, as well as traditional foods, saved colonial settlers from starvation and death" (FSC, 2011). Other than wild rice, corn is the only cereal farmed in Canada that did not originate in Europe (AAFC, 2006). Soybeans were harvested in Northeast China for centuries, until a swift transnational shift through Europe and to North America was facilitated by the US government in the early twentieth century (Prodöhl, 2013).

to keep up with the technology and review its potential benefits. Since 2014, each year hundreds of farmers gather at Farms.com's Precision Agriculture Conference in London, Ontario, one of several annual digital farming conferences in the province (Farms.com, 2019).

Given the study's epistemological foundations,[2] the research timeline and the experiences of farmers are essential to interpreting the findings and conclusions of the thesis. I developed the research proposal in the spring of 2018 and completed fieldwork from September 2018 to February 2019. Current events during the research process influenced the perspectives and experiences of farmers. In 2018, the wet growing season delayed harvest and corn crops were afflicted with high levels of deoxynivalenol (DON) due to mould or rotting (CBC, 2018). Consequently, Ontario grain farmers lost $200 million this harvest because of rejection or discounts for high DON-levels (Ontario Grain Farmer, 2019). In addition, public attention to environmental impacts of agriculture, especially Lake Erie algae blooms and potential links fertilizer runoff, is a sensitive topic for farmers (CBC, 2019). Global trade and market prices are front-of-mind for many farmers; in particular, farmers are paying attention to the impact of US-China trade negotiations on grain futures prices (Andrews, 2019). Interestingly, farmers do not seem to be preoccupied by Bayer's acquisition of Monsanto for $63 billion in June 2018 or the 11,200+ lawsuits facing Bayer due to glyphosate's health risks; however, these remain active and contentious debates in civil society and the media (Bassetti, Davidson, Douglas, & Fink-Haynes, 2017; Jones, 2017; Kelleher, 2019; Rosenblatt, Burnson, & Loh, 2019). Grain Farmers of Ontario reports that prices of inputs, tariffs, and taxes increased the cost of production by nearly 20% over the past year (Senft, 2019). Additionally, an aging labour force, rising land prices, increasing costs of production and debt levels, vulnerability to fluctuations in global grain markets, and climate change present complex challenges for Ontario grain farmers (Andrews, 2019; LeMoine, 2018; Rotz, Fraser, & Martin, 2017). These events and challenges condition farmer perceptions and decisions, as they appear in this study's empirical results. The digital agricultural revolution takes place in the context of complex phenomena as well as the interlocking problems and crises of food systems across scales.

1.4 Summary of Main Findings

This exploratory study offers a contribution to transdisciplinary social sciences literature on digital farming. The thesis presents novel empirical findings on the experiences and beliefs of Ontario grain farmers regarding the emergence and adoption of digital farming, in the context of the broader debates. Addressing the three research objectives yields the following insights.

[2] Chapter 4 provides a detailed description of methodology and the abductive and constructivist research design.

First, the interpretive analysis of current digital farming debates finds that proponents are generally more influential than critics, particularly the transnational corporations (TNCs) developing digital farming technology. Across a diversity of views and perspectives, a dominant narrative pervades public discourses: *Digital farming promises to improve agricultural efficiency, productivity, and profits, while addressing the challenges of a growing population and a changing climate*.

Second, according to study participants, digital farming currently presents more challenges than opportunities, but various factors, including economic risks, may still drive farmers to adopt the new technology. Participants see the potential of digital farming to offer operational benefits and data to inform better decisions for business and land stewardship. However, new technologies present complex challenges for farmers, including economic pressures to adopt expensive technology, new capacities required for successful farming, and lack of control over unreliable equipment.

Third, in comparing farmer perceptions of digital farming with themes in broader debates, the study concludes that, unlike the binaries in public discourses, Ontario grain farmers are not simply classified as either proponents or critics. Farmers respond to the promises of digital farming in nuanced and complex ways. The political and economic conditions of farmer experiences can motivate them to adopt digital farming technology or agree to part of the narrative without necessarily aligning with proponents. For instance, participants are doubtful of the promises that digital farming will offer economic benefits to farmers and solve food system challenges, although there is the potential for farmers to take advantage of the technology for social, environmental, or economic goals. The analysis also discusses the implications of digital farming on data governance, labour, and environment with recommendations for future work. The findings support several theoretical ideas in the nascent research community, while also presenting some surprising features of Ontario grain farmer perceptions.

1.5 Thesis Outline

The overall structure of the thesis takes the form of six chapters. Following the introduction, Chapter 2 describes the research design employed in the study, outlining and defending methodological decisions. Chapter 3 reviews the existing literature on digital farming, establishing key definitions and analyzing themes of power, data, labour, and environment in relevant social sciences discourses. Chapter 4 presents the study’s empirical results to understand the experiences and perceptions of Ontario grain farmers in the digital agricultural revolution. Chapter 5 compares the results on farmer perceptions with the narratives in current digital farming debates and the key themes in the study. Finally, Chapter 6 concludes the thesis with a summary of contributions and recommendations for further research.

Chapter 2
Epistemology, Perspective, and Methods

2.1 Introduction

This chapter outlines the methods employed to answer the study's central research question. I present the methodology and epistemological perspective in the form of a research design, understood as "a flexible set of guidelines that connect theoretical paradigms, first, to strategies of inquiry and, second, to methods for collecting empirical material [and] situates the researchers in the empirical world" (Denzin & Lincoln, 2011, p. 14). Epistemology precedes methods and the research question and objectives serve as the foundation to the research design. The study is exploratory and contextual as it intends to "investigate and capture interpretations of social phenomena as experienced and understood by participants," focusing more on 'what' questions, and pointing to questions about 'why' things occur in recommendations for future work (Neuman, 2014; Ritchie et al., 2014, p. 32). The research design draws from the strengths of qualitative methods, including situational analysis of social phenomena, thematic analysis, and the study socially constructed realities (Neuman, 2014). Grounded in a constructivist and abductive epistemology, this study uses a suite of qualitative methods, including a review of academic and grey literature, an online questionnaire, semi-structured interviews, and fieldwork observations. The combination of methods provides a richer, more in-depth understanding of the phenomena in question. While the research design assigns specific methods for data collection and analysis for each research objective (summarized in Table 2), the research is an interconnected and iterative process rather than a linear sequence of tasks (Silver & Lewins, 2014). I prioritize transparency in the research process and the chapter aims to provide clear descriptions and justification of the research design.

2.2 Researcher Epistemology

Epistemology, *how we know what we know*, is the foundation of all investigation and inquiry (Bowleg, 2017; Denzin & Lincoln, 2011b; Ritchie et al., 2014). Thus, a declaration of researcher epistemology must come before any discussion of methods employed for data collection and analysis. Before I can explore the knowledge produced in this study, I will explain the perspective on how knowledge is generated and the "relationship between the inquirer and the known" (Denzin & Lincoln, 2011, p. 12).

2.2.1 Constructivism

The central epistemological assumption of the thesis is that knowledge is *constructed*. Each person has their own truth and the knowledge that they produce is grounded in experience, which also implies that the information collected in this study is unique to its conditions and context: knowledge is social (Charmaz, 2014; Lynch, 2013). Rose asserts, “all knowledge is produced in specific circumstances and that those circumstances shape it in some way” (1997, p. 305). Rather than there being one universal ‘truth’ about reality in a positivist perspective, there is a co-construction of knowledge in an intersubjective experience (England, 1994; Lincoln, Lynham, & Guba, 2011; Trochim, Donnelly, & Arora, 2016). Constructivism contradicts the positivist assumption that there is a reality outside of the observer, which would suggest a dichotomy of reason and embodied experience (Lincoln et al., 2011). I argue that, there is no objective truth; knowledge is value-laden (Lincoln et al., 2011; Ormston, Spencer, Barnard, & Snape, 2014). Charmaz states that constructivist perspectives must “acknowledge subjectivity and the researcher’s involvement in the construction and interpretation of the data” (2014, p. 14).

Furthermore, the constructivist perspective brings with it a relational ontology and a dialectical methodology (Lincoln et al., 2011). In simpler terms, because knowledge is socially constructed, it relies on relationships between perspectives (and those who construct them) in an interconnected way of being, which requires diverse flexible research methods that can embrace multiple truths. The aim of constructivist research is to understand, interpret, or re-construct social phenomena (Lincoln et al., 2011). As such, the research design is grounded in an understanding of how the participants might perceive or construct their experiences. Moreover, constructivism aligns well with a normative understanding that social factors affect the construction of knowledge, including both the identity of those who know and the social structures that determine what knowledge is legitimate (Haraway, 1997; Harding, 2006; Merchant, 1980; Worthy, Allison, & Bauman, 2019).

2.2.2 Abductive Reasoning

Research is categorized by the ways in which one gains knowledge (Blaikie, 2000; Ormston et al., 2014). Epistemology affects understandings of theory generation (Charmaz, 2014). Traditionally, research epistemologies are oriented toward one of two general logics: inductive or deductive (Trochim et al., 2016). *Inductive* reasoning works from an observation of the world to build generalizations, hypotheses, and theories; whereas, *deductive* reasoning begins with an existing theory and tests hypotheses with observations of empirical realities (Blaikie, 2000; Ritchie et al., 2014; Silver & Lewins, 2014; Trochim et al., 2016). While deductive approaches are directed toward theory testing, inductive approaches are used to develop new hypotheses to explain patterns and mechanisms (Blaikie, 2000; Silver & Lewins, 2014). Inductive logic is particularly useful to answer ‘what’ questions in effort to describe and understand phenomena (Trochim et al., 2016).

One approach is not inherently better than another, but some research questions are better served by particular approaches. It is not uncommon for social researchers to use some combination of both approaches (Trochim et al., 2016). The epistemological and theoretical foundations of the thesis caution against the use of dichotomies. Rather than abiding by one approach, I join an *abductive* tradition built on inductive and deductive approaches (Charmaz, 2014; Silver & Lewins, 2014; Trochim et al., 2016). The dialectic of inductive and deductive logic offers more depth because it draws from empirical realities and abstract ideas. Following Blaikie, I present abductive logic as an iterative strategy to "describe and understand social life in terms of social actors' motives and accounts" (2000, p. 101).

As this is an exploratory study, inductive logic undergirds the research design. I am primarily interested in developing new ways of thinking about digital farming, based observation of its implications and the perceptions of farmers. The research design accumulates information in order to develop ideas, hypotheses, and generalizations as building-blocks to theory. I also remain in an openly transdisciplinary framework, which does not provide the necessary structure for a traditional deductive approach. Still, there are deductive elements of the analysis as I reconcile the stories that the data is telling with the theories and claims of the literature. I assess the validity and reliability of theoretical propositions in the existing studies in a deductive fashion. The data analysis also includes the development of themes in cycles of coding. As I perceived themes emerging or developed theoretical ideas, I went back to the data. Abductive approaches are harmonious with constructivism and an appreciation for intersubjective knowledge.

2.3 Positionality and Reflexivity

Constructivist perspectives assert that it is not possible to be truly objective, and such a claim would erase important power and relational elements of the research process. In constructivist scholarship, the identity of researchers is relevant to the research design and the interpretation of findings (England, 1994; G. Rose, 1997; Rowe, 2014). Positionality and reflexivity contextualize the epistemological foundations of the thesis. Positionality is the act of positioning oneself in the context of their work (Rowe, 2014). Considering a researcher's positionality might begin with the dynamic and fluid relations between the researcher and the research population (Herr & Anderson, 2005). For instance, I am an outsider to Ontario grain farmers, but I developed relationships and an ongoing dialogue in the research process. Positionality also considers intersectional[3] power relations at a societal level; experiences of researchers and study participants take place in much greater power structures, such as racism and

[3] Intersectionality is a concept to understand the ways in which interacting and overlapping axes of identity (e.g., gender, race, class, ability, etc.) affect one's experiences of themselves and the world (Crenshaw, 1989).

sexism (England, 1994). Reflexivity can be conceived of as the continuous consideration of positionality in research, involving self-scrutiny and self-conscious inquiry (Bourke, 2014).

From conception to execution, the research process may be influenced by the identities and positionalities of both those participating in and those conducting research (Bourke, 2014; Charmaz, 2014; G. Rose, 1997). However, this practice does not compromise the rigor or credibility of social science research (Lincoln et al., 2011). Positionality and reflexivity in research do not reduce analysis to personal anecdotes. Despite best efforts to remove oneself from the research and to use systematic methods, knowledge is *always* necessarily socially constructed.[4] I argue that this practice does not compromise research methods, but rather strengthens them by offering a more complete and accurate view of the research process. Still, it is my priority to restrict the influence of my perspective, prioritizing the narrative and experiences of Ontario grain farmers, clearly differentiating my interpretation from those of the participants (Charmaz, 2014; Ritchie et al., 2014).

2.3.1 Situated Perspective

While I prioritized the direction and narrative of participants during fieldwork and employed a systematic methodology, I acknowledge that my identity influences the research process. I spent most of my life in a rural Ontario town, surrounded by grain and dairy farmers, but I have no direct experience of farming. I am privileged to not have experienced food insecurity. I have no immediate connections to the agri-food system in my employment or research funding, but I have six years of volunteer experience in social and environmental justice groups, especially around food. Also, I hold privilege in my identity: I am a 24-year-old Canadian cisgender woman embedded in white privilege and settler culture. Presently, I live and work on land promised to Six Nations in the Haldimand Tract and the traditional territories of the Attawandaron (Neutral), Anishnawbe, and Haudenosaunee peoples.

Along with the majority of the research population of this study, I am a settler and I have lived in Ontario for the majority of my life. Colonialism conditions our experiences and perspectives. Also, colonialism is relevant to topic of research. Agriculture has been and continues to be a colonial force in Canada: settlers violently eradicated Indigenous Peoples and their food systems to expand European production with monocultures; agriculture in North America is tied to a history of slavery and the exploitation of Indigenous labour; residential school system malnourished Indigenous children and prohibited connections to traditional foods and cultures; and, the effects of colonialism are apparent in disproportionally high rates of food insecurity, food-related physical health problems, and mental health

[4] Even those who claim that science is objective cannot liberate themselves from social factors, contrary to the assumption and value of objectivity in dominant paradigms (Haraway, 1997; Harding, 2006; Hird, 2012).

crises (Desmarais & Wittman, 2014; FSC, 2011; Matties, 2016; Morrison, Martens, McIntyre, & Mendes, 2019; Rotz, Gravely, et al., 2019; Weis, 2007). Moreover, science and technology are intertwined in legacies of colonialism and oppression: historically and institutionally, Western science has a predatory relationship with Indigenous knowledge and other ways of knowing; agricultural technologies, like GM seeds, are forced upon Indigenous Peoples across the globe, invalidating and threatening the viability of traditional food systems; Indigenous Peoples are often most significantly affected by the unintended consequences of technological innovation, including the impacts industrial agriculture and the fossil fuel industry; and, technological 'solutions' often violate the consent and sovereignty of Indigenous Peoples, who have invaluable ecological knowledge for sustainability and harmonious relationships with more than human life (Amnesty International, 2016; Shiva, 1993, 2001; Tuck & Yang, 2012; Whyte, 2019).

As an 'outsider' to what one study participant called the 'very cliquey' population of Ontario farmers, my life experience and perspective likely affected my interaction with participants. This aspect of my positionality is a strength in the research design because there are limits to my preconceived notions and assumptions about agriculture and digital farming. Also, I can investigate elements that may otherwise be taken for granted. Many constructivist inductive and abductive scholars argue that the researcher should limit their engagement with the literature or research problem prior to conducting research (Charmaz, 2014). Because of my limited prior knowledge, I included observations and ongoing commutation with actors in digital farming and agri-food sectors to verify my interpretations.

Throughout fieldwork and observations, I took note of farmers' general disdain toward citizens of urban areas (and academics, in some cases). Some farmers with whom I spoke expressed particular distrust and contempt for environmentalists. If we had met in another context it is possible that some participants would not have been interested in speaking with me. I welcomed open exchange throughout the fieldwork, and I answered any questions posed to me openly and honestly. Still, I hold power in the participants' limited knowledge of my identity and experiences. I acknowledge an uneven power relation in my role as a researcher, as I control the construction of the research design and the knowledge it produces (Charmaz, 2014; MacLean, 2013). Also, my identity as a woman who is also younger than most of my participants, likely affected the ways in which participants interacted with me. At times, I experienced patronizing tones and assumptions pertaining to my identity, experiences, and knowledge from participants, though most exchanges were comfortable and respectful. I intentionally positioned myself as an "interested but naïve learner" to reduce the influence of any preconceived notions and to give power to the interview participants (Charmaz, 2014; MacLean, 2013).

2.3.2 Language and Perspectives

This research exists at the intersection of several different perspectives and discourses, without a common language. The transdisciplinary nature of this thesis presents challenges of integrating theory and methods from different academic traditions – food studies, political economy, and sociology – and interrogates the perceptions of farmers, industry actors, government representatives, and other groups. Language is an important element of perceptions and ways of knowing. The study's reflexive perspective informed the reconciliation of diverse connotations and assumptions in language. For example, in food studies literature, John Deere and Bayer are described as TNCs or corporate actors (Brooks, 2005; Clapp & Fuchs, 2009; McKeon, 2015; Weis, 2010). However, the term 'corporation' has very different connotations for farmers; farms can be incorporated, due to size, family succession, or for tax purposes (McLeod, 2016). Indeed, 22% of farms in Ontario are incorporated (Statistics Canada, 2017a). Many farmers see themselves as corporations, so they responded with confusion when I wanted to discuss tensions between corporations and farmers. I revised my language, accordingly, echoing the use of 'industry' and 'business' by farmers. In contrast, despite concerns about choosing a term to describe the rise of big data and digitalization in agriculture, the choice 'digital farming' was effective.[5] In the interviews, farmers defined 'digital farming' and related terms, corroborating my interpretations.

2.4 Research Design and Methods

The research design is built on the epistemology, and the methods flow from the research question. The methodology grounding this research views the role of qualitative research as "to study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people bring to them," in line with the research objectives regarding farmer experiences and public debates (Denzin & Lincoln, 2011, p. 3). Qualitative methods offer effective ways to analyze perceptions and socially constructed realities (Neuman, 2014; Ritchie et al., 2014). Certainly, there are relevant and important questions about digital farming to be addressed with quantitative methods, but I argue that qualitative methods are best suited to collect information about the narratives and experiences of farmers.[6] Methodology also uses the classification of empirical and theoretical, where the former is

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[5] It is possible that the choice of 'digital farming' limited the participants who engaged in the study, but the term was also used and well-understood at conferences organized by farmers.

[6] I refrain from placing qualitative and quantitative methods in opposition. The ways in which researchers come to know and explore knowledge are different based on whether they have a qualitative or quantitative viewpoint (Goertz & Mahoney, 2012). Neither one nor the other is more valuable or effective in research (Denzin & Lincoln, 2011a; King, Keohane, & Verba, 1994). The relationship and power between qualitative and qualitative research is a rich topic of discussion (Elizabeth, 2019; Merchant, 1980; Nelson, 1992). Many scholars in STS and other critical discourses elucidate the ways in which positivist and quantitative knowledge are privileged over

"based on direct observation and measurements of reality" and the latter is "concerned with developing, exploring, or testing theories or ideas" (Trochim et al., 2016, p. 13). The research design uses empirical data on farmer perceptions and current debates, with theoretical engagement across disciplines to understand the realities in which their perspectives are situated.

While the research question is answered holistically by considering the heterogeneous empirical dataset, there are primary methods for each research objective, summarized in Table 2. Embracing the limitations of each method, I argue that collecting and analyzing data from a variety of approaches to address the same research problem can offer a richer, more profound understanding of the phenomenon (Lynch, 2013; Ritchie et al., 2014). Moreover, using multiple methods can triangulate the findings to strengthen the internal validity of respective methods or, from a more positivist perspective, to improve the external validity that the methods are providing and accurate depiction of the 'objective truth' (Gallagher, 2013; Lynch, 2013). In the research design, I triangulate both the data collection and the data analysis. I chose to sequence the interviews after the questionnaire to be able to interrogate preliminary questionnaire data in the interviews and to collect detailed information on the perceptions and experiences, which is rarely possible with questionnaires alone.

2.4.1 Literature Review

Through a review of academic research as well as grey literature, I retraced arguments of proponents and critics of digital farming, and their underlying values, to inform which questions to ask in the semi-structured interviews and themes on which to focus in the analysis. This method provided more depth to the survey of current debates, as an additional contribution to the emerging scholarship. The literature review was also essential to situate the analysis in the context experienced by Ontario grain farmers. Furthermore, it provided the epistemological bedrock for the data interpretation and analysis. Certainly, reviewing the literature is an elemental step to any research project, but it is considered a method in the research design because it yielded data to address the research question.

I used a combination of search engines available through the University of Waterloo (e.g., Scopus), though Google proved most useful in collecting information and publications from industry and the media. I did not complete a systematic review because the research questions did not demand such an extensive or inclusive approach (Neuman, 2014; Veal, 2011). The summary and overview of current debates were sufficient in identifying clear themes and narratives in digital farming debates. The thesis prioritized farmer perceptions, so I remained mindful of their perspectives and information to which

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qualitative approaches in academia, which is in turn privileged over other ways of knowing, in terms of the credibility, validity, and legitimacy.

they have access. I analyzed the data by synthesizing and investigating underlying assumptions, but it was not necessary for the study to perform and formal discursive analysis. This method is unique in the study's research design because knowledge construction occurred before my engagement; however, Charmaz explains, "documents do not stand as objective facts" (2014, p. 46). Documents represent the author's perspective and are framed by the reader's subjectivity. Thus, the analysis considered the intent and intended audiences of the documents (e.g., it is in the interest digital farming developers to focus on farmer success stories in their publications).

2.4.2 Research Population and Recruitment

This research engages with farmers in Ontario who grow soybeans, corn, or wheat.[7] Decision-making on the recruitment of participant and associated sampling method were pragmatic and flexible, as permitted by the exploratory nature of the study. The study seeks to understand phenomena and perceptions as situated realities, rather than proposing a high-level universal theory, which would require random sampling or a more systematic method (Lynch, 2013). The research design intentionally differentiates itself from existing studies, while making choices to remain relevant in the emerging scholarship. For instance, I aligned my interview guide with similar work in other countries to facilitate comparison and global exchanges in the discourse. However, there are also intentional decisions to differentiate this research from other studies, beyond the changes of geographic location.

While it is valuable to study the perspectives of diverse actors in the digital agricultural revolution, it remains important to prioritize farmers as they are potentially most directly affected. Many existing digital farming studies focus on developers and engineers, industry actors across the food system, researchers and consultants, and government officials, with or without farmers (Bronson, 2019; Carolan, 2018b; Fleming et al., 2018; Jakku et al., 2018; Regan, 2019; Rijswijk, Klerkx, & Turner, 2018; Tsouvalis, Seymour, & Watkins, 2000). For instance, in study of digital farming perceptions in Australia, only five of the 26 interview participants were farmers (Jakku et al., 2018). In a similar study in Ireland, two of the 21 interview participants were farmers (Regan, 2019). The amalgamation of various actor groups in digital farming studies may lessen farmer contributions and cloud the nuance of their experiences. It is also interesting that some studies focus on 'experts' on digital farming (Regan, 2019; Rijswijk et al., 2018), but do not highlight the knowledge and expertise of farmers. Furthermore, the characteristics of farmers and their operations can influence their perceptions and experiences of digital farming (Fleming et al., 2018). Thus, the study of farmer perceptions will require various identities and contexts. Carolan makes substantial contributions to the growing body digital farming

[7] Eligibility criteria: live in Ontario; over 18 years of age; work on a farm that grows soybeans, corn, or wheat.

literature with rich empirical data, but he focuses on specific groups (2016, 2017, 2018a, 2019). In one study, the research population is limited to digital farming adopters operating farms over 1,200 acres or farmers involved in particular resistance movements (2018b). Farmer interactions with technology are shaped by their values, identities, and experiences. Therefore, choices regarding research population will limit the analysis to a specific perspective. This study collects empirical data on the perceptions of Ontario grain farmers with a diversity of scales, identities, and locations, rather than a specific group.

All participants were recruited through email and farming organization newsletters or other publications for members. In Ontario, any farmer who declares a gross income of $7,000 or more in their taxes must register with an Accredited Farming Organization (AFO) as per the *Farm Registration and Farm Organizations Funding Act, 1993, S.O. 1993, c. 21* (Agricorp Ontario, n.d.; Government of Canada, 2018a). There are three Ontario AFOs: Christian Farmers Federation of Ontario, National Farmers Union, and Ontario Federation of Agriculture. In September 2018, I contacted the three AFOs and other recognized farming organizations in Ontario to ask for support in disseminating the information letter and a link to the online questionnaire through their newsletters or online mailing lists.[8] Although this was my only formal means of recruitment, I interacted with the research population through an *Ontario Grain Farmer* magazine article (Ruder, 2018) and participation at farming conferences. The research sample included 75 online questionnaire respondents.[9] All questionnaire responses were submitted between September 2018 and February 2019. I recruited interview participants through the questionnaire, using an optional contact textbox. I extended an invitation for an interview to each of the individuals who offered their contact information. If they did not respond, I followed up once after approximately two weeks. I received the contact information of 26 participants, and I conducted 12 interviews.[10]

2.4.3 Online Questionnaire

The questions asked emerged from the literature review and the research question and objectives. While the data collection was primarily directed to the farmer perceptions, there were also questions to inform

[8] The following farming organizations shared study information: Ag Women's Network, Christian Farmers Federation of Ontario, Grain Farmers of Ontario (GFO), Huron County Soil and Crop Improvement Association, National Farmers Union (Ontario), Ontario Soil and Crop Improvement Association (OSCIA), and Organic Council of Ontario. Additionally, GFO and OSCIA shared the letter again a few months later

[9] I do not have the information regarding the number of farmers who received the recruitment materials through online mailing lists, so I cannot determine a response rate.

[10] I interviewed an OMAFRA employee with digital farming research and engagement with farmers. The interview was not recorded, and the individual remains anonymous. It was not included in the data analysis, but it provided important context and supported the external validity of the analysis.

the analysis of public debates. The majority of the questionnaire comprised of five-point Likert scale questions, a common format to measure attitudes created by Rensis Likert in 1923 (Allen & Seaman, 2007; Sullivan & Artino, 2013).[11] Such questions are familiar to respondents and can provide helpful frames for participants to describe their opinions. In addition, I collected demographic information and farm operation data to assess the representation of the research population in the sample and to explore the relationship of these factors with perceptions (e.g., impact of age on perceptions of technology). Specifically, I was interested in age, gender, education, farm size, land tenure, ecological practices, and labour. The full list of questions is included in Appendix B.

I chose to use an online questionnaire to collect data on farmer perceptions because the farming population is remote and spread across the province. Advantages of online questionnaires include the speed with which responses are collected, access to a wider population, convenience for respondents, elimination of paper, and low cost; however, drawbacks include barriers to access[12] and low response rates due to the volume of spam mail (Morgan, 2014; Trochim et al., 2016; Veal, 2011). The pragmatic advantages of the method and the convenience for collecting and analyzing data outweigh the disadvantages. Contacting farmers through the farming organizations prioritized member privacy. Moreover, the anonymity of the questionnaire might provide more honest or sincere responses (Charmaz, 2014). The questionnaire was hosted online through Qualtrics, a survey software company. All responses were anonymous. I did not collect personal information and I removed the IP address information from all responses.

The content of questionnaires and interview guide was inspired in part by a similar study of big data perceptions in Australia's grain industry (Fleming et al., 2018).[13] Fleming et al. (2018) interviewed key actors, including farmers, policy-makers, and industry representatives, to explore perceptions and experiences of digital technologies and big data in grains. They make the claim that they are "the first study of big data in agriculture that takes a discourse analysis approach and thus interrogates the status quo and the prevailing norms and values driving decisions with impacts on both farmers and wider society" (Fleming et al., 2018, p. 1). In addition to their originality, I admired their methodology in data collection and analysis. The similarities in research design were also intentional to foster discussion

[11] Five options: strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, strongly disagree.

[12] The choice of online questionnaire limits respondents to individuals who have the access and capabilities necessary to complete it. In the study population this might exclude older farmers and those without internet access in rural Ontario. The age and geographic distribution of respondents appeases this concern.

[13] I include the relevant questions from Fleming et al. (2018) in Appendix B for comparison.

and a more global perspective of a digital agricultural revolution. However, the research objectives, coding approaches, research population, and geographic area remain distinctive.

2.4.4 Semi-Structured Interviews

While Likert style questionnaires yields valuable information about the direction and intensity of opinions and beliefs, they are limited depiction of perceptions. Saldaña compares the "linear continuum of responses" of surveys to the "three-dimensional *ocean* allowing for diverse responses of varying levels of depth" in interviews (2013, p. 114). Interview data allowed me to overcome other restrictions of the questionnaire (e.g., asking follow-up questions). The support of interviews intended to enrich the value of the questionnaire findings. Therefore, it was important to select a method that would allow for flexibility and collect in-depth responses.

I used qualitative semi-structured interviews to collect data on the different perspectives on digital farming to provide the participant with more agency and allowing them to set the direction of the conversation, while also maintaining structure and consistency across the interviews for coding and hypothesis testing (Charmaz, 2014; MacLean, 2013; L. Mosley, 2013). This methodological decision also aligns with the constructivist abductive frame; I use exploratory, open-ended questions that support inductive analysis, while imposing structure and topics of conversation for deductive analysis. The interview guide was flexible, but followed an introduction, three intermediate sections, and a conclusion (see Appendix B). The first intermediate section focused on values and assumptions to contextualize the farmer's response and reveal their priorities. The following two sections discussed digital farming in general, followed by specific theme questions pointed to specific challenges and opportunities or an appraisal of the promises in current digital farming debates.

In practice, conversations with farmers remained along a similar trajectory due to the interview guide. I asked the participants about each topic that I identified as important through the literature review, bringing it up topics near the end of the interview if they did not come up naturally to ask why they chose not to include something in other open-ended responses. I allowed farmers to pursue their narrative and tangents with reflective questions and prompts. The conversations were all different and I offered as much control as I could to the interviewee (Charmaz, 2014; MacLean, 2013). I was respectful of the participant's time, offering to keep pace, but also allowed them to speak for as long as they liked. In a practice interview, I estimated that the calls would last from 30 to 40 minutes. In reality, the average duration of interviews was 56 minutes. The shortest interview was 26 minutes and the longest was one hour and 39 minutes. Each participant was given the choice to conduct the interview in person or by phone, and all chose phone. This was advantageous in the study to ensure consistency and improve the practicability of surveying a sample spanning Ontario. There are limitations without non-verbal communication and context, but I used other observations to enrich my understanding. I was able to establish a rapport with the participants through my tone and reflexive listening, evidenced by the anecdotes of participants and my subjective experience.

2.4.5 Observations

I collected observations throughout the research process as a supplementary method, to provide additional context and triangulate findings from other methods (Creswell, 2009; McNaughton Nicholls, Mills, & Kotecha, 2014). Kawulich describes observation as, "the process enabling researchers to learn about the activities of the people under study in the natural setting through observing and participating in those activities" (2005, p. 2). While observations are often attributed to ethnographic research, they are central methods across many qualitative traditions (Kawulich, 2005; Ritchie et al., 2014). Observations allow qualitative researchers to collect additional information about the events and processes described in other means of data collection, investigate the use of language and nonverbal communication, practical experiences, or uses of machinery, and other opinions and behavioural norms (Creswell, 2009; Kawulich, 2005; Ritchie et al., 2014). Observational methods align with constructivist and reflexive practices, recording information on the context and perspective of experiences and supporting a situated analysis of socially constructed knowledge.

I collected observations in a research journal and took photos when appropriate. I documented all correspondence with farmers and farming organizations, including emails and phone calls. For instance, I took notes during interviews on the silence or hesitation in response to certain questions. The use of observational methods was crucial to understanding of digital farming and interpretation of results. I had very limited knowledge of the lived realities of Ontario grain farmers at the outset of the study and I was not familiar with digital farming in practice. Given the geographical expanse of the research population, mobility limitations, and the ethics agreement, I did not visit participants on their farms. Still, I had the privilege to spend several days meeting with farmers and other actors in the digital farming space, over the six months of fieldwork.

Through the online recruitment, several farmers and individuals in the agri-food system reached out to me to learn more about my research and to extend invitations to meet. I spent time interacting with farmers, municipal politicians, technology developers, and TNC executives over the course of the fieldwork and conducted five informational interviews with representatives from industry, government, civil society at local, provincial, and national levels.[14] The farming conferences I attended were particularly helpful as they congregated diverse farmers from across the province to discuss their experiences with digital farming. They also provided another medium to see how farmers respond to the current debates. I learned about the material realities and mechanisms of digital farming through demonstrations at the tradeshow at Farms.com's Precision Agriculture Conference & Ag Tech Showcase in February 2019. I also visited farms and facilities using digital farming technologies with Grey County's Ag 4.0.2 in November 2018.

2.4.6 Data Analysis and Coding

Data analysis was an iterative and dialectic activity. I performed analysis throughout the literature review and fieldwork, exercising reflexivity in recording observations and reviewing questionnaire responses as I conducted interviews. Still, I shifted to more explicit and systematic methods of data analysis once the data collection was complete (see Table 1). I will explain the process linearly for the sake of clarity, but, in reality, the analysis of the questionnaire responses and interviews was abductive and iterative. Questionnaire findings influence the construction of codes; emerging themes in interviews contextualize trends in questionnaires.

The questionnaires provide an overview of farmer perceptions of digital farming. I began by familiarizing myself with the dataset, using different spreadsheet analysis and visualization tools to explore the data. Then, I performed descriptive statistics to understand the demographic and characteristics of participants and their farms (Trochim et al., 2016; Veal, 2011). Likert scale questions yield ordinal measurement, which provides indictors of perception, but assumptions cannot be made on the meaning of frequencies or the differences between responses (Sullivan & Artino, 2013; Veal, 2011). Despite the limitations of ordinal data and the sample size, quantitative analysis is possible. However, I did not conduct any statistical analysis because it did not suit the qualitative research design or the needs of the research question. I used frequencies and visualizations to observe trends and analyze perceptions, then used interview data to assist in the interpretation of the questionnaires.

The interview analysis was much more elaborate. I personally transcribed each interview in full, adding annotations for pauses and intonation, by listening to the audio recording. I referred to my observations and notes to ensure accurate data collection. I used a software called Express Scribe, allowing changes to volume and speed of recordings, to ensure that I was transcribing the interviews verbatim. Listening to each recording and reflecting throughout the process of transcription served as

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[14] These interviews were not recorded or included in the formal analysis, but they offered valuable context and external validity to the analysis. The conversation as well as the names of these individuals are confidential.

a valuable familiarization with the dataset (Ritchie et al., 2014). I also referred to questionnaire data during transcription to generate analytic memos (Charmaz, 2014; Saldaña, 2013).

Next, I used codes to support theoretical and interpretive analysis of the various sources of data, supporting the construction of both theoretical statements regarding the general implications of digital farming and more contextual descriptions of Ontario grain farmers' experiences. In qualitative research, a *code* can be understood as "a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" (Saldaña, 2013, p. 3). *Coding* is a researcher's active engagement to link data collection with the theory and explanations in analysis (Charmaz, 2014). Although to code requires a subjective engagement with the data to organize ideas, coding itself is not a method of analysis (Silver & Lewins, 2014). The data analysis is largely built on the coding and memos that I generated in NVivo and a research journal. I used Computer Assisted Qualitative Data Analysis Software (CAQDAS) to offer transparency in the coding process, to support more complex and iterative coding methods, and to accelerate the analysis (Charmaz, 2014; Ritchie et al., 2014; Saldaña, 2013; Silver & Lewins, 2014). Most CAQDAS offer similar programs; I chose to use QRS Nvivo 11 because of its applicability to the study's methodology, useful visualizations and query functions, and the compatibility with other software used in the study (e.g., Qualtrics and Word).

Researchers *construct* codes, though they emerge from the data (Charmaz, 2014; Saldaña, 2013). The act of coding and the data itself are influenced by the researcher's positionality and the study design (Saldaña, 2013). As per the earlier discussion of constructivism, analysis is embedded in the researcher's perspective rather than a single empirical truth (i.e., positivism). Constructivism and positionality in data collection and analysis does not compromise the findings; it strengthens the analysis by acknowledging the unavoidable social construction of knowledge and its influence. From the study's research question to the interview guide, the questions posed influence the data collected. The choice of coding method was informed by the study's epistemology, but more importantly they are aligned with the research question. As illustrated in Table 1, I crafted a multi-method coding approach based on Saldaña's classification, influenced by grounded theory research traditions (Charmaz, 2014; Corbin & Strauss, 1990; Saldaña, 2013).

The analysis focused on the qualitative aspects of the rich dataset. Separate from the codes, I wrote short interview summaries to verify the analysis. In follow-up communication with participants, I provided their respective summaries with instructions on providing feedback or corrections and received positive responses. Because the frequency of codes or words are not necessarily indicative of significance, the summaries assisted in the interpretation of what was most important to each farmer. Through coding cycles, memos, and abductive reasoning, I increased the level of analysis in abstraction from the data in developing themes and theoretical insights (Charmaz, 2014; Saldaña, 2013; Silver & Lewins, 2014).

Table 1: Coding methods used in data analysis with examples (based on Saldaña, 2013)

Coding method	Definition	Examples from my codebook
	First Cycle	
Open Coding	Constructing prolific descriptive codes in an exploratory fashion; focus on context and meaning over content	- Challenges of digital farming - Access to Data - Labour shortage - Return on investment - Compromise
In Vivo	Key words or phrases in the voice of participants, copied verbatim form the transcript (and coded over other text with the same words or meaning) ** Employed in Open Coding*	- 'Smart decisions' - 'Keeping up with technology' - 'No choice' (adoption) - 'Right thing to do' - 'Data vs. gut-feel' - 'Enough food' (food security)
Values Coding	Codes for participants *attitude* (way we think and feel), *values* (priorities, what is important), *beliefs* (system of values, attitudes, and knowledge) to understand their worldviews and perspectives; requires reflexive positionality as it is an interpretive exercise (i.e., not always explicitly stated)	- Optimistic - Frustrated - Values: Profit - Values: Knowledge - Farmers are stewards - Farming is a business first
	Second Cycle	
Axial Coding	Development of node hierarchies for organization and theorizing; abductive analysis working iteratively to reconcile emerging trends from data (inductive) with theory and literature (deductive) to develop themes in analytic memo writing	- *Beliefs (Values Coding)* > Impact of digital farming >> DF makes farming more efficient >> DF doesn't change anything … - *Environmental dimensions* > Impact of agriculture >> Soil >> Water …

2.5 Chapter Summary

This chapter offered a discussion of the epistemology and methodology that ground the thesis. Table 2 summaries the research design.

Table 2: Research questions, objectives, and methods

Research Question
How do Ontario grain farmers perceive digital farming, and how do their perspectives compare to public debates and academic research?
Research Objectives and Affiliated Methods
Identify key narratives in digital farming debates, focusing on proponents and critics. Data Collection: review of grey and academic literature Analysis: interpretive analysis of grey literature and the existing academic discourses (implications, problem-solution framing, claims)
Describe the perceptions of farmers regarding challenges and opportunities of digital farming. Data Collection: Questionnaires (n=75), semi-structured interviews (n=12), and observations Analysis: descriptive statistics; qualitative coding; thematic analysis; abductive reasoning
Compare farmer perceptions with key themes in digital farming debates. Data Collection: consider all previous data collected Analysis: holistically considering the heterogeneous empirical dataset; abductive analysis

Appended materials:

- Appendix A: University of Waterloo Office of Research Ethics (ORE#23305)
- Appendix B: Online Questionnaire and Semi-Structured Interview Guide
- Appendix C: Qualitative Interview Analysis: Example Codes
- Appendix D: Study Participant Demographics

Chapter 3
Joining the Conversations on Digital Farming

3.1 Introduction

This chapter orients the reader to the existing discourses and debates on digital farming. I systematically review relevant academic literature on digital farming in the social sciences – particularly food studies, political economy, and STS – as it relates to the research topic. To begin, I make the case for complexity-informed research on food systems and digital farming. From this foundation, I address important terminology and concepts to equip the reader for meaningful engagement with this thesis. I offer a primer on digital farming and big data as dynamic phenomena embedded in complex systems, and I present literature on digital farming adoption. Then, I provide an overview of public conversations on digital farming, drawing from government documents, corporate publications, civil society reports, and the media. The interpretation of affirmative and negative perspectives and their claims initiates the research to address the study's first objective, revealing a dominant narrative across perspectives and discourses with the main promises of digital farming. Mirroring the views of proponents and critics in current debates in broader discourses as reflected in grey literature, there are tensions within and between scholarly perspectives on digital farming.

The second half of the chapter surveys themes in digital farming literature, discussing corporate power and farmer autonomy, big data and knowledge in farming, agricultural labour, and environmental concerns. Because the digital agricultural revolution affects diverse dimensions of food systems, relevant research is scattered across many disciplines. To date, the majority of the academic literature on digital farming is from the perspectives of science, technology, engineering, and math (STEM), much of which presents technical research to support digital farming innovation and adoption (Auernhammer, 2001; Bhakta, Phadikar, & Majumder, 2019; Bongiovanni & Lowenberg-Deboer, 2004; Chi et al., 2016; Daberkow & McBride, 2003; Gebbers & Adamchuk, 2010; Karim, Karim, & Frihida, 2017; P. Roberts, 1999; Tey & Brindal, 2012). Certainly, there are important roles for engineering, computer science, modelling, and agronomy in studying digital farming developments and their impacts; however, this thesis primarily engages with research in the social sciences, as per the study's objectives pertaining to farmer perceptions and current debates on digital farming.[15] Ultimately, this chapter aims to situate the thesis in the context of existing literature and establish the significance of the study and its potential contributions.

[15] Still, the thesis will feature many STEM publications to support technical descriptions and analysis.

3.2 Food Systems, Complexity, and Wicked Problems

In Bronson and Knezevic's agenda-setting piece in *Canadian Food Studies* (2016b), they claim to be the first to investigate the implications of big data in agri-food contexts. In their most recent publication, Bronson and Knezevic maintain that "agricultural big data receive relatively little policy or critical social science attention" (2019, p. 64), acknowledging the contributions of Carbonell (2016) and Carolan (2016). While there is growing attention across various social science disciplines, food studies literature is a particularly effective niche for digital farming research because of the rich and diverse literature on food systems. The 'food systems' concept is pervasive across food studies literature and transdisciplinary discussions about food and agriculture. The Food and Agriculture Organization writes, "food systems encompass the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption and disposal of food products that originate from agriculture, forestry or fisheries, and parts of the broader economic, societal and natural environments in which they are embedded" (FAO, 2018a, p. 1). Food systems describe the assemblage of actors and inputs in food production and consumption in a variety of ways (Ericksen, 2008). Colloquially, this concept is related to or even synonymous with more linear ideas of supply or value chains. However, I join a more holistic, complexity-informed perspective in food studies and STS. Food systems include interactions of cultivated and wild ecosystems, metabolic and physiological processes in organisms as food, co-production of knowledge and (agri)culture, intertwined political, economic, and financial systems in agri-food, and countless other complex systems with a multiplicity of scales and structures (Clapp, Desmarais, & Margulis, 2015; Ericksen, 2008; Iles, Graddy-Lovelace, Montenegro, & Galt, 2017; McKeon, 2015).

Complexity theory acts as a foundation to discuss the interaction of diverse systems across scales, and their emergent characteristics as "the whole is more than the sum of the parts" (Simon, 1962, p. 468). Complexity and systems thinking shape the conceptualization of this research problem and provide a foundational background to the thesis (Gibson, 2017; Holling, 2001; Kauffman, 1995, 2000; Ostrom, 2009; Simon, 1962; Walker & Salt, 2012). This scholarship is essential to the study of food systems and the implications of a digital agricultural revolution. In particular, complexity theory supports a conceptualization of food systems that understands the interconnection of systems and their emergent properties and challenges. For STS scholars and others studying the implications of technology beyond its material existence and desired aim, complexity supports the exploration of the ecological, social, cultural, political, and economic dimensions of technology (Guston et al., 2014; Jasanoff, 2004; Kranzberg, 1986; MacKenzie & Wajcman, 1999). The humility and an acceptance of uncertainty in systems literature is pertinent to the study, as there is much unknown in changing food systems and a complete understanding of the digital agricultural revolution and its implications is likely beyond epistemic limits (Gibson, 2017). Finally, transdisciplinarity and complexity support one another in research because complexity integrates multiple perspectives and transdisciplinary scholarship offers richer and more accurate interpretations of complex realities (Huutoniemi, 2014; Pohl, 2014).

Prominent food scholars postulate that the global food system is increasingly complex, distanced, and interconnected (Clapp, 2014; Clapp & Scott, 2018; D'Odorico, Carr, Laio, Ridolfi, & Vandoni, 2014; Howard, 2016; McKeon, 2015). In North America, the average meal travels an estimated 1,500 miles from field to fork (Clapp, 2016). Food provisioning relies on intricate transnational supply chains embedded in global political and economic relationships, which raises concerns for vulnerability to external shocks (Clapp & Scott, 2018; McKeon, 2015; Pretty, 2008; Rotz & Fraser, 2015). Volatility and fragility in the food system are amplified by climate change and unpredictable weather, as well as the infiltration of financial actors that undermine social justice and ecological sustainability (Clapp & Isakson, 2018; Clapp & Scott, 2018). The global food system is dynamic and evolving over time, but it is presently at the precipice of many thresholds across biophysical and social-economic systems (Holling, 2001; Ostrom, 2009; Raworth, 2012). The interlocking crises of climate change and ecological destruction, food insecurity and a growing population, and financialization and corporate power reside in complex systems. Given their complexity, uncertainty, and value-conflicts, these food system crises could be framed as wicked problems without a consensus on 'the problem' at hand or the possibility of a single optimal solution (Balint, Stewart, Desai, & Walters, 2011; Garnett, 2015). The rise of digital technologies and big data in food systems takes place within already complex systems and the implications of innovation and adoption to address wicked problems in the food system are uncertain and difficult to predict.

3.3 Terms and Concepts in the Digital Agricultural Revolution

Precision agriculture, smart farming, big data, and digital farming[16] are becoming buzzwords in agribusiness and the media, reflecting recent advances of agricultural technology (AAFC, 2018a; Bayer, 2019b; Bronson & Knezevic, 2016a; Fleming et al., 2018; Whale & Hand, 2019; Wolfert et al., 2017). Despite their popularity, the foregoing terms are typically ill-defined; however, clear definitions are essential to understanding this thesis and its contributions. Because of its longer history and perceived neutrality, *precision agriculture* is the most common and well-established term within and

[16] A longer list of terms is digital farming, digital agriculture, smart farming, precision agriculture, climate-smart agriculture, site-specific crop management, soil-specific farming, satellite farming, clean tech, sustainable intensification, sensors, internet of things (IoT), robots and artificial intelligence (AI), and cloud computing.

beyond academic discourses (van der Burg, Bogaardt, & Wolfert, 2019). The premise of precision agriculture is to use technology and data collection to inform more efficient, site-specific, and timely farm practices, to maximize yield and minimize environmental impacts (Bhakta et al., 2019; P. Roberts, 1999; Yost et al., 2019; Young, 2018). There is no uniform language to discuss the digital agricultural revolution; authors typically choose a term in accordance with the theoretical foundations and purpose of the study. Many publications in the emerging social sciences literature use *smart farming* to describe the use of digital technologies to inform holistic farm management and decision-making (Eastwood et al., 2017; Regan, 2019; Wolfert et al., 2017). Alternatively, others use *big data* as the central concept to explore the changing landscape of food systems (Bronson & Knezevic, 2016a; Carbonell, 2016; Carolan, 2018a; Weersink et al., 2018). I argue that *digital farming* is most the effective terminology because it stresses the interconnection of machinery, digital technology and software, and big data applications changing agriculture.

3.3.1 What is Digital Farming?

Digital farming refers to the complex assemblage of systems, drivers, and implications of the emerging digital technologies in agriculture. This assemblage includes the use of computers and smartphones for information access and gathering, the use of satellite positioning and imaging software for farm management and analysis, integrating computers and sensors into farm machinery, collection and analysis of big data, as well as robots and machine learning to replace farm labour, among many other applications. Digital farming harvests massive amounts of data that interact with the agricultural practices of a particular site, the transfer of this data with service providers, as well as decision-making at the farm-level and the corporations who are privy to the information (Pivoto et al., 2018; Wolfert et al., 2017; Wolfert, Goense, & Sorensen, 2014). In the past few years, the rise of digital farming has begun to transform agricultural practices and change the face of the global food system.

In technical terms, digital farming technologies originated in the 1980s with the rise of precision agriculture technology, and have since grown to be applied across millions of acres across the globe (Mulla & Khosla, 2016). John Deere, the largest farm machinery TNC, only began investing in GPS and data collection in 2001, but Massey-Ferguson (a subsidiary of AGCO, the fourth largest farm machinery firm) has been digitizing field data since 1982 (Mooney, 2018). In the 1990s, the adoption of precision agriculture practices grew rapidly, particularly in Canada and the US, with the use of satellite imaging, GPS enabled real-time kinematic (RTK) 'auto-steer' tractors, and early versions of variable rate application (VRA) and yield monitor technologies (Balafoutis et al., 2017; Griffin & Yeager, 2019). The accelerated adoption of precision agriculture in North America is attributed to a combination of factors including: increasing size of crop farms, appetite for entrepreneurship and innovation in agri-food, accessibility of loans and financing options for farmers, and the relative economic stability of large industrial farming operations (Balafoutis et al., 2017; Mulla & Khosla, 2016). The uptake and evolution of digital farming stalled in the early 2000s (McBratney, Whelan, Ancev, & Bouma, 2005; Mulla & Khosla, 2016). But, in the past decade, adoption grew alongside advances of robotics, the decreasing costs of sensor technology, and computing capabilities for collecting and analyzing massive volumes of data, and the influence of digital technologies and big data in the food system continues to rise (Balafoutis et al., 2017; Weersink et al., 2018). In 2017, the global precision agriculture[17] market was estimated at $4.18 billion USD, and it is projected to grow to $10 billion USD in the next five years (IMARC Group, 2018; PR Newswire, 2018). In the larger agri-food technology sector, developers accumulated $16.9 billion USD in venture capital over 2018 to innovate digital farming, 3D food printers, online food retail platforms, and other technology across the food system (AgFunder, 2019).

The conceptualization of digital farming in this thesis is distinctive because of the complexity-informed perspective. This definition is in conflict with the general understanding of digital farming in public discourse and across most STEM research, which prioritize technical realities and often omit other dimensions. According to the emerging social sciences literature on digital farming, it is imperative to consider the emergent ecological, social, ethical, political, and economic systems that interact with the material realities of the technology (Bronson & Knezevic, 2016a; Carolan, 2016; Eastwood et al., 2017; Regan, 2019). The brief history above illustrates that economic conditions influence innovation and adoption (e.g., cheaper sensors leads to wider adoption), but it is essential to consider the various drivers of the digital agricultural revolution and the implications across complex systems, to have an accurate view of the phenomenon.

The motivations for digital farming adoption and the implications for farming practices are complex, emergent, and unpredictable. For instance, the effectiveness of agricultural and environmental policy tools interacts with technology. The policy context and priorities of farmers influence the impacts of digital farming. According to a whole-farm study of large corn and soybean operations, carbon or nitrogen taxes and other policy tools failed to reduce environmental impacts when precision agriculture technologies were in use (Schieffer & Dillon, 2015). While more abstract, there are also very real interactions of digital farming with social systems, such as knowledge and culture (Tsouvalis et al., 2000). According to STS scholars and others studying technology in the social sciences, technologies are inextricable from the ways of knowing and being through which they are created and

[17] The report cited includes GPS, GIS, remote sensing, and VRA hardware and software applications in farming.

those that they create (Funtowicz & Ravetz, 2003; Guston et al., 2014; Hird, 2012; Pinch & Bijker, 1989; Singleton & Law, 2013). For example, the values and concerns of developers influence what information is collected in digital farming; a focus on yield and production data can promote economic priorities and continue the dominance of industrial agricultural (Bronson, 2019; Carbonell, 2016). Technology is not value-neutral and it will necessarily have consequences beyond its intended purpose (Kranzberg, 1986; MacKenzie & Wajcman, 1999).

3.3.2 What is Big Data?

For better or for worse, "the era of Big Data has begun" (boyd & Crawford, 2012, p. 633). The amount of information in the age of big data is difficult to comprehend. For example, Walmart, produces 2.5 petabytes[18] of customer data *every hour* (Carolan, 2018b). Globally, 2.5 quintillion bytes[19] of data are produced each day, and there was more information generated in the past few years than in all preceding human history (Chi et al., 2016; Marr, 2018). Big data is integral to the development of digital farming equipment. Eric Hansotia, the Senior Vice President of one of the largest farm machinery firms, speaks to the data power of AGCO's IDEAL combine launched in September 2017: "This is the most complicated product in the industry… The amount of intelligence on this combine is 5 million lines of code. The first space shuttle that went up had a half-million lines of code" (Hearden, 2018).

Despite increasing popularity across public, private, and academic discourses, the term 'big data' is often used without a clear definition (boyd & Crawford, 2012; Bronson & Knezevic, 2016b; Carolan, 2016; Kitchin, 2013). Firstly, 'data' can be understood as "anything recordable in a relational database in a semantically and pragmatically sound way" (Frické, 2015, p. 652). Data are generated or constructed, and they cannot be separated from their social context and constructs (Bronson & Knezevic, 2016a). Every field of research collects and studies data of some form. Various apparatus or instruments collect data, and then established statements or 'facts' are used to interpret the information (boyd & Crawford, 2012; Frické, 2015). Data cannot be evidence *simpliciter*; for data to be meaningful, it is necessarily shaped by embedded epistemological frameworks and assumptions, often in the form of statistical models (Frické, 2015).

Big data shares these characteristics, although it refers to a much larger scale. As the term suggests, big data refers to unprecedented accumulation and availability of data, which are beyond the capabilities of traditional computer processes (Wolfert et al., 2017). The criteria for big data are volume (size), velocity (collection and processing speed), variety (diverse, multi-source), and veracity (quality,

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[18] 1 petabyte = 1,000,000 gigabytes (1 million GB) = 1,000,000,000,000,000 bytes

[19] 1 exabyte = 1 quintillion bytes = 1,000,000,000 gigabytes (1 billion GB) = 1,000,000,000,000,000,000 bytes

accuracy, reliability) – though the concepts and challenges of big data apply without the presence of all characteristics (Chi et al., 2016; Kamilaris, Kartakoullis, & Prenafeta-Boldú, 2017; Kitchin, 2013). In applications to agriculture, the capacity to collect, access, aggregate, cross-reference, and analyze vast quantities of information is more important to 'big data' than the volume of information (boyd & Crawford, 2012; Kamilaris et al., 2017; Wolfert et al., 2017). Moreover, what counts as 'big' data continues to evolve, as information that satisfies the volume criteria today will likely be small in the near future (Carolan, 2016).

In line with the understanding of digital farming, big data is far more than its technical definitions. Big data exists as a complex cultural, technological, and epistemological phenomenon, which is the sum of technological developments, changes in analysis and management of data sets, and emerging ways of knowing (boyd & Crawford, 2012; Frické, 2015; Kitchin & Lauriault, 2015). The accumulation of information about farm-level crop production and weather is the foundation of digital farming (Carolan, 2016; Weersink et al., 2018). Big data can refer to the massive accumulation and analysis of data by the corporations offering digital farming services, but it can also include the data collected on-farm, which may or may not be 'big' data. Digital farming technologies rely on data collection to inform decisions on stewardship and farm management. Data collection in agriculture is not new, but the capacities of big data may transform agricultural practices and farmer identities, shaping a more 'data-driven' and scientific view of farming (Bronson, 2019; Pivoto et al., 2018; Regan, Green, & Maher, 2018; Zhang, 2016). Furthermore, big data gathers information about present conditions, but can also analyze historical trends and make predictions, which has applications for farmers as well as TNCs across the food system (Carbonell, 2016).

3.3.3 Digital Farming Adoption

Digital farming does not refer to any single technology, but rather a suite of tools that alters agricultural practices with the aid of digital technologies and new sources of data for decision-making. The diversity of technology available, buzzwords inconsistencies, conceptualization discrepancies, and the ubiquity of technology in everyday life make digital farming adoption difficult to measure. Farmer perceptions of adoption and future intent to adopt pose additional challenges. Across Canada, GPS, auto-steer, and Geographic Imaging System (GIS) are the most common applications of digital farming, though adoption depends on farm size (Statistics Canada, 2017c). For operations smaller than 500 acres, 21.4% of farmers use GPS, 11.2% of auto-steer, and 6.2% use GIS, but for farms over 10,000 acres the adoption rates are 97.1%, 93.6%, and 52.7% respectively (Statistics Canada, 2017c). Likewise, the US Department of Agriculture finds that larger farms have higher rates of digital farming adoption; corn farms over 2,900 acres have double the adoption rates of smaller farms (Schimmelpfennig, 2016). The

Government of Canada estimates that 13.8% of Ontario farmers use auto-steer equipment (Statistics Canada, 2017a). Statistical analysis of 2016 Census of Agriculture data concludes that 56% of Ontario farmers use computers, 39% use smart phones, 32% use GPS, 16% use auto-steer, and 12% use GIS mapping (Duncan, 2018). A recent 62-questionnaire study of Ontario crop farmers found that 96% of respondents use some form of digital farming (Mitchell, Weersink, & Erickson, 2018). The current statistics on digital farming adoption in Canada are limited and more empirical research is required to have a better understanding of the digital agricultural revolution. While it is not the focus of the thesis, the data on adoption offers an additional contribution and enriches the description of farmer perceptions.

In the social sciences, much of the empirical research on digital farming measures the extent or motivations of adoption using survey approaches. In reviewing the available literature, Bronson concludes that, "the market for smart farming technologies is bifurcated between large, commodity farms whose managers are adopting these tools, and smaller-scale, unconventional growers whom are not adopting at equal rate" (2019, p. 2). Many studies perpetuate the idea that the typical digital farming adopter is "an educated farmer, owner of a larger farm with a good soil quality, and aiming to implement more productive agricultural practice to face growing competitive pressures" (Pierpaoli, Carli, Pignatti, & Canavari, 2014, p. 64), although there is usually acknowledgement of more diverse realities. Many studies assert that older farmers are less likely to adopt new technology (D'Antoni, Mishra, & Joo, 2012; Feder & Umali, 1993; R. Roberts et al., 2004). However, Tey and Brindal find that the relationship between age and adoption is inconsistent (2012). The farmer's level of education, size of the operation, and land tenure are more consistently positive influences on adoption, as the increased capacities and capital reduce barriers and alleviate risk (R. Roberts et al., 2004; Tey & Brindal, 2012). Another important factor is the size of the operation, where large farms have a significant advantage because they are more likely to have financial resources available for investment in digital farming and the equipment is designed with them in mind (Bronson, 2019; Jensen, Jacobsen, Pedersen, & Tavella, 2012; Lambert, Paudel, & Larson, 2015; Reichardt, Jürgens, Klöble, Hüter, & Moser, 2009).

Furthermore, there is a growing understanding that the motivations of adoption are much more complex than individual farmer characteristics, and adoption rates vary with the type of technology. Some digital farming tools require more technological knowledge and skills than others. Farmers are more likely to adopt embodied-knowledge technology like auto-steer than information-intensive technology like yield monitors, where the benefits of the former rely on knowledge and capacities of operators (Griffin & Yeager, 2019). Another adoption study finds that the farmer's behavioural attitude – such as perception of the technology's ease of use and personal innovativeness – is the most influential predictor of adoption (Far & Rezaei-Moghaddam, 2018). Other factors in adoption studies include knowledge and familiarity with technology, perceived future importance of precision agriculture, perceived difficulty or ease of adoption, credit and borrowing capacity, risk management attitude, and compatibility with existing equipment (Aubert, Schroeder, & Grimaudo, 2012; D'Antoni et al., 2012; Far & Rezaei-Moghaddam, 2018; Feder & Umali, 1993; Pierpaoli et al., 2014; Tey & Brindal, 2012).

One of the most significant barriers to adoption cited in the literature is the cost of the digital farming machinery and services (D'Antoni et al., 2012; Silva, de Moraes, & Molin, 2011; Tey & Brindal, 2012). Other barriers to adoption include smaller, more diverse, or fragmented farm operations, not owning farmland, insufficient knowledge of digital technology, lack of trust, lack of training, and lack of support or skilled staff – common conditions of small-scale farms in less industrialized settings (Bhakta et al., 2019; McBratney et al., 2005; Mondal & Basu, 2009; Wolfert et al., 2017). In addition, despite some success in demonstrating marginal decreases in environmental impact through the adoption of digital farming, several studies suggest that there is very little evidence of economic benefit or return on investment for the technology at this time, even large crop farms (Weersink et al., 2018; Yost et al., 2019). There are also several technical and organizational obstacles to widespread adoption, namely data security and lack of rural connectivity (Fleming et al., 2018; Weersink et al., 2018; Wolfert et al., 2017). Connectivity is a persistent challenge for Ontario farmers, although there are initiatives at the federal and provincial level to improve internet access in rural communities (Collins, 2018; Government of Canada, 2016). Economic factors remain primary in the study of drivers to adoption. For instance, Aubert et al. find that farmer voluntariness as well as perceptions of ease of use and usefulness do not overcome resource constraints (Aubert et al., 2012). Still, decision-making for adoption is embedded in social conditions and innovation systems beyond the individual farmer's operation, including levels of coordination across entities in food systems and changing market conditions (Aubert et al., 2012; Bronson, 2019; Eastwood et al., 2017; Pierpaoli et al., 2014). Considering this evidence, there are complex factors in adoption, beyond the individual characteristics of farmers. The experiences and perceptions of farmers are essential to understanding the digital agricultural revolution and its implications (Fleming et al., 2018).

3.4 Outlining Key Narratives in Public Debates on Digital Farming

The rise of digital technologies and big data in the food system prompt policy debates on digital farming. These debates are pertinent to understanding the experiences and opinions of farmers because they influence public perceptions of agricultural technologies. Public discussions of digital farming, as represented in academic and grey literature, present conflicting narratives of proponents and critics. In line with the first research objective, this section will outline the key narratives in digital farming debates, prior to the analysis of central themes in relevant academic literature.

3.4.1 Who are the Proponents and What are Their Claims?

Supporters of digital farming are diverse, spanning corporate elites, start-up founders, government officials, academics from various disciplines, journalists, and even some farming organizations. Arguably, the most forceful and influential proponents of digital farming are those developing the technology. TNCs in agricultural inputs and farm machinery sectors, as well as large venture capital firms, are making significant efforts to invest in digital farming and innovate new technologies (Bronson & Knezevic, 2016b; Weersink et al., 2018; Wolfert et al., 2017). Globally, there are over 1,600 digital farming start-ups, with a diversity of products for agronomic data collection, farm management, financial operations, and other applications (Day, 2019). Since 2010, global investments in agri-food technology start-ups exceed $14 billion (WEF, 2018). As Wolfert et al. note, "start-ups are at the heart of the action," but traditional agribusiness and other industry actors are powerful actors shaping the digital agricultural revolution (2017, p. 75).

Many of the big players in agribusiness own digital farming technology or partner with developers: for example, the top companies in the seed and chemical, fertilizer, and farm machinery sectors – BASF, Nutrien Ag Solutions (previously Agrium), and John Deere – each launched their own digital farming platforms – Maglis, Echelon, and FarmSight, respectively (Mooney, 2018; Pham & Stack, 2018). Another top seed and chemical company, Bayer, states that in the past two years, "Canadian farmers across 4 million acres have experienced the value of the platform's [Climate Fieldview] data-driven, digital tools to help address the many decisions they make each year to optimize productivity," illustrating their reach and influence on the proponent narrative (Bayer, 2018c). Furthermore, TNCs who are proponents of digital farming extend beyond traditional agribusiness. International Business Machines Corporation (IBM) supports innovation and adoption of digital technologies and big data applications in the food system; for instance, IBM developed Walmart's permissioned (one-way) blockchain[20] to improve supply chains traceability, safety, and efficiency (IBM, 2018b, 2018a). In addition to IBM, many non-food TNCs, including Google and Microsoft, are making advances to shape the future of food (Antle, Jones, & Rosenzweig, 2017; Baird, 2018; Chandra, 2018; IBM, 2018a, 2018c; Microsoft, 2015). From marketing materials to press releases and corporate publications, industry frames digital farming as an innovative solution to the big challenges in agri-food systems.

[20] Blockchain is an encrypted digital record of transactions or data that can be shared, but never altered. In a permissioned blockchain, farmers must provide information to Walmart, but they cannot see up the chain.

Outside of industry, there are many notable supporters with moderate influence in digital farming debates. Across municipal, provincial, and federal levels, governments generally present as proponents. Investment and programs from the federal government demonstrate support for further development and implementation of digital technologies in agriculture. For instance, the Advisory Committee on Economic Growth of the Government of Canada outlines several avenues for data and technology in agriculture, with an emphasis on public-private innovation (ACEG, 2017). In 2018, Agriculture and Agri-Food Canada announced a $25 million investment program entitled the Agricultural Clean Technology, which prioritizes precision agriculture (AAFC, 2018a). Coupled with the $155 million Clean Growth Program and the five-year Agricultural Greenhouse Gas Program, these investments exhibit a trend of government support for research and development of technologies, practices, and processes that can reduce GHG emissions in agriculture and work toward 'clean growth' (AAFC, 2018b; Natural Resources Canada, 2019). Likewise, at the provincial level, digital farming is central to Ontario's Agricultural Soil Health and Conservation Strategy (OMAFRA, 2018). There are also initiatives for education and innovation around digital technologies at regional levels (Gowan, 2018; McDonald, 2015). Named a Top 7 Intelligent Community in 2017 and one of the Smart 21 Communities in 2016, Grey County in Ontario is attracting international attention for its agricultural technology community programs (Grey County, 2017).

Moreover, farmers can also be digital farming proponents on their farms, in their communities, and for social media followers. Ontario farmers are setting their own narrative by organizing conferences and developing entrepreneurial ag-tech ventures (A&L Canada Laboratories, 2018; Devron UAS, 2019; Farms.com, 2019; SoilOptix, 2019). Farmer organizations, including Grain Farmers of Ontario and the Ontario Federation of Agriculture are conducting research and programing to support the adoption of technology on farms and in rural Ontario (Collins, 2018; GFO, 2019a; OAFT, 2018; Schaer, 2017). However, there is little research on farmer experiences of digital farming in Ontario (Duncan, 2018).

Digital farming proponents share several common promises and make similar arguments. Despite the diversity of experiences and perspectives, there is a dominant narrative of proponents threaded through the debates: *Digital farming promises to improve agricultural efficiency, productivity, and profits, while addressing the challenges of a growing population and a changing climate*. The most common and influential promises are those relating to economic dimensions of agricultural production. There is an explicit valuation of growth and profits, especially across industry and government perspectives. According to proponents, digital farming innovations "help farmers sustainably enhance yield potential, improve efficiency, and manage their risk" to "maximize their return on every acre" (The Climate Corporation, 2019). Furthermore, TNCs promise that the benefits are not limited to large industrial farmers; for instance, Bayer highlights its crop protection cellphone applications for farmers in India and Ghana in their *Crop Science* publication (Bayer, 2018a). While the focus is on agricultural productivity, proponents are making claims that digital farming is a 'solution' or 'fix' to the challenges and crises facing food systems across scales: agricultural productivity, growing populations, food security, food waste, climate change, economic wellbeing of farmers (Bayer, 2019b; Foresight, 2011; Rotz, Duncan, et al., 2019; van der Burg et al., 2019; Wolfert et al., 2017; Zhang, 2016). Yara, a leading fertilizer company, states, "The digital revolution in agriculture will allow a step-change in the optimum use of crop nutrition products, which help to feed the world and protect the planet" (2019a). Likewise, the Government of Canada promises that investment in digital farming "will contribute to Canada's place as a world leader in agricultural clean technology, helping farmers to develop new and efficient uses of energy, while also protecting our environmental resources and mitigating climate change," in parallel with the narratives of industry (AAFC, 2018a).

3.4.2 Who are the Critics and What are Their Concerns?

The interpretive analysis of academic and grey literature on digital farming reveals that the proponent narrative is dominant in public debates, given the volume of literature proponents produce, the avenues of discussion to which they have access, and their power in society. However, there are communities standing in solidarity as adversaries or opponents of digital farming and its supporters. Even at farmer-organized digital farming events, like Grey County's Ag 4.0: Digital Agriculture Conference or Farms.com's Precision Agriculture Conference, among many other annual meetings, many farmers express doubts, anxieties, and skepticism about digital farming. While some farmers identify as proponents of digital farming, many others are opposed to the technology for various reasons. For example, in response to restrictions and laws imposed by TNCs developing digital farming machinery, 'Right to Repair' and other farmer movements are calling for farmer autonomy and control over their machinery, often centered around the right to fix or modify their own equipment (Carolan, 2018b; Koebler, 2018; Wanstreet, 2018). Accordingly, farmer groups like Farm Hack are building communities to share data, hacks, and strategies to maintain control of their operations in the digital agricultural revolution (Farm Hack, 2018).

The general category of critics contains a diversity of perspectives. Though digital farming critics express doubts or concerns about the rise of digital farming in the current system, some remain optimistic. Organizations such as Ontario Agri-Food Technologies (OAFT) are skeptical of digital farming promises, particularly regarding the implications for farmer autonomy and economic wellbeing (Whale & Hand, 2019). However, OAFT does not oppose the digital revolution of agriculture. Instead, OAFT develops several initiatives to support farmers and help them to take advantage of technology, such as the Canadian Digital Agri-Food open platform for sharing and using agricultural data (Schaer, 2017). At the Farms.com Precision Agriculture Conference in February 2019, Dr. Tyler Whale, CEO of OAFT, presented the organization's progress in developing a new data-sharing platform, AgBox, where those generating the data have ownership and control (Whale & Hand, 2019).

Some civil society organizations are making clear arguments to oppose digital farming; there are several public reports outlining the dangers of the digital revolution of agriculture. For example, the Action Group on Erosion, Technology and Concentration (ETC Group), an international organization researching the impacts of technological change and corporate power in the food system, authors numerous publications and reports on this topic (ETC Group, 2015, 2016, 2018; Mooney, 2018; Mooney & ETC Group, 2015). In the ETC Group report *Blocking the chain: Industrial food chain concentration, Big Data platforms and food sovereignty solutions*, Mooney (2018) explores the impacts of corporate concentration. Mooney views technological developments as inevitably reinforcing the power relations in the food system and the political power of 'objective science' in justifying technological innovation. There are other groups making similar arguments against digital farming and other biotechnology such as GM seeds (e.g., IPES-FOOD, 2017). Leading up to the Bayer-Monsanto merger, SumOfUs, Friends of the Earth, and the Open Markets Institute collaborated to draw attention to the consequences of corporate concentration and the interweaving of agricultural inputs and technologies (Bassetti et al., 2017). Likewise, the digital agricultural revolution was the primary focus of the *Right to Food and Nutrition Watch* annual publication in 2018, focusing on the intertwined implications of dematerialization, financialization, and digitalization in food (Morena, 2018).

Moreover, while governments in Canada are primarily optimistic about digital advances and applications of big data in the agri-food sector, others are more critical (Bogaardt, Poppe, Viool, & Zuidam, 2016; van der Burg et al., 2019). For instance, European Parliamentary Research Service published a report on the legal, social, and ethical implication of digital farming, making a series of recommendations for legislation and codes of conduct (Kritikos, 2017). The analysis and underlying assumptions of this government report align with scholarly debates on digital farming, as introduced in the first chapter. For instance, they state, "technology in itself is neither good nor bad, it is the way in which it is used that determines the effect," but they express significant concerns for the implications of digital farming in current power structures (Kritikos, 2017, p. 55).

Taken together, digital farming critics are calling attention to various environmental, social, political, and economic concerns. The narratives are skeptical of the promises of digital farming, questioning the goals and motivations of proponents (van der Burg et al., 2019). There is also a persistent concern for the distribution of risks and benefits in the digital agricultural revolution (Jakku et al., 2018; Regan, 2019; van der Burg et al., 2019). The interpretive analysis of the public debates highlights the importance of corporate power, data access and ownership, labour and quality of life, and sustainability. I will now turn to the academic literature to analyze narratives in public debates and establish a theoretical foundation for the study.

3.5 Surveying Themes in Academic Literature on Digital Farming

Building on the analysis of digital farming as a complex phenomenon, the remainder of this chapter will highlight central topics and themes in the transdisciplinary social science research on the digital agricultural revolution. As mentioned above, most of the literature on digital farming is within the STEM disciplines, proliferating alongside the development of precision agriculture technologies since the late twentieth century (Blackmore, 1994; Roberts, 1999; Sonka & Coaldrake, 1996; Wolf & Buttel, 1996). Generally, digital farming research from a STEM perspective focuses on technical realities, supporting the narratives of digital farming proponents. Numerous studies published in the past two decades attempt to demonstrate positive environmental and economic impacts of digital farming with varying levels of success (Balafoutis et al., 2017; Bongiovanni & Lowenberg-Deboer, 2004; Kamilaris et al., 2017; Plant, Stuart Pettygrove, & Reinert, 2000; Schieffer & Dillon, 2015; Yost et al., 2019). Despite growing attention in transdisciplinary social sciences, publications advocating for digital farming adoption from STEM perspectives continue to outnumber digital farming research that considers implications beyond technology's intended impact.

With the exception of a couple early political economy articles on precision agriculture (Wolf & Buttel, 1996; Wolf & Wood, 1997), the majority of digital farming literature in the social sciences is from the past few years. This thesis joins what Carolan called a "nascent but growing body of scholarship" in the social sciences exploring big data and the digital agricultural revolution (2018b, p. 750). Contrasting with the proponent narrative in most STEM research, many social scientists are more skeptical and propose critiques of digital farming and its implications (Bronson, 2018; Carbonell, 2016; Carolan, 2018b; Eastwood et al., 2017; Rotz, Gravely, et al., 2019). Others present a much more neutral, or even positive, stance (Duncan & Fraser, 2018; Rijswijk et al., 2018; Weersink et al., 2018; Wolfert et al., 2017, 2014). Although the literature featured in this review spans a diversity of disciplinary perspectives and conflicting conclusions, there is a commonality in the research topic and the centrality of the following four themes: power, data, labour, and environment.

3.5.1 Power Relations: Corporate Concentration, Technology, and Industrial Farming

In the relevant literature on digital farming, power is a fundamental theme and topic of research, particularly the role of corporations and whether or not technological change will reinforce and reproduce existing uneven power relations in the food system (Bronson, 2018; Bronson & Knezevic, 2016b; Carbonell, 2016; Rotz, Duncan, et al., 2019; Rotz, Gravely, et al., 2019). The focus on power relations is not surprising considering the academic traditions in which the research is situated, namely political economy, sociology, and food studies. Prior to the rise of digital farming, these three disciplines have decades of theorizing power relations, including those pertaining to corporations and technology in agri-food. Thus, many scholars theorizing the digital agricultural revolution draw from existing literature outside of the digital farming discourse.

Corporate concentration in the food system reinforces the power of TNCs and the dominance of industrial agriculture (Clapp, 2018; Clapp & Fuchs, 2009; IPES-FOOD, 2017). There is a long history of concentration in agri-food sectors. The dominance of Arthur Daniel Midland, Bunge, Cargill, and Louis-Dreyfus – collectively ABCD – in global commodity-trading (e.g., grains) markets dates back to the late-1800s; ABCD now controls approximately 90 percent of the market (Clapp, 2015; Howard, 2016). However, there is now a marked increase in corporate concentration across the food system, with unprecedented megamergers and acquisitions in recent years (IPES-FOOD, 2017). Through mergers and acquisitions of hundreds of companies in the 1990s and early-2000s, the top six ag-input companies[21] already controlled 75 percent of the agrochemical market by 2009 (Clapp, 2018; IPES-FOOD, 2017). Today there is consolidation across these massive firms, illustrated by the $133 billion USD Dow-DuPont merger in 2017, ChemChina's acquisition of Syngenta for $43 billion USD in 2017, and Bayer's acquisition of Monsanto for $66 billion USD in 2018. In addition, John Deere, Kubota, CNH, and AGCO control 56 percent of the farm machinery market, with burgeoning alliances between agricultural input and farm machinery companies; John Deere collaborates with each of the Big Six ag-input firms (ETC Group, 2015; Mooney, 2018).

Drivers of corporate concentration include technological innovations (e.g., digital farming platforms), development of complementary biotechnology (e.g., pesticides and pesticide-resistant GM seeds), and financialization[22] (Clapp, 2018; Clapp & Isakson, 2018; Howard, 2016). In the global food economy, corporate concentration and financialization are inextricably linked. Financialization can

[21] BASF, Bayer, Dow, DuPont, Monsanto, and Syngenta are the 'Big Six' ag-input firms, where agricultural inputs include seeds and agrochemicals such as pesticides and fertilizer (ETC Group, 2015).

[22] Epstein defines financialization as "the increasing role of financial motives, financial markets, financial actors, and financial institutions in the operation of the domestic and international economies" (2005, p. 3).

trigger or accelerate corporate concentration; financial actors, such as institutional investment firms, commonly invest in or own agri-food companies and can exert power to demand a restructuring of the market through mergers and acquisitions to maximize profits (Clapp & Isakson, 2018). According to agri-food and farm machinery TNCs, megamergers are essential to develop the technology required to feed the world and face the challenges of climate change (Clapp, 2018; ETC Group, 2015; Mooney, 2018). However, research suggests that financialization and corporate concentration in the food system prioritize short-term economic gains over long-term priorities, with detrimental effects on food security, farmer autonomy, sustainability, and justice in the food system (Clapp & Isakson, 2018; ETC Group, 2015; IPES-FOOD, 2017; Mooney & ETC Group, 2015). Corporate concentration and the stronghold of industrial agriculture reinforce one another, perpetuating the known environmental consequences of large, agrochemical-intensive, monocrop farming (Clapp, 2018; Clapp & Fuchs, 2009; Garnett, 2013).

Powerful TNCs in the agricultural inputs and farm machinery, as well as the financial actors underpinning them, are engaging in developments, acquisitions, and investments in digital farming (IPES-FOOD, 2017; Mooney, 2018; Wolfert et al., 2017). In a landscape of venture capitalism and corporate concentration, there are complicated histories of investment and acquisition in digital farming (Clapp, 2018; Clapp & Fuchs, 2009; Howard, 2016; McMichael, 2000). Trimble is one of many cases of digital farming companies growing and evolving by buying up their competition. Founded as a three-person start-up in 1978, today Trimble supplies equipment and software to farms internationally, holds over 1,000 patents, and owns over 50 other companies, including several Canadian businesses (Trimble, 2019). Another early innovator of digital farming technology, The Climate Corporation of Climate Fieldview, followed a more complicated path. Founded as a start-up in 2006, The Climate Corporation grew quickly and developed farm management software and insurance services, then was acquired by Monsanto in 2013 for $930 million US (Bronson & Knezevic, 2016b; Carolan, 2018b). Maintaining its operational independence, The Climate Corporation acquired 640 Labs and Solum in 2014 (The Climate Corporation, 2017). In 2018, Bayer acquired Monsanto for $66 billion, with The Climate Corporation as a subsidiary, despite procedural opposition due to corporate concentration concerns (Bayer, 2018d; Jones, 2017; Mooney, 2018). In the integrated global food economy, digital proponents are not limited to those developing and selling digital farming machinery. Industry lines are blurred in the digital agricultural revolution; not only are there megamergers in already concentrated sectors, but there are also mergers and reciprocal relationships across seed, pesticide, fertilizer, farm machinery, and information technology sectors (Mooney, 2018; Pham & Stack, 2018).

Previous research examines the role and implications of corporate power in driving technological change in food systems (e.g., Brooks, 2005; Chopra, 2015; Clapp, Newell, & Brent, 2018; Fraser et al., 2016; McKeon, 2015; Tourangeau & Smith, 2015; Williams, 2009). Technology and industrial agriculture have been central to the rise of the productivist paradigm, since the 1950s (De Schutter, 2014). Productivism refers to the pursuit of maximizing production as the ultimate aim of agriculture in line with worldviews prioritizing economic growth and modernization, with an unquestionable faith in science and technology (Burton, 2004; De Schutter, 2014; McKeon, 2015). In this view, increasing production is a *value*, good without qualification; thus, productivism is implicitly a moral stance, although it claims to be apolitical (Thompson, 1995). The dominant paradigm perpetuates the "myth of value-neutrality," where the objectivity and reason of science and technological innovation cannot be questioned and progress is inevitable (Huesemann & Huesemann, 2011b, p. 235), even though sociologists, philosophers, and historians of science offer extensive theory to explain the ways in which science is value-laden and socially constructed.[23]

In line with the existing research on corporate power and technology in agri-food contexts, there is a prevalent theme in the academic literature exploring the political dimensions of digital farming in criticizing the productivist paradigm of digital farming proponents (Carolan, 2018b; Mooney, 2018; Morena, 2018; D. C. Rose et al., 2018; Rotz, 2018). For instance, Bronson highlights the similarities between the productivist priorities of boosting productivity through innovations of GM seeds and chemicals in the second half of the twentieth century and recent advances of digital farming, exemplified by the industrial productivity-maximizing farms envisioned in John Deere's *Farm Forward* video (2018). While the proponents above argue that digital farming is a new and innovative solution, they build their claims and promises on the existing infrastructure of productivism in the global food economy, namely a value of continued economic growth through increased production and an unquestionable faith in science and technology. Early iterations of productivism, such as President Truman's famous inaugural speech,[24] echo in the language and arguments of digital farming proponents today (AAFC, 2018a; Bayer, 2019b; Proagrica, 2018a; The Climate Corporation, 2015; Yara, 2019b).

Despite the expansive literature on corporate power and technology in the agri-food sector more generally, the research examining the power dynamics of digital technologies and big data in agri-food is only just recently developing (Bronson, 2019; Carolan, 2019). Carolan remarks, "this relative silence among critical agro food scholars is made even more pronounced when one considers how much research colleagues in the information and crop sciences do on the subject, whom all evaluate practices

[23] See, for instance, Haraway, 2016; Harding, 2006; Hird, 2012; MacKenzie & Wajcman, 1999; Merchant, 1980; Pinch & Bijker, 1989; Puig de la Bellacasa, 2017; Thompson, 1995; and Worthy et al., 2019.

[24] Truman proclaims, "*Greater production* is the key to prosperity and peace. And the key to greater production is a wider and more vigorous application of *modern scientific and technical knowledge*" (1949, *emphasis added*).

through a distinctly productivist lens" (2016, p. 138). Today, social sciences research is proliferating quickly and there are many studies currently underway, in Canada and elsewhere. Scholarly debates are carving out new research areas as the discourses evolve. For example, in her recent digital farming study, Bronson evaluates that "social scientists have predominantly assessed the implications of the use or governance of digital agricultural tools, rather than the ways in which power and authority may be built right into their design" (2019). Many unanswered questions remain about power in the digital agricultural revolution and implications for farmers.

This thesis joins emerging scholarly debates on power dimensions of digital farming. There are differing views on the effects of corporate power and the futures that may be possible. Many leading scholars on digital farming call attention to corporate power and the continuation of productivist agriculture paradigms in dominant portrayals of digital farming, including the proponent narrative and promises reviewed in the previous section (Bronson, 2018; Carolan, 2018b; D. C. Rose et al., 2018; Rotz, Gravely, et al., 2019). Some research suggests that digital farming could support a return to more agroecological and sustainable farm practices (Balafoutis et al., 2017; Bongiovanni & Lowenberg-Deboer, 2004; Kamilaris et al., 2017; Rotz, Duncan, et al., 2019; Weersink et al., 2018). Even so, most research in this space predicts that digital farming will reinforce intensive, industrial modes of production and farm consolidation, eroding farmer autonomy and environmental sustainability (Bronson, 2018; Bronson & Knezevic, 2016a, 2019; Carolan, 2018b, 2019; Mooney, 2018; Morena, 2018; Wolf & Buttel, 1996; Wolf & Wood, 1997; Wolfert et al., 2017; Zundel & Ribeiro, 2018).

Generally, the literature reviewed outlines how the power of TNCs developing digital farming technology continues a trend of farmers losing control over their operation and becoming increasingly dependent on corporations, from the intellectual property laws of GM seeds, to user agreements making it illegal for farmers or third-party actors to service or repair digital farming tractors (Carbonell, 2016; Carolan, 2018a; Piesse & Thirtle, 2010; Wanstreet, 2018). Recent research examines the rise of farmer movements in the US and the UK to reclaim power from corporations, advocating for the rights of farmers to own their data and repair machinery as they see fit (Carolan, 2018b; Rotz, Duncan, et al., 2019). However, the views of farmers and perceptions of digital farming from other actors in the food system are not easily categorized. Empirical studies in Australia, New Zealand, Ireland, the UK, and the US reveal several conflicting narratives even within farmer populations (Carolan, 2016, 2018b; Eastwood et al., 2017; Fleming et al., 2018; Regan, 2019; Rijswijk et al., 2018). Further research is needed to understand the implications of digital farming for farmers and complexities of power in the future of food. The following sections will discuss three themes in the emerging digital farming literature – data concerns, labour, and environment – that can be discussed in the context of power.

3.5.2 Data and Knowledge: Ownership, Access, Privacy, and Governance

One of the most prevalent themes in the emerging social science research on digital farming is the topic of big data and its implications, particularly in the context of existing power asymmetries. Although, the study of big data and its implications for the agri-food sector lag behind the research in other sectors, like healthcare (Bronson, 2019; Eastwood et al., 2017; Pham & Stack, 2018; Rotz, Duncan, et al., 2019). The discussion of big data in the agri-food sector builds on the food studies and political economy literature presented above, as well as the existing dynamic and expanding discourses exploring digitalization, biotechnology, and big data beyond agri-food in STS and critical data studies (boyd & Crawford, 2012; Frické, 2015; Guston et al., 2014; Iliadis & Russo, 2016; Lyon, 2014; Newman, 2015). The rise of big data presents a diversity of concerns for ownership, access, privacy, and equity. For instance, Bronson and Knezevic ask, "Who has a role in deciding on the context for the data production, storage and use of particular data tools used in food and agriculture? Who decides which kinds of data are to be collected, given the functioning of current big digital collection and analytics tools?" (2016a, p. 3). Elsewhere, scholars are raising questions about ethics and justice in the digital agricultural revolution, relating to power, rights, and governance (Bronson, 2018; Carbonell, 2016; Eastwood et al., 2017; Rotz, Gravely, et al., 2019; Weersink et al., 2018). Big data also provides an entry point to explore political ontologies in perceptions of ownership and agri-food governance (Carolan, 2017, 2018a, 2018b).

Data are valuable. A Kansas-based digital farming start-up, Farmobile, declares that "data is among the most valuable commodities a farm produces" (2019). Likewise, TNCs are well aware of the value of data. Even in 2014, when DuPont launched its digital farming platform, Encirca, they predicted that agricultural data services would yield $500 million USD in annual revenues in the coming years (Bunge, 2014). In political economy, the transformation of items, people, services, experiences, and ideas into mere transactional commodities (i.e., commodification) is a central concept and area of research. The digitalization of agriculture and integration of big data in the food system present new dimensions of the phenomenon, where the commodification of food and knowledge interact. In their forward-thinking publication, Wolf and Wood make accurate predictions:

> Precision farming reinforces industrial development, dissemination, and application of information by supporting an expanded market for agricultural information services and associated biological and mechanical inputs. It is expected that this market will be dominated by corporations such as John Deere, Monsanto, and Rockwell. It is worth noting that agricultural production information service markets have existed for over three decades, but these transactions have been conducted between farmers and independently operating technical consultants, not highly capitalized agribusinesses (Wolf & Wood, 1997, p. 180).

As one of the earliest publications on digital farming in the social sciences, their article is quite significant to the field, despite the relative silence in the following decade. In their theoretical analysis, they predict that precision agriculture will continue existing trends of corporate control over farmers and their operations, entrenching industrial agriculture models. They also understand that TNCs in agricultural inputs, farm machinery, and automation will have the most power because they will hold the most data and control how it is collected. More recently, Mooney calls attention back to this point: "The big question is not just about who is collecting the data, but more importantly who is able to analyze the data to their advantage" (Mooney, 2018, p. 9). The commodification of agricultural data may reinforce existing patterns of uneven power dimensions.

Prior to acquiring The Climate Corporation, Monsanto (now Bayer) "arguably *already* assembled the world's most extensive agricultural databases," through decades of field tests and developing seeds and other agricultural inputs (Carolan, 2018b, p. 748). Therefore, not only are the megamergers in agricultural inputs an accumulation of capital, but they are also an accumulation of (big) data, raising important questions for power in the food system (Bronson & Knezevic, 2016a; Carbonell, 2016; Carolan, 2018b; Mooney, 2018). However, the interactions within industry are not limited to mergers or acquisitions. The Climate Corporation prioritizes a lasting relationship with John Deere; more than 70% of the 10,000 Climate Fieldview Drive Devices sold by 2017 are housed in John Deere machinery (The Climate Corporation, 2017). The Climate Corporation has formal partnerships for compatibility with 50 platforms globally, including three Ontario-based digital farming ventures: SoilOptix, A&L Canada Laboratories Inc., and Devron UAS (Bayer, 2018c). Compatibility across data sources, digital farming machinery, and analytic platforms – also called interoperability – is a growing concern for farmers in a range of contexts (Duncan, 2018; Kruize et al., 2016; Tzounis, Katsoulas, Bartzanas, & Kittas, 2017; Wolfert et al., 2014). These partnerships are marketed as a priority to improve data accessibility and convenience for farmers (Bayer, 2018c; The Climate Corporation, 2018), but such collaboration also expands the data to which TNCs have access, which could further power disparities in the food system.

The existing empirical studies on digital farming suggest that farmers should be concerned about the implications of big data (Carbonell, 2016; Carolan, 2018b; Eastwood et al., 2017; Jakku et al., 2018; Regan, 2019). In particular, it is important for farmers to know whether or not they own their data, who has access to it, and what others can do with it. Farmers are worried about governments and TNCs using their data; according to a American Farm Bureau survey, 67% of respondents are "concerned about which entities can access their farm data and whether it could be used for regulatory purposes," and 61% are "worried that companies could use their data to influence market decisions" (AFBF, 2016).

Likewise, a Farm Credit Canada survey finds that 66% of Ontario farmers are 'not sure' who owns their data and how it can be used based on their current agreements with digital farming companies, but 73% of Ontario farmers believe that the conditions and agreements on use of their data by a third party are 'very' or 'extremely important' when selecting a technology or service provider (FCC, 2018).[25] A recent review paper reports that data privacy and security are potential barriers to digital farming adoption and establishing trust with farmers should a top priority for developers and other proponents (Wolfert et al., 2017). Research in Australian suggests that trust and transparency are key concerns for farmers in regard to their data; lack of trust increases perceived risks and disincentivizes adoption (Fleming et al., 2018; Jakku et al., 2018). Others are exploring alternatives such as open-source data for public domain, which some degree of optimism (Carbonell, 2016; Carolan, 2018b).

3.5.3 Agricultural Labour: Skills, Shortage, Employment, and Equity

The digital agricultural revolution has the potential to impact agricultural labour in various ways. A number of studies postulate that farmers ought to be concerned about their labour and expertise being replaced by digital farming technologies (Bronson & Knezevic, 2016a; Carolan, 2016; Rijswijk et al., 2018; Rotz, Gravely, et al., 2019; Wolfert et al., 2017). Historically, anxieties regarding the loss of employment follow technological change. Since the Industrial Revolution, technology and labour have been central topics of debate in public consciousness and political economy – recall the writing of Thomas Mortimer, David Ricardo, Sir James Steuart, Adam Smith, John Stuart Mill, and Karl Marx – and technological unemployment concerns continued to ebb and flow in the centuries to follow (Mokyr, Vickers, & Ziebarth, 2015). Therefore, the concerns for risks to the labour and expertise of farmers is not unprecedented, but critiques of technology remain relevant as the relationship between labour and digital farming is uncertain and equity.

Technological development in agriculture can improve the quality of life for humans and non-human animals used for labour or food, as was the case for tractors and other farm machinery, but the economic gains of developers, usually TNCs, overshadow marginal improvements for farmers (Huesemann & Huesemann, 2011a; Weis, 2007). Some propose that the same will occur with digital farming (Bronson, 2018; Bronson & Knezevic, 2016b). Rotz, Gravely, et al. (2019) perform a critical analysis of the historical shifts in agricultural labour in a North American policy context, tracing the roots of colonialism in the expropriation and oppression of Indigenous Peoples by European-settlers, the reliance on 'free' familial labour on the farm, and the more recent exploitation of temporary migrant labour to support the consolidation of increasingly large farms. They explain:

[25] Findings shared with permission from Fred Wall, Vice President of Marketing at Farm Credit Canada.

> It appears that the technophilic promise of agtech will likely displace existing agricultural labour hierarchies with a radically bifurcated labour market, where on the one side, highly-skilled, highly-trained workers use digital agricultural technologies to increase productivity and find evermore efficiencies, while on the other side, lower-skilled workers in the fields, greenhouses, processing plants and warehouses are subject to increased employer scrutiny and surveillance, further rationalization of their workplaces, and ever-escalating expectations of productivity. (Rotz, Gravely, et al., 2019, p. 8)

In the context of uneven power dynamics in agriculture, the rise of digital farming presents a risk for groups that are already marginalized in the agri-food sector. Not only are there uneven power dynamics between TNCs and farmers, but digital farming may also exacerbate inequities between farmers as owner-operators and other labourers in the food system.

Digital farming will change the skills and capacities needed to farm, which may also change labour requirements of agriculture sector (Eastwood et al., 2017; Rotz, Gravely, et al., 2019; Weersink et al., 2018). As previously mentioned, the knowledge and capacities needed to operate digital farming technology influences their respective adoption rates (Griffin & Yeager, 2019). The integration of digital technology into existing farm machinery requires flexibility and familiarity with computers and newer technology. In response, there is a growing demand for education and capacity building support for farmers, including the population of Ontario grain farmers (Duncan & Fraser, 2018). The labour pressure in agriculture compound with an farming aging population, rural depopulation, and a shortage of farm labour (ACEG, 2017; Collins, 2018; Weersink et al., 2018). Chronic labour shortages in Canadian agri-food are predicted to rise to 113,800 jobs by 2025, with the largest labour gaps in Ontario and Alberta (Canadian Agricultural Human Resource Council, 2016). Labour shortage is a challenge for Ontario grain farmers and the requirements for new technical knowledge and skills can make labour even more difficult to find. Digitalization and robotics are impacting the existing trends of mechanization and the reduction of farm labour (Rotz, Gravely, et al., 2019; Weersink et al., 2018). In this sense, digital farming could improve the state of the agri-food sector by alleviating the labour burden, replacing jobs that cannot be filled (D. C. Rose & Chilvers, 2018). Alternatively, some propose that agricultural technology can draw new labour to rural communities. A case study of the Eastern Ontario Regional Network evaluates the social benefits of digitalization and internet connectivity, proposing a potential route to economic growth, social inclusion, and sustainability transitions (Pant & Hambly Odame, 2017). In response to the concerns mentioned above regarding farm labour, some scholars project that farm labour may change and evolve, but that digital farming does not threaten the work of a farmer (Regan, 2019; Wolfert et al., 2014). For instance, Wolfert et al. claim that "humans will always be involved in the whole process but increasingly at a much higher intelligence level, leaving most operational activities to machines" (2017, p. 70). The implications of digital farming on labour and rural communities are uncertain and farmer perceptions will be valuable in understanding and mitigating the potential risks moving forward.

3.5.4 Environment: Efficiency, Impacts, and Sustainable Intensification

The global food system contributes from 15% to 28% of global GHG emissions, and agricultural production makes up the largest share (Balafoutis et al., 2017; Garnett, 2013). There are also indirect GHG emissions (6-17%) resulting from deforestation in creating and expanding farmland, in addition to the costs for biodiversity and water quality/quantity (Garnett, 2013). The environmental impacts of agriculture are well reported, and the industry is receiving external pressure to make improvements. In response to this pressure and the need to sustain the land as an asset to farmers, there is growing attention on agricultural sustainability (Garnett, 2013; Pretty, 2008; Pretty & Bharucha, 2018). Many have turned to digital farming as the way to resolve these challenges, while also offering economic benefits to the farmer (Balafoutis et al., 2017; Schieffer & Dillon, 2015). For example, Bayer states, "digitalization in farming can help us deploy our resources efficiently and sustainably, enabling farmers to get the best out of their fields with minimal environmental impact" (Bayer, 2018b).

Literature in STEM journals supports this narrative with selected studies and optimistic predictions. The most commonly proposed environmental benefit of digital farming is the use of VRA machinery, changing agricultural input use in accordance with the requirements of the soil in a heterogeneous field to reduce costs and decrease impacts of run-off (Bhakta et al., 2019; Tey & Brindal, 2012). Others claim that digital farming can reduce GHG emissions by supporting low/no tillage practices to improve carbon sequestration in the soil, reducing fossil fuel consumption through more efficient farm machinery, and minimize the volume of agricultural in-puts, such as inorganic fertilizers and pesticides (Balafoutis et al., 2017). According to proponents, not only will digital farming decrease environmental impacts, but it could also support the viability of farming despite the effects of climate change (Pivoto et al., 2018).

Findings regarding the environmental impacts of digital farming vary widely, depending on the study parameters, geographic location, crop, and technology in use. In a case study of citrus farming in south Texas, the combination of remote sensing, VRA, and environmental modelling for site-specific application of agricultural inputs can reduce surface run-off and soil erosion up to 92% (Du, Chang, Yang, & Srilakshmi, 2008). A VRA study of nitrogen run-off in Canadian corn operations shows decreases in nitrogen run-off in all trials (Thrikawala, Weersink, Kachanoski, & Fox, 1999). According to a whole-farm study of a corn and soybean operation in Kentucky, RTK auto-steer increases tractor speed and minimizes the overlap,[26] which can reduce operational time by 5% for planting and by 10% for fertilizer application, equating to 10% cost benefits for tractor fuel (Schieffer & Dillon, 2015). However, auto-steer increased the nitrogen footprint by 7.2% and increased the carbon footprint by 3.3% and VRA increased carbon and nitrogen impacts by 0.7% and 1.1% respectively, demonstrating the common 'rebound effect' of technological efficiencies (Schieffer & Dillon, 2015).

In addition to the STEM literature reporting specific potential environmental gains, there also exists a more holistic promise that digital farming is a food system solution. Proponents across industry (Bayer, 2019b), and civil society (Foresight, 2011), and academic circles (Rotz, Duncan, et al., 2019) propose that digital farming will "produce more food on less land, with fewer environmental impacts," in line with a vision of sustainable intensification (Weersink et al., 2018, p. 22). While sustainable intensification of agriculture overlaps with digital farming debates, it is a much larger and more extensive body of literature (Garnett, 2013; Garnett & Godfray, 2012; Lindblom, Lundström, Ljung, & Jonsson, 2017; Lundström & Lindblom, 2018; Pretty, 2008; Pretty & Bharucha, 2018). Pretty & Bharucha describe sustainable intensification as "a process or system where yields are maintained or increased without adverse environmental impacts and without the conversion of more land" (2018, p. 3). The concepts of sustainability and intensification in agriculture emerged in the 1980s but create new meaning when combined. Historically, agricultural intensification focuses on increasing yield by changing the agronomic practices (e.g., increasing the number of crops per acre and planting crops with higher nutritional content), with unintended adverse consequences for the environment and surrounding social systems (Pretty & Bharucha, 2018). Yet the promise of sustainable intensification remains hopeful to many; digital farming may be a route to reconcile Earth systems and planetary boundaries (Pretty & Bharucha, 2018; Raworth, 2012; Rockström et al., 2009, 2017). Biotechnology (e.g., GM crops and digital farming) may play an important role in sustainable intensification and meeting the needs of a growing population, but this is yet to be determined (Garnett & Godfray, 2012; Pretty & Bharucha, 2018; D. C. Rose & Chilvers, 2018; Tilman, Balzer, Hill, & Befort, 2011).

Across the central body of literature situating this study, environmental impacts are not at the forefront of digital farming research. There are some important contributions to note, but most scholars merely make passing references to ecological implications of the digital revolution of agriculture. Previous research critiques environmental promises in STEM literature, casting doubt on the potential of incremental gains (Bronson, 2019; Wolf & Buttel, 1996). Others are enthusiastic that digital farming

[26] Overlap or multiple passes are when the tractor does not drive straight across the field and passes over parts of the field more than once due to farmer fatigue, error, or machinery issues.

can resolve the environmental problems from Green Revolution's expansive and homogenous practices, by supporting more efficient, intensive, and precise agriculture (Weersink et al., 2018). Generally, there is a sense that research should pay attention to the environmental impacts, but the literature often mentions the issue in the outset of the paper only to set it aside for its primary focus (e.g., Regan, 2019; Rotz, Duncan, et al., 2019). While Carbonell focuses primarily on the ethical implications for power relations between farmers and TNCs in digital farming, she makes an astute observation that "there is no big data collection on industrial agriculture externalities and vulnerabilities, hindering research on that topic" (2016, p. 3). These ideas are helpful in informing further research that prioritize environmental dimensions of the digital agricultural revolution and addressing this gap.

Moreover, digital farming discourse typically does not acknowledge the environmental impacts of developing and using new technologies in agriculture. There is much published on environmental impacts of technology, including direct impacts of manufacturing, planned obsolescence and the legacies of e-waste, energy use, rebound effects, and global environmental injustices (Berkhout & Hertin, 2004; LeBel, 2016; Longo & York, 2016; Sarr & Swanson, 2017; Smith, Sonnenfeld, & Pellow, 2006). Digital farming will contribute to global e-waste chains, where 44.7 million tonnes of e-waste are already produced annually (Baldé, Forti, Gray, Kuehr, & Stegmann, 2017). With the rise of big data, energy use of digital technology and the internet will account for an increasingly large portion of energy consumption, with estimates ranging from 14% to 20% of global electricity use in the next two decades (Vidal, 2017). While there may be the potential for environmental benefits, they must be considered in the context of complex ecological systems through the life cycle of digital farming technologies.

3.6 Chapter Summary

There is an explicit sense of urgency to the research on digital farming. It is common to open research articles with assertions that a digital revolution of agriculture is underway and to situate the technological change in the perspective of unprecedented challenges and pressures in the global food system (Bronson & Knezevic, 2016; Rotz, Gravely, et al., 2019; Weersink et al., 2018). Especially as the technology continues to evolve, research to investigate the unknown and unintended consequences beyond the technology's intention is increasingly important (Kranzberg, 1986; MacKenzie & Wajcman, 1999; van der Burg et al., 2019). Despite the important contributions of empirical and theoretical research in this space, much remains unknown and unexplored in the context of the digital agricultural revolution. Even studies published this year continue to make claims that explorations of the impact of digital farming lag behind discourses on digital technologies and big data in society (Bronson, 2019; Rotz, Duncan, et al., 2019) and that there is a dearth of empirical studies on implications of the digital agricultural revolution on ecological, social, political, and economic systems (Regan, 2019). This chapter provided an overview of the existing literature on digital farming as it relates to farmers. Working from an understanding of complexity in food systems, I provided definitions of key terms to guide the thesis. The discussion of central narratives in public debates on digital farming gather evidence for the first research objective of this study. The literature review identifies the central ideas of power, data, labour, and environment, with a discussion of theory and tensions in the scholarly debates, to position themes for the analysis of the third research objective. Overall, this chapter situates the study in its comparator academic literature and broader public debates, as a foundation to the rest of the thesis.

Chapter 4
Ontario Grain Farmer Perceptions

4.1 Introduction

This chapter presents an overview of the empirical results from questionnaires, interviews, and fieldwork observations. In particular, I focus on the second research objective, regarding farmer perceptions of the challenges and opportunities of digital farming. The first portion will provide context to understand the perspectives of Ontario grain farmers. To begin, the chapter will present descriptive statistics, drawing attention to notable participant characteristics, farm operation demographics, and digital farming adoption levels to situate the analysis. Next, I review results that contextualize the farmer perceptions. Before discussing the how farmers perceive digital farming, it is important to explore their underlying assumptions and values. The section summarizes the role of a farmer, the main challenges of grain farming, key values and priorities, and relationships with other actors in the food system. Finally, I describe the challenges and opportunities of digital farming from the perspective of Ontario grain farmers. I discuss the results as they were presented by participants, synthesizing the main areas of concern and providing nuance where there is disagreement among participants. Ultimately, the summary of results will position the analysis to answer the research question in the following chapter.

4.2 Descriptive Statistics of Participants

In this section, I sumarize the demographic of the study participants and their farm operations, to compare them to Ontario grain farmring more generally. Given the exploratory nature of the study and its qualitative methods, the demographics of the participants do not necessarily need to correspond to the research population. Fortunately, the sample is reasonably representative. I collected 75 online questionnaires and conducted 12 semi-structured interviews. In the descriptions below, I calculated percentages based on the number of responses provided, rather than the total number of participants.

4.2.1 Participant Demographics

Through the farming organization recruitment, I received questionnaire responses from 28 counties across the province.[27] As illustrated in Figure 1, the distribution reflects grain producing areas. The interview participants were all from different regions of Ontario. The sample is somewhat younger than the average Ontario farmer, which could be due to the online recruitment method. Table 3 presents the

[27] In the questionnaire, 66 participants provided their county of residence. I received responses from: Brant; Bruce; Chatham-Kent; Dufferin; Durham; Elgin; Essex; Grey; Haldimand; Huron; Lambton; Middlesex; Norfolk; Northumberland; Ottawa; Oxford; Perth; Peterborough; Prince Edward; Renfrew; Simcoe; Leeds and Grenville; Prescott and Russell; Stormont, Dundas, and Glengarry; Waterloo; Wellington; and York.

description of questionaire respondents by age, gender, and highest level of education completed. The average age of interview participants is 53 years and 48 years for the questionniare. The average age of Ontario farmers in the 2011 Census of Agriculture was 54.5 years (Statistics Canada, 2018c). For the online questionnaire, 15% of respondents are female and 83% are male. In Ontario, 28% of farm operators are women and 72% are men (Statistics Canada, 2016a). Conversations in fieldwork and observations reveal that grain farming is more male dominated than the broader general farming population, which is consistent with the research sample.

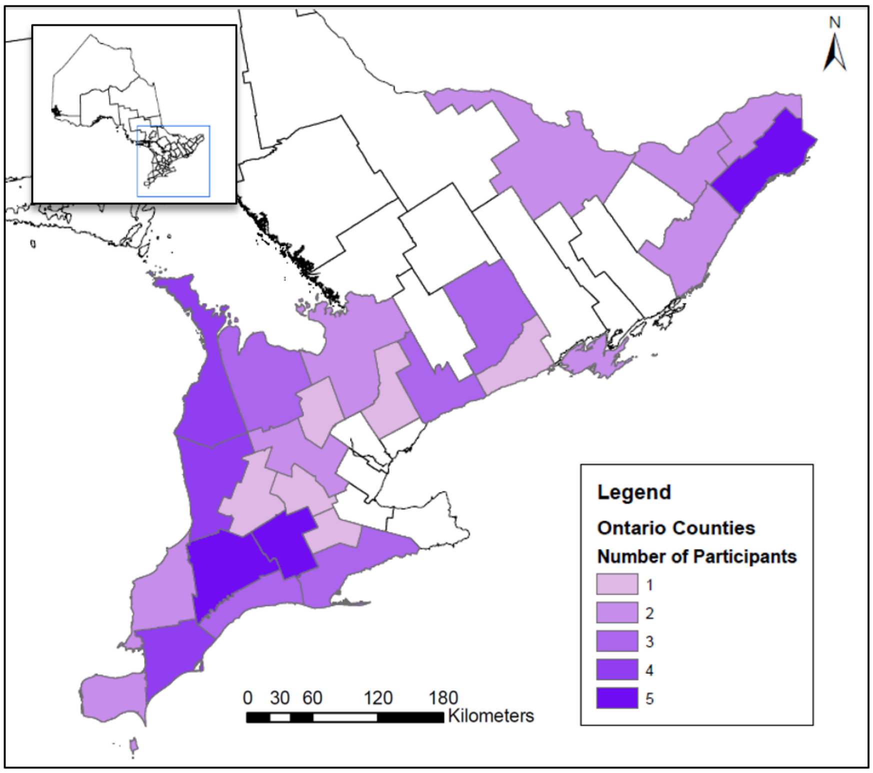

Figure 1: Questionnaire respondent demographic map by Ontario counties

While the age and gender demographics of participants correspond with Ontario farmers, there remain notable discrepancies. The survey respondents are somewhat less ethnically diverse than the demographics of all farmers in Ontario: 97% of respondents were born in Canada. The only two responses outside of Canada are both from Europe. As of the 2011 Census, 8.6% of farmers in Ontario are immigrants, most of whom are from Europe (Statistics Canada, 2016b). The community informed me that grain farming is predominantly white. Moreover, Table 3 shows that participants have completed higher levels of education than the general population of farmers. In 2011, the percentages of farm operators who completed their highest level of education at secondary school, college and other post-secondary, or university degree were 27%, 34%, and 17% respectively (Statistics Canada, 2016b).

In contrast, 15% of participants in this study have completed secondary school, 37% of respondents have completed college and other post-secondary, and 45% have completed education at the university level. The proportion of individuals with post-secondary education may link to the higher proportion of technology adopters.

Table 3: Age, gender, and education of questionnaire respondents

Age	100%	n = 73	**Gender**	100%	n = 72	**Education**	100%	n = 72
18-24	1.37%	1	Female	15.28%	11	Elementary	0	0
25-34	20.55%	15	Male	83.33%	60	Secondary (no diploma)	2.78%	2
35-44	28.77%	21	Non-binary	0%	0	Secondary diploma	15.28%	11
45-54	9.59%	7	Prefer to self-describe:	0%	0	College	31.94%	23
55-64	26.03%	19	Prefer not to say	1.39%	1	Undergraduate	31.94%	23
65-74+	13.70%	10				Graduate or professional	13.89%	10
						Other (post-secondary)	4.17%	3

4.2.2 Farm Operation Data

The information collected on farm operations further contextualizes the experiences of the participants. Table 4 presents the distribution of questionnaire respondents with particular farm characteristics, focusing on primary crop, size, and land tenure. While the eligibility criteria only required participants to work on a farm that grows soybeans, corn, or wheat, the majority of the participants farm one or more of these grains as their dominant production. Soybeans, corn, and wheat are often farmed in combination or rotation in Ontario, due to environmental and economic benefits (Statistics Canada, 2017a). This grain rotation increases biodiversity, pest resistance, nutrient uptake, and it can decrease economic risk through crop diversification and multiple harvests. Many participants farm a rotation of soybeans, corn, and wheat, sometimes including oats or other small grains. Moreover, 63% of respondents follow ecological practices or procedures on their farms.[28] With or without certification, 13% of respondents identify as organic farmers, and I interviewed one certified organic farmer.

[28] Agroecological practices are most common (24% of respondents), followed by no-till and cover crops.

Table 4: Distribution of questionnaire respondents by primary crop, farm size, and land tenure

Crop	100%	n = 65	Size	100%	n = 65	Land Tenure	100%	n = 65
Soybeans	24.62%	16	< 50	1.54%	1	Own and operate	87.70%	57
Corn	50.77%	33	50-99	76.92%	5	Leased from individual	7.69%	5
Wheat	3.08%	2	100-149	3.08%	2	Leased from corporate owner	0%	0
Other:	21.54%	14	150-199	4.62%	3	Leased from government	0%	0
			200-250	4.62%	3	License	0%	0
			250-299	6.15%	4	Profits-à-prendre	0%	0
			300-349	12.31%	8	Memorandum of understanding	1.54%	1
			> 350	60.00%	39	Other	3.08%	2

The majority of the participants operate large farms: 60% of questionnaire respondents and 50% of interview participants work on over 350 acres of farmland. I assigned the response options of the online questionnaire based on Ontario's average farm size, 249 acres (OMAFRA, 2017). Grain farms are typically larger, but there is no data publicly available on the average size of soybean, corn, and wheat farms in Ontario.[29] As presented in the literature review, adoption is more favourable to large farm operations (Aubert et al., 2012; Bronson, 2019; Jensen et al., 2012; Lambert et al., 2015). Furthermore, 88% of the participants identify as owner-operators, though participants explain that many of these farmers also rent a portion of their land. Accordingly, rented farmland and hybrid models of owned and rented land are on the rise in Ontario and across Canada (Deaton, 2018; Statistics Canada, 2018c). Recent research in Ontario reveals that land tenure influences farmer decision-making regarding stewardship and conservation (Deaton, Lawley, & Nadella, 2018; Rotz et al., 2017). Land tenure may also influence or contextualize farmer perceptions of digital farming. In this study, information on farm size and land tenure suggests that most participants are managing large capital-intensive farms, which illustrates the relative economic satiability and cash flow of these farmers.

The relationship between grain production and animal agriculture is a growing concern in food studies (D'Odorico et al., 2014; Garnett, 2013; Gerber et al., 2013; Van Zanten et al., 2018; Weis, 2007, 2013). Many of the farmers in the study are explicitly connected to the "grain-livestock complex"

[29] I also requested additional data from OMAFRA and GFO, but neither were able to provide an average.

(Weis, 2007, p. 47). A significant portion of participants (44% of the total) sell their grains for animal consumption; 64% of this this subset farm over 350 acres. It is also interesting to note that 16% of participants sell their grain for biofuel production. In the study, animal agriculture is the dominant farming activity for 5% of the respondents, where grains are supplementary cash crops for the operation or sources of animal feed. While it is not included in this study, the impact of digitalization on the grain-livestock complex is potentially quite significant. In this study, Farmer #5 is a dairy farmer and she explains how the reliable income of dairy farming under supply management enabled her to afford digital technologies on the farm. Duncan (2018) explored the adoption of digital technologies for dairy farmers and grain farmers in Ontario as part of her study; however, understanding how digital farming adoption interacts with crop or animal agriculture, in the context of complex food systems, requires further research.

4.2.3 Digital Farming Adoption

On any given spring morning, an Ontario grain farmer might wake up and start the day with instant access to information about the weather and commodity prices on their tablet, engage in digital farming debates with farmers on Twitter, review GIS yield and vegetation maps of their fields from drone or satellite imaging, receive information from a third-party analytics company studying a soil sample for nutrient content, and then drive across their field in a planter steered by GPS to ensure that the rows are planted perfectly straight, while the farm equipment simultaneously collects data on weather, time, soil moisture, and the location of each individual seed planted. Indeed, several of the farmers in this study use these applications of digital farming every day. However, the degree of digitalization and the specific approaches of farmers varies significantly, even among Ontario grain farmers.

Despite the limitations of the adoption statistics available, research suggests that the integration of digital technologies in Ontario agriculture is slowly rising (Duncan, 2018; Mitchell et al., 2018; Statistics Canada, 2017c). Estimates of adoption rates are wide-ranging and depend on the technology in question, where the use of smartphone and personal computers are most common, followed by GPS, auto-steer, and GIS (Statistics Canada, 2017c). Evidently, 73% of respondents in this study are currently using some form of digital farming. The most common digital farming technologies are smartphone applications (81% of respondents to question), GPS and auto-steer (78%), and GIS (50%). Other popular options are grid or zone soil sampling (61%), sensors (45%), VRA (28%), and drones or UAVs (26%). The adoption statistics align with existing literature reviewed in Chapter 2. In this study, most participants describe some level of digital farming adoption in their operations, which could be due to response bias, but also reflects the available statistics. On average, questionnaire respondents have been using some form of digital farming for 8.9 years. Moreover, 12% of participants were using digital farming technologies as early as the 1990s. One participant cited 31 years of experience using digital farming technologies. Still, many participants do not engage in digital farming in any way. When asked whether digital farming technologies are included in their business plans moving forward, 7.25% participants selected "not at all" in the online questionnaire. Even though the majority of participants use digital farming presently, or intend to at some point in the future, there is a rich diversity of perspectives in the research sample.

4.3 Contextualizing Participant Experiences and Perspectives

Although the research sample includes a diversity of identities and experiences, the empirical data demonstrates several commonalities in the experiences of Ontario grain farmers that contextualize their perceptions. This section builds a foundation from which to interpret and analyze the data. Following the information letter and the collection of some demographic data, the state of a potential digital agricultural revolution was the first perspective question of the online questionnaire. Figure 2 illustrates that across a diversity of farmers (large and small, conventional and organic, enthusiasts and skeptics), 89% of respondents agree that we are experiencing a digital agricultural revolution, and none disagree with the statement.

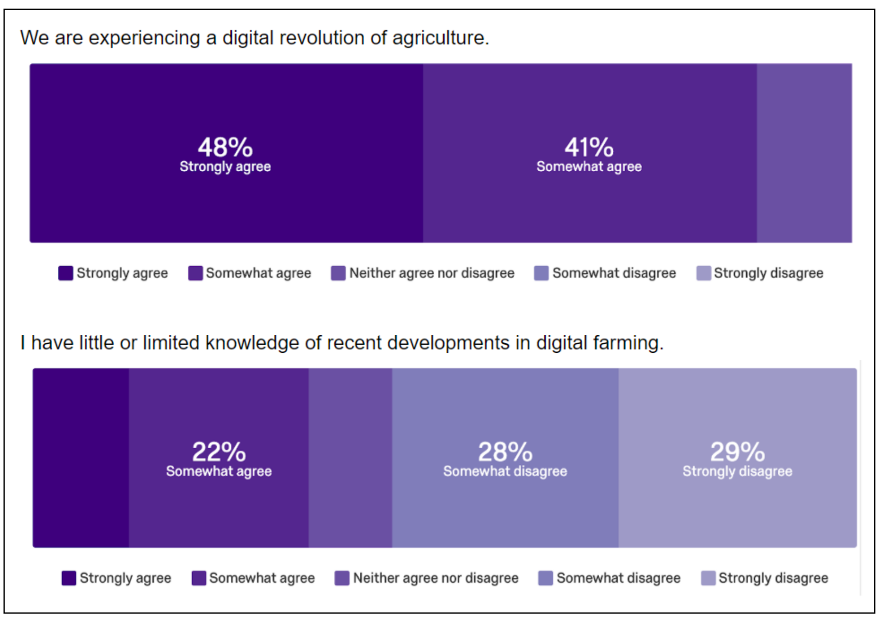

Figure 2: Farmer knowledge of the digital agricultural revolution (Questionnaire)

While much more varied, the majority of the respondents (57%) feel that they have some knowledge and familiarity with the recent developments in digital farming, as illustrated in Figure 2. The questionnaire responses suggest that whether or not farmers adopt digital farming or are knowledgeable regarding technological developments, the research sample is aware of the popularization of digital farming and believe it to be revolutionizing agriculture. The following section will highlight other empirical findings from the questionnaire and interviews to contextualize farmer perceptions of digital farming. In particular, I summarize farmer identities, perceived challenges of grain farming, and underlying values in the narratives of participants. The literature proposes that farmer experiences and identity influence perceptions of digital farming (Fleming et al., 2018).

4.3.1 Role of a Farmer: Multifaceted Identities

In the interviews, I asked all participants: "What is the role of a farmer?" This question serves as a transition from the introductory questions (What does a typical day look like for you?) to more in-depth questions about opinions and beliefs (Do you feel pressure to use digital farming technology? If so, from where?). Moreover, this question intended to reveal farmer values and assumptions. Across the interviews, there were four key beliefs – and corresponding codes – with notable overlap.[30] Of the eleven coded interviews, 82% believe that the role of a farmer is to *'produce food'*, 72% believe that the role of a farmer is to *'care for the land'*, 55% believe that the role of a farmer is to *'make a profit'*, and 45% believe that the role of a farmer is to *'feed the world'*. The responses to this question display centrality of production to farmer experiences.

> "Well, I think the role is to *produce food* products for either human food or for use in industry. And it's also to *make a profit* so that they can support their families and make all of their payments." (Farmer #2)
>
> "*Produce food*. Plain and simple." (Farmer #7)

It is striking that a variety of farmers from across Ontario use similar phrases to convey their viewpoint and describe their identity. The other important lesson is that farmers are constantly balancing different dimensions of their work and identity. Farmers respond to the aforementioned question:

> "Ah, to *care for the land* in a socially responsible manner, to *produce and supply food* and feed grains to support a *growing population* on planet Earth in a *socially responsible* manner. To care for their family, *pay the bills*." (Farmer #4)
>
> "Trying to *make money* and *feed the world*. That's about it. And *look after the soil*." (Farmer #6)
>
> "To *feed the world*. Like that's probably a cheesy answer. But I would say to feed people and to *take care of the land*… We are also a *business person*. I aim to be *profitable* in my business and I will not apologize for that." (Farmer #5)

The interviews demonstrate that farmer identities are multifaceted. In addition to the prevalence of farmers as producers, they also see themselves as business people and stewards. There is a sense of *compromise* between economic and environmental factors, which foreshadows a prominent theme.

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[30] The 'single quotation marks' signify an *In Vivo* code (see Chapter 2). "Double quotation marks" indicate that I am quoting a farmer directly. *Italics* are to mark emphasis and important codes in the text.

It is also important to note that identity is not predictive of these perceptions and that assumptions are problematic (e.g., small farmers prioritize stewardship; large farmers are business-minded). For instance, Farmer #2, a certified organic farmer, does not include caring for the land in his role, though the importance of stewardship weaves through responses other questions, but many large farmers, like Farmers #4 and #6, consistently include caring for the land in their sense of self. While the characteristics do not predict responses in the research sample, certainly identity and experiences are important to determining worldviews. Contexts and identities influence the values and concerns of farmers. For instance, the perceived challenges and opportunities may differ based on farm size, age, and other characteristics.

4.3.2 Main Challenges of Grain Farming in Ontario

The following question in the interview guide asked farmers about the big challenges of grain farming in Ontario. Farmers experience challenges as pressures or obstacles that intervene or inhibit their roles. The responses contributed to an understanding of farmer experiences, assumptions, and priorities (e.g., value coding). This context offers a better understanding of the challenges and opportunities of digital farming, because it reveals their perceptions of problems that digital farming might improve or worsen. In addition, the challenges reveal factors in farmer decision making. In the interviews, I encouraged farmers to consider digital farming in relation to their perceived problems. Farmers with 'producer roles' or who focused on economic dimensions in their challenges often returned to economic factors in decisions of whether or not to adopt digital farming or the economic issues it may affect. Still, digital farming triggers a whole suite of new and unforeseen challenges, as discussed below.

The primary challenges facing farmers are increasing costs, unpredictable weather, and labour constraints. The economic dimensions of farming pose the most significant challenges, as these are the conditions of their livelihood and accomplishing their role. *Rising costs*—land, agricultural inputs, labour, and living expenses—are 'shrinking margins' for farmers, also called the 'cost-price squeeze' (NFU, 2012). Across agriculture in Ontario, capitalization and corporatization are increasing the prices of inputs and production costs, but prices paid to producers and farmer incomes are stagnant (Rotz et al., 2017). Farmers also state that the cost of land affects land ownership, another challenge. Commodity prices are volatile, relying on the global market, but they continue to decline. In addition, the unknown and unpredictable profits will likely worsen with *changing weather* (note: interestingly, farmers never said 'climate change'). Farmers notice that weather is increasingly unpredictable and that there are *'smaller windows to get things done'* (e.g., fewer days to plant). The cost of *labour* is increasing, but the more important concern for farmers is the *shortage of labour*. Farmers simply cannot find people to work.[31] Taken together, these challenges make farming increasingly *competitive.*

Farmers tell a story of changing landscapes of Ontario grain farming: bigger farms, more rented land, smaller communities (NFU, 2012; Rotz et al., 2017; Statistics Canada, 2017a). Overall, the interviews reveal that farmers are facing diverse pressures and increasingly complex challenges. Farmers are very aware of trends of labour and rural communities in Ontario and across North America (Rotz, Gravely, et al., 2019). Moreover, farmers understand the risks and implications of selling to an interconnected global grain market. Farmers express that conditions are worsening and that their jobs are becoming more difficult, new technologies aside. Farmers are facing pressures at the intersection of complex systems and the challenges above – costs, weather, and labour – exacerbate the effects.

> "What we are going to have facing farmers in the next few years is all these *new and unforeseen problems* that we *should have enough room in our margin* to absorb. But the *margins get tighter and tighter every year* and there is just no room for it." (Farmer #10)

Historically, farmers have been comfortable with risk and uncertainty, out of necessity. Yet, the current pressures push farmers into a much more vulnerable position, eroding economic resilience. Because of shrinking margins and the cost-price squeeze, farm operations are unable to absorb the economic pressures and problems that may arise, meaning that even small changes can cut into their profits.

In addition to the challenges above, a more complete list includes: soil health, disease and pests, government regulations, lack of understanding from non-farming population (e.g., consumers, government, industry), pressure from environmentalists, migration of retirees and urban sprawl, pressure to adopt new technology, adapting to change (e.g., traditions, weather, economics), effects of farming on physical and mental health, lack of infrastructure (e.g., internet connection), and succession planning. Presented in order of importance, these other challenges were less frequent in interviews, mentioned by fewer participants, or presented by farmers as less important.

4.3.3 Values and Compromise

These challenges illustrate the interplay of key values: *profit*, *yield*, and *stewardship*. Ensuring that farm operations are profitable and environmentally sound is paramount to the priorities and challenges of grain farmers, while knowledge and yield follow close behind. Connections between the values even within each interview are dynamic and context-dependent, presenting multifaceted identities in practice. There is one response in particular that illustrates this dance of values particularly well. Farmer

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[31] Labour shortage was key concern in the presentations and conversations at farming conferences.

#11 operates a small grain farm in addition to several off-farm jobs, including research and media. He says that farmers are "trying to marry the best agronomic practices for *yield* with the practices that have the *minimum impact* on the environment," but there is a challenge in balancing the two aims.

> "We need to grow yield, because *if you don't have yield you are not profitable* and if you are not profitable you are out of business – and yet to *maximize yield*, sometimes we do things that have more *environmental impact* that you would like." (Farmer #11)

Farmer livelihood and the success of their operations relies on the negotiation of economic and environmental factors. Acting as factors in decision-making, the priorities of these values depends on contexts, but usually the environment is a priority when it aligns with economic gain.

The connection of yield and profits is not as simple as it may seem. The centrality of production and yield to the role and experience of farmers aligns with the productivist worldview of industrialized farming. In the current economy and policy context, farmers usually understand profit as dependent on yield, because farming income relies on selling a crop. Yet, there can be increases in profit without increases in yield, depending on market prices or high-value crops (e.g., organics). Contrastingly, there can be high yields without profit, as illustrated by the high levels of mycotoxins in the 2018 corn harvest causing discounts or even the inability to sell at all. Separation of yield and profit also occurs for cover crops or other ecological practices without a direct return on investment.

While *yield* is central to the worldview and priorities of Ontario grain farmers, it is less prominent in the value coding, because it depends on another important value: *stewardship*. Farmers understand themselves as stewards of the land. There is an inherent value to caring for the land, which draws on a sense of connection, but there is also an acute awareness that *stewardship* is essential to ensuring ongoing use of the land to harvest *yield* and make a *profit*. There is a common language of *'next generation'* in discussions of stewardship, which points to values of *family*, *community*, and *tradition*. The notion of stewardship is predominantly anthropocentric and economically driven. Still, economic pressures often motivate yield-maximizing decisions that undermine stewardship. Thus, *compromise* is central to farmer decision-making. Finally, the value of *knowledge* is less explicit, but permeates this trifecta through a belief that more information leads to better farming decisions.

4.3.4 Farmer Perceptions of Relationships across the Food System

Recalling the central research question, farmer perceptions of other actors in the food system are relevant to understanding farmer experiences and positioning them in the broader debates. Moreover, value coding in the interviews reveals that the feelings of farmers toward non-farmers are important to contextualize farmer experiences. Relationships in the food system were central to farmer experiences and perceived challenges of some participants. For instance, when asked about the big challenges of grain farming in Ontario, two participants responded:

> "All the *different government bodies* – municipal, provincial and federal – who think their only job is to make sure that the *red tape and all the regulations is piled up for you*. Plus, all the taxes, the carbon tax." (Farmer #6)
>
> "We are looking at so many *regulations that are bringing us back*. We have the *environmentalists that are working against us* to take safe, low toxicity herbicides and pesticides off the market, only to be replaced with more toxic organic products." (Farmer #8)

There are strong feelings that non-farmers, especially government officials and environmentalists, are getting in the way of farmers and making it more difficult for them to perform their roles, categorized by non-farmers' *lack of trust* and feeling *frustrated* and *misunderstood*. Moreover, farmers are not trusting of other actors in the food system, especially governments. Participants express that those making the decisions have little understanding of agriculture or working with the land. For example, Farmer #8 tells a story of being invited to a government meeting pertaining to farm regulations. Out of frustration, he asks the room if anyone knows what a corn planter looks like and only three of 20 OMAFRA employees respond affirmatively, reinforcing his existing attitudes and beliefs. In addition, in farmer interactions with non-farmers government officials and environmentalists suggest think that they know more about the environment and that farmers need to be told what to do. Farmers do not feel included or represented in decision-making processes.

According to farmers, public mistrust in the food system comes from a lack of understanding about agriculture and food production. In a policy brief to the Government of Canada, the National Farmers Union explains that "lack of public trust is also related to a sense that increasingly, private corporate interests are taking precedence over the public interest, particularly for health, food safety, environment, animal welfare and climate change" (NFU, 2019). While causes driving an erosion of public trust in the food system relate to corporate power, data from this study suggests that Ontario farmers are feeling the lack of public trust most acutely.

> "They [non-farmers] don't understand what's going-on on the farm or what is involved in bringing 'em this *GMO-filled plate of death* that they seem to think that we are giving them. And the other perception too is that everything on that plate that is so bad for them comes from farmers. But the reality is that most of the stuff they eat is *all processed food* and the *stuff that they are eating that is bad generally gets put in a food plant somewhere*." (Farmer #10)

Participants in this study feel that the consumers wrongly blame farmers for the actions of other industry actors in the food system. The misunderstanding is prevalent when discussing health and environmental problems, namely GM crops, fertilizer runoff and algae blooms, and land use change. Farmers feel attacked by environmentalists and the government, with accusations that they are mistreating the environment. Some of the discussion was much more heated than I anticipated based on the centrality of stewardship and caring for the land farmer sense of self. For instance, one farmer says, "*environmental extremism*—I think that's our *biggest enemy* right now," another says that farmers are "the *last line of defense* against the *environmentalists*." These were emotionally charged conversations. Other than consumers, governments, and environmentalists, discussions of other actors in the food system, such as industry and academics, were much generally mild.

4.4 Opportunities of Digital Farming According to Ontario Grain Farmers

Many Ontario grain farmers are excited about the digital agricultural revolution and the opportunities that it may present. Several of the participants in this study are enthusiastic proponents of digital farming, explaining the benefits in their operations. In several of the interviews, participants spoke about digital farming with optimism and excitement.

> "I would say that I am overall *excited*. I am 37 years-old. I'm not a millennial, I just made the cut-off prior. And I deploy a lot of technology in my life and on my farm and I think it's going to play a huge role going forward. *We are going to have to make smarter decisions to feed the world and it's going to play a big role*." (Farmer #1)

> "I think it's certainly going to *impact the decisions* that are made. I think it'll allow more *efficient use of inputs*, so it will probably have a pretty positive impact on the *environment*." (Farmer #7)

Many farmers are optimistic about the potential of digital farming for their farm operations, but also for food security and environmental improvements, responding to the promises of digital farming in current debates. It is also interesting to note that farmers believe in the potential for operational benefits for diverse farm operations. As illustrated in Figure 3, 48% of questionnaire respondents strongly disagree with the statement that digital farming only helps big industrial farms.

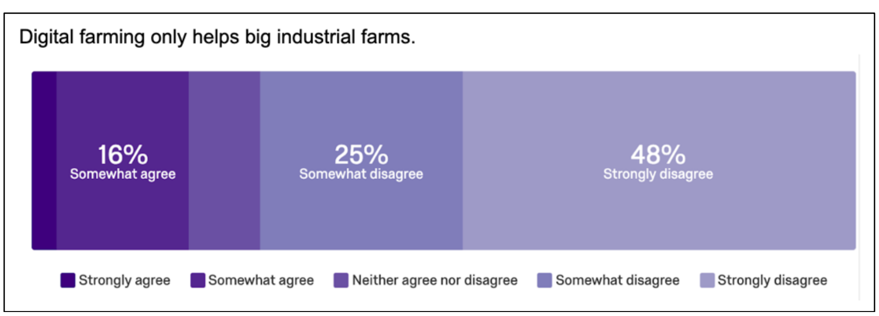

Figure 3: Digital farming only helps big industrial farms (Questionnaire)

According to Ontario grain farmers, the diversity of digital farming applications and services available are not limited to applications on large conventional farm operations. Across the empirical data collected, the opportunities of digital farming fit in two main categories: operational benefits and decision-making.

4.4.1 Operational Benefits: Increasing Yields, Decreasing Inputs and Impacts

Grounded in the context established above, I read the data through the lens of farmers as producers. Given farmer roles and values, it follows that the key opportunities of digital farming proposed by the participants are production-focused. However, farmers are also business people and stewards, enshrining tensions and compromise in their perspectives. In the questionnaire, 82% of respondents believe that digital farming improves farm productivity (see Figure 4).

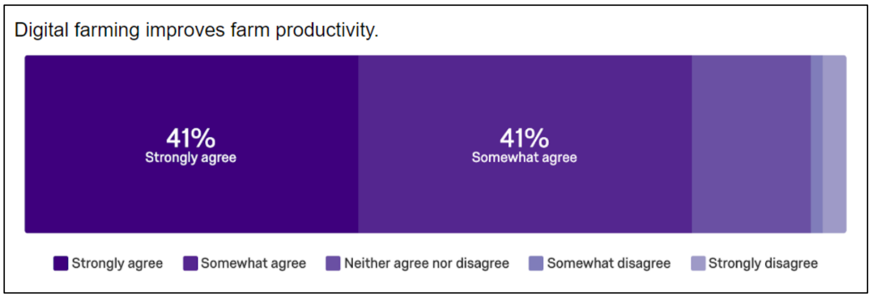

Figure 4: Digital farming improves farm productivity (Questionnaire)

In practice, improvements to productivity relate to finding efficiencies and increasing profits. Productivity benefits depend on the nature of the farm operation and the technology in use. For example, the use of GPS can ensure that planting and harvesting machinery drives across the field in perfectly straight lines with tolerance of one inch. Some express enthusiasm for the precision and efficiency, with impressive anecdotes:

> "As far as some of the tools that are available. I feel that they are really helpful, and they've definitely *increased our yields*, they've *lowered our costs,* and they have *reduced our environmental impact* by targeting fertilizer application to where they can do the most good and to keep them off of areas where they are susceptible to losses to the environment." (Farmer #9)

> "I went and bought a great big corn planter. Just huge. And now I can plant it by myself in three days. And the technology helps because now I've got automatic row shut off, I've got auto-steer, I've got controls of my fertilizer on it, everything. So, it allows me to be *able to do three things at once and do it with a much better job*. Because now my spacing is *perfect* and they all come up all at the same time." (Farmer #10)

According to farmers, the operational improvements improve yield and decrease agricultural inputs, which may also decrease costs and environmental impacts. There is hope that digital farming can simultaneously support farmer priorities of profits and stewardship.

It is important to remember that the use and impacts of different digital farming technologies vary greatly, considering their mechanical realities and intent. One of the most common digital farming applications is variable rate application (VRA), changing the rate of fertilizer application in accordance with the specific needs of different regions of the farm.

> "It will have a positive effect on *decreasing the costs of application for people who adopt the technology and change their practices from flat rate blanket applications*. For people who were previously very engaged in their own farming operation to an extreme detail, I don't think that those people will see a significant return." (Farmer #4)

Not all participants believe that digital farming will improve economic wellbeing for farmers, and many that do remain skeptical. There is simply no guarantee. For proponents, the potential of digital farming to increase profits is contingent on farmer skills and capacities, economic conditions of the farm, and improvement of the technology. Farmer #11 is a vocal advocate for digital farming, especially VRA to reduce fertilizer runoff, but understands that the benefits are presently limited.

> "I think that we will *eventually get to the point that it will be a very valuable tool*. There's aspects to it that are already valuable, but I don't think that in general terms so far – *the actual outcome has not lived up to the hype or promise*. It's very typical with new technology. You know that they have this big of a capability, but *the technology is way ahead of what I do, the agronomy*. And until you understand the agronomy, so that you can apply the agronomy with the technology, you can spin your wheels a lot." (Farmer #11)

In his off-farm job with the media, Farmer #11 meets many digital farming adopters across the country and has the opportunity to hear their experiences. For many farmers, the perceived opportunity of digital farming is anticipatory; they adopt because they think that the technology will be beneficial with further innovation and capacity building. Some of the uncertainty in participant responses is due the relationship between yield and profits and the importance of weather. The industrial agriculture mentality centres on increasing production, but the challenges of grain farming means that increasing yield goes not guarantee economic gain.

In addition to the values mentioned in the previous section, *convenience*, *efficiency*, and *pleasure* (value codes) influence the experiences of participants. Farmers believe that there can be an immediate improvement to quality of labour due to digital farming, if it works. It is common in the interviews for farmers to say that digital farming makes their work *easier* and *more enjoyable*. Farmers are able to relax while operating machinery on the field, relying on the technology to multitask. I even spoke to one farmer on the phone while they were driving a combine. In general, operational benefits improve farmer quality of life and allow them to do their jobs better, but their experiences are complicated by other factors. In reality, the relationship between digital farming and labour is much more complex, as will be discussed in later analysis. Across the dataset, the clearest benefits of digital farming related to farm operations are the improvements to efficiency and productivity, for their potential to increase profit and decrease environmental impacts.

4.4.2 Decision-Making: 'Better Decisions' for Data-Driven Farming

It became clear in interviews and observations that farmers are constantly making difficult decisions and working through compromises. Given the challenges facing grain farmers, including environmental and economic pressures, farmers are enthusiastic about the potential of digital farming to improve their decision-making and support more efficient farm management.

> "We've employed digital technology on our farm to help us make *smarter decisions*, especially around *soil and fertility*. There is a *cost benefit* to that, from an *efficiency* standpoint." (Farmer #1)

Because of their identity as stewards, the impact of digital farming in caring for the land is very important to farmers. In this respect, 85% of respondents either strongly or somewhat agree that digital farming can improve decision-making for land stewardship (see Figure 5).

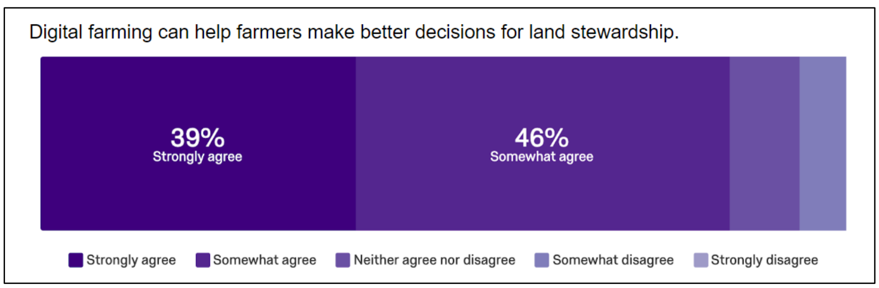

Figure 5: Better decisions for land stewardship (Questionnaire)

Collectively, participants respond positively to the impact of digital farming on stewardship. The collection of timely and site-specific information about their land helps farmers to make better decisions for crop management, such as the operational benefits of VRA. The data that digital farming yields can also help farmers handle the environmental stresses and mitigate losses.

> "I have a map up here right now because it was raining so I was in the office. *I know exactly what varieties are planted in each field*. So, I can actually go to the row and say, how does that variety compare to the other varieties? Is there a disease in this variety that is not in the other varieties? That kind of stuff, *I think is fabulous, for the information that it provides, for the ability to help me farm better*." (Farmer #2)

This year, mould and high levels of deoxynivalenol (DON) affected the harvests of many Ontario corn farmers, accounting for $200 million CAD in losses (Ontario Grain Farmer, 2019). When I spoke to Farmer #2 in the fall, he had just received an online notification on the DON-issue. He explained how he used data analytics to evaluate and predict the impact of the disease on his crops, which he would then use in deciding what to plant the following season.

The data collection involved in digital farming influences all aspects of farm operations. In the face of complex and volatile markets and climates, farmers appreciate that increased volume and frequency in data collection, as well as better quality information.

> "Certainly, *information* is the basis for making *better decisions*." (Farmer #7)

> "I believe *up until now very few farmers have had any idea of their cost of production* or where their money is coming from. And this year was the first year that we actually sat down and did a *cost of production for each crop*. So, we need those *numbers and whether we got them from digital*... some areas we saw that we're *more productive* and we're gunna have to fine-tune those." (Farmer #8)

Some farmers are using agricultural data in sophisticated ways, especially Farmer #8. From agronomy to economics, the argument is that more data leads to better decisions, although technically the quality of data is also hugely important. There are complex factors in decision-making. Participants consistently ground their rationale in *return on investment (ROI)* and the *'bottom line.'* Therefore, economic information is particularly valuable, but digital farming technology is currently limited in its applications for profitability analysis because of the complexity of changing prices in grain markets and other economic factors.

In sum, the connection of data improvements in digital farming to farmer identities as stewards and business people highlights the importance of this perceived opportunity of digital farming. Discussions of decision-making in the interviews reveal an interesting implication of more data-driven agricultural practices. There is a shifting sense of normative assumptions in what a *'good farmer'* looks like. As illustrated the quotations included above, farmers are using normative or evaluative words like *better* and *smarter* to describe digital farming, implying an improvement from existing or traditional ways of knowing. However, more information does not necessarily mean that the farmers will make 'better decisions' because of all the other factors in decision-making.

> "It just become somewhat of a more management or *more modern way of making decisions with more information at our fingertips*. So, you would assume that if it's there and easily gathered and available that we would make *better decisions*, but that *assumes that people make what we've called 'better decisions' with the information that they have*. And that is really, well it comes back to the individual person themselves and how that information is used. So, it has the potential to [improve decision-making], *but ultimately it comes back to the user of the information*." (Farmer #7)

The values and priorities of farmers influence their decision-making and farm management, which would not change in the context of digital farming. The impacts of this perceived opportunity of digital farming are complex and interrelated with other implications of the digital agricultural revolution.

4.5 Challenges of Digital Farming According to Ontario Grain Farmers

Even though farmers see the potential for digital technology and big data to improve their operations, participants express significant concerns about the implications of digital farming and feel that this is a prevalent attitude in the Ontario grain farming population. Some doubt that it is helpful at all.

> "I think, honestly, it's *overwhelming* to a lot of people because I think it's – *I just don't think you really get any value out of it*. I think it's just something else that somebody is *marketing* to try and make a profit or make living out of it. It's not making *no difference* in the outcome of the farming. Or in the environment." (Farmer #2)

Many participants are dubious about the promotion of digital farming as the 'next big thing' when they have been the subjects of so much marketing technologies as solutions in the past, while continuing to experience persistent challenges in their operations. In addition to the doubts and skepticism from both adopters and non-adopters, there are new challenges for grain farmers arising with the digital agricultural revolution. I collected a long list of issues about which farmers are concerned, but there are three dominant categories across the dataset: economic pressures and barriers to adoption; changes to skills and labour; and, risks of unreliable equipment and obsolete technology.

4.5.1 Economic Factors: 'No Choice' but to Adopt Expensive Technology

Across all interviews, farmers discuss their experience in terms of the economic dimensions, more than the environmental, social, or political. Layered on top of existing cost challenges of grain operations, the economic implications of digital farming are complex. Primarily, the judgement that digital farming is *'phenomenally expensive'* is predominant in the dataset. Digital farming tractors range in price from $500,000 to $1,000,000 dollars (Hearden, 2018; Rotz, Duncan, et al., 2019). Minor retrofitting or additions on older machinery can cost tens of thousands of dollars.

> "Technology can do a lot of stuff, but *the problem is that it costs a fortune* to set this up. A new sprayer, *well that comes to $400,000 easy*. So, a lot of it relies on the company doing the spraying, whether they can afford that, but then *you have to pay too*." (Farmer #6)

Farmer #6 explains that many Ontario grain farmers 'hire out' or pay a company with digital farming technology for planting, crop management, or harvest services to access the operational benefits without the astronomical costs of purchasing the new technologies themselves. Still, many farmers cannot afford such sizable expenses. Otherwise, farmers may find less expensive technology, but there are risks involved in cost saving decisions.

> "Well, the *problem* with [digital farming] is that it's *expensive*. Like, if you are buying *GPS systems* – We just bought ours this spring and it was *$29,000 – that's a lot of money to spend over 300 acres of crop*. It's a really high-end degree of accuracy. So smaller operations probably have to buy stuff *that's only $10,000 and isn't quite as good*. So, the cost of the digital can be really something." (Farmer #2)

Additionally, the quality and effectiveness of digital farming depends on the technology and services that farmers are able to purchase, which can disadvantage small farmers. Collectively, Ontario grain farmers experience the increasing cost of production as a primary challenge, so the price of digital farming technology and services presents as a barrier to adoption.

Despite potential economic barriers, the risks of not adopting might pose even greater challenges to farmers. Although several farmers are enthusiastic about the new technology and feel that they are adopting on their own volition, most participants believe that adoption is necessary. As demonstrated in Figure 6, below, 66% of farmers agree that adoption is essential to the viability of their farms.

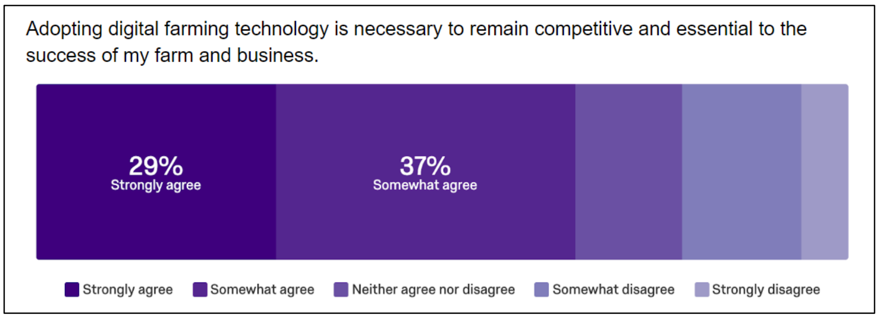

Figure 6: Adoption is necessary to remain competitive (Questionnaire)

In the interviews, participants provided further explanation. Grain farming is a highly competitive market and farmers are in a cost-price squeeze. Even if the operational benefits are marginal, farmers feel that they need to adopt the technology to keep up with others in the global grain market. If digital farming improves productivity even slightly, then adopters may be able to outperform non-adopters, which could disadvantage their business or lower grain prices to exacerbate the cost-price squeeze. Therefore, when asked about motivations and pressures, farmers often described digital farming adoption as *'inevitable'* or what they *'have to do'* in order to *'survive.'*

> "You really have *no choice*." (Farmer #11)
>
> "It's just something that *I felt I had to learn*. And therefore, you do it. *Because you have to, in order to stay up* and in order to stay relevant in the current farming economy. If this farm is going to *survive to the next generation*, you just have to be there." (Farmer #9)

Farmers feel that they are losing their autonomy. The main concern is that the farmers who adopt will have more productive and profitable farm operations and they will eliminate small or non-conventional farmers. As discussed in the context of the perceived opportunity of digital farming, some are doubtful of the economic benefits of the new technology. Although there is *no guarantee*, most farmers believe that digital farming presents an economic opportunity, but it is the context of an increasingly competitive food system that is not designed to for farmer success. Consequently, digital farming secures farmers in a double bind: the cost of digital farming is a disincentive for adoption, but not adopting may lead to their economic demise.

The economic conditions of digital farming advantages a particular farm model. Some participants believe that digital farming is in lockstep with aforementioned trends of fewer, larger, more capital-intensive farms. As Farmer #11 succinctly states, "you need to *spread the costs over enough acres*," capitalizing on economies of scale. Developers primarily design digital farming technology for industrial monocrop operations. In addition, the size of the operation matters because farmers need enough capital to invest in the new technologies. Generally, grain farms need to expand the size of the operation in order to increase profits. Many farmers believe that digital farming will accelerate the changing landscape of Ontario agriculture, but others say that the trends will continue with or without digital farming. In addition, digital farming may also create a rift between adopters and non-adopters.

> "I guess that you just should be aware of the almost *two-tiered farm community*, where you have the *adopters that are doing very well* but those people who have not adopted, *I don't know if those farms are going to continue to be viable in the future*. Just the way that technology is going. It seems that the costs of the machinery – All the machinery is based around technology now, and any new machinery comes with that technology. So, I think it just makes it *more difficult for the non-adopters to continue*." (Farmer #9)

Given the economic conditions of grain farming, non-adopters may be in an increasingly precarious position. Moreover, the new technology is increasingly difficult to avoid because it is a part of most new machinery. Even if farmers decided that they did not want to adopt, they may lose control over the decision based on the technology that is available to them.

Taken together, this evidence contributes to the theme of economic dimensions in farmer experiences and perceived challenges of digital farming. Concern for the cost of digital farming technology is widespread in the research population, according to study participants, where the cost presents a barrier to adoption. However, the choice not to adopt in a competitive market with tight margins may lead to the operation's demise. Thus, many farmers feel that they have no choice but to adopt. Even the farmers with whom I spoke that did not feel external pressure to adopt digital farming describe a lack of choice or a sense that the digital agricultural revolution is *'inevitable.'* The economic pressures also interact with the trend of increasing farm size because larger farms generally have more capital available to invest in new technology. Smaller or non-conventional farms may not be able afford adoption, which could make their operations unviable in the future.

4.5.2 Adoption: Capacities, Skills, and 'Keeping Up with the Technology'

In the past few decades, changes in agriculture have proceeded at an accelerated rate. Global grain markets are increasingly interconnected and financialized; the climate is changing; farmer-consumer relationships are evolving as distance increases but public interest in health and environment peaks; and, technology is innovating at an unprecedented pace.

> "*Agriculture is constantly in a state of change*. The problem that I see is that it is *changing so fast now* that it is almost impossible to stay ahead of it. I try very hard to stay ahead of it. And it's *starting to get ahead of me!"* (Farmer #10)

> "The *biggest challenge* for us has been *keeping up with the changes in technology and the changes in the way that you farm…* I think even if we weren't converting to organics, keeping up with the technology that is available *and using it to our maximum benefit*. That's probably the biggest challenge." (Farmer #2)

Many grain farmers in Ontario have been farming for generations, but technological 'advances' have dramatically altered farming operations and the capacities needed to farm. In addition, farmers make the astute observation that some digital farming benefits are conditional on new capacities and skills. For instance, putting a yield monitor in a tractor does not, in itself, increase productivity or profits. Economic conditions are pressuring many farmers to adopt digital farming, but this presents additional challenges of learning how to use and benefit from the technology. Moreover, there is a risk of negative agronomic results from misinterpreting the data. Thus, it is common for farmers to feel *overwhelmed*.

While many farmers have exceptional capacities and skills for their operations, from a combination of tacit knowledge, intergenerational teaching, and formal education, farmers do not feel that they have the supports needed to learn how to use digital farming effectively. Participants who are most comfortable with digital farming often also have off-farm employment that provides time and resources to become proficient with new technologies. Other advantages include farmers who went to school more recently or have more familiarity with technology in their everyday lives. Many participants believe that age is an important element in adoption, often thinking in terms of generations. However, discussions of adoption and building capacities for new technology interrelate with key values of *knowledge*, *tradition*, and *trust*. Farmer #4 describes the different experiences of digital farming across the three generations working on his farm.

> "Some people, it's going to take them more time, the older generation. *My grandfather won't get into any of the new equipment. He is a lever puller, not a button pusher*. Whereas my parents and my uncle's generation understand levers and they understand buttons. Whereas my generation – I am rather mechanical – so, I understand the levers and the buttons and the *virtual dashboard*… It was a full year of running that combine by himself before my uncle would use it [auto-steer] … *It took him a year to become comfortable enough to trust that system*." (Farmer #4)

Here, there are differences in *traditions* and expectations of farming practices. One's identity relates to their *knowledge* and experience of farming, as a 'lever puller' or 'button pusher' for instance. However, with time, farmers can develop the comfort to *trust* new technologies. Other participants argue that loyalty to traditions and the status quo is too strong for older farmers to adopt digital farming. Still, age is not a necessary condition of adoption or familiarity with digital farming in this study. Of the farmers who stated in the questionnaire that they are presently using digital farming, 41% are older than 54.5, the average age of Ontario farmers (Statistics Canada, 2017c). Additionally, in the interviews, some enthusiastic adopters are over 65-years-old. Overall, there is a theme in the interviews that everyone experiences digital farming differently, where factors in adoption are more complex than individual characteristics, like age.

Lastly, the challenge of changing capacities and skills affects labour. Despite potential fieldwork efficiencies and improvements to farmer quality of labour, it is not the case that digital farming necessarily alleviates labour overall. The need to develop new skills is *labour* and it take time, particularly in the context of continuous change. For instance, Farmer #1, a farmer-entrepreneur, says:

> "To read all the manuals for all the stuff that you have is *time-consuming*. And *once you know it, you know it, but by then something else has come out* and you've swapped it in and out of machines." (Farmer #1)

This challenge is continuous because digital farming will continue to evolve, rendering previous technology – and the knowledge required to make use of it – obsolete. It is also worth noting that learning about digital farming is a new kind of knowledge; not only are farmers facing new machinery, but they must engage in a new way of thinking to understand computers and data analysis. In addition, the new skills and capacities required to operate digital farming technology heighten the challenges of finding and affording the labour of others, particularly in the context of an aging labour force and a growing employment gap in Ontario. Farmers also explain that digital farming significantly alters their labour over the winter months. The labour burden of planning for the season is much higher, which can pose challenges for quality of life and mental health. These extend into the year because, as Farmer #5 puts it, farmers can *"become addicted"* or *"get swallowed up"* by the technology and continuous flow of information.

4.5.3 Technical Difficulties: Risks of Unreliable Equipment and Obsolescence

The third category of challenges refers to technical issues and their consequences. Generally, participants feel that digital farming developers are overpromising and underperforming. Farmers are very concerned about the reliability of digital farming technology. Unfortunately, many farmers have already experienced unreliable digital farming equipment. Last year, Farmer #4 spent nearly $1,000,000

CAD on digital farming tractors that "completely *failed to function* in any way, shape, or form," causing huge economic losses and a great deal of stress. This section will feature several quotations from Farmer #4 because his interview demonstrates extreme cases of equipment related challenges, and he communicated several important points particularly well. However, technical challenges and their implications permeate through the dataset. In addition to the risks of buying expensive technology without guaranteed returns, faulty equipment on the field can compromise an entire harvest, especially with unpredictable weather and increasingly narrow windows to get things done.

> "In agriculture you have *a very specific and limited window* to make some of that stuff happen… You don't get today's weather tomorrow and when the seed needs to be in the ground it needs to be in the ground. *And if it's not in the ground by a certain date, it's costing you yield. And costing you yield is costing you money*." (Farmer #4)

When the equipment does not work, small changes to planting, spraying, or harvest can compromise yield and profits for the season. Contextualized by cost-price pressures and climate change, unreliable equipment poses significant economic risks to farmers. However, the ubiquity of digital farming in new equipment presents barriers to alternatives.

Farmers view the new technology as considerably less reliable or trustworthy than the older technology. Digital farming is also more complicated, contributing to the challenge of new capacities and skills. As discussed above, digital farming technology requires new skills and capacities to operate, and the same is true for repairs. Moreover, the high stakes of faulty equipment make repairs and service to farm equipment increasingly important, as Farmer #11 describes in the following quotation.

> "You have five different screens in your tractor cab when you are going down on the field and something screws up. *You either have to have somebody who is really good at troubleshooting or you have a lot of downtime* which is something that – because of the time pressures in agriculture – you just *cannot tolerate*." (Farmer #11)

Although most farmers hone mechanical skills for repairing equipment, most farmers do not have the capacities to repair digital farming technology. Challenges of adoption and changing capacities contribute to technical challenges. Most farmers who adopt digital farming are reliant on the companies that develop and sell the technology, for the tools and knowledge to operate and service them. Farmer #4 explains that farmers traditionally owned their equipment, understanding tractors as their property. Today, he makes payments on tractor, but does not own it, which he later compares to renting. Not only are there limits to the capabilities of farmers to repairing the technologies, but farmers no longer have ownership or control over their machinery. Furthermore, even if farmers are able to fix the new technology, digital farming companies enforce product agreements and intellectual property law that prohibit farmers from repairing or tampering with digital farming technology that they own. Again, digital farming compromises the autonomy of farmers.

Participants describe very different experiences of receiving support from the companies that provide digital farming equipment and services. For instance, Farmer #2, a 67-year-old organic farmer and digital farming enthusiast, expresses his excitement for the potential of information technologies to accelerate repairs; he can take a picture of a broken tractor piece on his phone, send it to the dealership, and they immediately place an order for a new part. However, other participants have experiences that are more negative. When asked about the risks of digital farming, Farmer #4 answers:

> "I would say that the risks are *the failure of the equipment and the failure of the system* to be able to provide us with their obligation to provide us with what we were paying for… a *lack of reasonable serviceability* of some of the newer technologies that are to some degree being *forced upon us…*
>
> "So, if today says that I need to be planting and my tractor is broken and my dealer says that he can get me a tractor, it might not be until tomorrow until that tractor shows up. It just simply takes some time to be able to work out these problems." (Farmer #4)

Farmer #4 is extremely disappointed. The expensive digital farming equipment failed to work during the spring planting, with devastating consequences for his operation. As stated in the previous excerpts, agriculture cannot tolerate delays due to narrow windows in weather and tight margins. In addition, he described a frustrating relationship with the service providers, who were unable to service the machinery in a timely fashion or to satisfying degree. Technical issues continued throughout the season and all four tractors were eventually returned to the dealership due to severe safety concerns. Due to a confidentiality agreement with the company, he was not able to tell me the brand of equipment or some details of his experience.[32]

Some farmers are hopeful that continued innovation will improve the quality of technology available and make it more reliable. However, constant change also presents challenges. Besides the risk of technology not working, some participants believe that there is a sizable risk for the technology to become obsolete. Farmer #2 speaks to the risks of obsolescence.

> "Computers tend to become obsolete or wear out after two, three, maybe four years… so the risk is, you know, *if you are buying a combine, and you are planning to keep it for 15 years, like people use to do, the combine maybe working fine, but the technology may become obsolete.*" (Farmer #2)

Participants experess concerns that the technology would become obsolete in a matter of years and the entire tractor would be useless. Not only is digital farming equipment more expensive, but it also will need to be replaced more frequently, from decades to a matter of years. Even if there is only one part of the computer that is outdated or in need of repair farmers fear that they would need to replace the

[32] This raises questions about corporate power in structuring narratives, but I set aside this analysis.

entire machine, much like experiences of information communication technology in everyday life. Farmer #4 offers a powerful anecdote, comparing a harvesting combine tractor to an iPad tablet.

> "I can't update the iPad because the new iOS system is larger than the memory in the thing. *So, I had to go and buy a new iPad*. There is nothing wrong with the old iPad, but it is now *technologically obsolete*…
>
> *The iPad is worth $600 or $700, but my combine is $700,000!* And if I have to buy a new one every other year just because they will no longer service the computer that runs it, well I can't just take that computer off and put a piece of bailer twine on the ejector pipe and pull on the bailer twine. *It doesn't quite work that way [laughs]. It used to, but it doesn't anymore*." (Farmer #4)

Although there was nothing technically faulty or broken, his iPad became obsolete after a few years. In the past, tractors could operate without significant challenges for decades, and farmers had the capacities to address any problems that arise. Now, farmers are unable or prohibited from repairing their machinery and it may become obsolete within years. The economic losses of needing a new tablet every few years are much more detrimental to farmer livelihoods than the replacing an iPad.

Finally, participants point to general challenges of the broader research population. Most Ontario grain farms are located in rural settings. There are significant infrastructural challenges for information communication technology in rural areas in Ontario, and North America more broadly, which compromise the effectiveness of the digital farming equipment. Much of the digital farming enabled-equipment requires access to broadband communication (e.g., 4G, LTE) to upload the data that it collects to 'the cloud' or the servers of the companies that provide digital farming services. However, participants experience poor quality broadband communication for internet access and limited access to mobile service and data towers. In addition, there are periods of several hours where machinery will not access a satellite service, which disables GPS equipment like auto-steer on tractors. Another challenge for rural farmers is the limited choice of retailers due to their geographic area. For instance, to visit a dealer other than the local Kubota and John Deere, one farmer must drive 150 kilometers.

4.5.4 What about the Data Concerns? 'Forced to Accept it and Drive On'

The final topic in this section refers to *data* concerns, including *ownership*, *access*, *privacy*, and *control*. Although the results do not support the classification of data concerns as a central challenge of digital farming, there are important elements to consider. The questionnaire and interviews gathered information on farmer perceptions of data concerns, based on the centrality of the theme in literature reviewed. Interestingly, data concerns did not emerge as a persistent challenge of digital farming across the respondents. In the questionnaire, when asked if they were concerned about the power of corporations over the use of their technology and data, 61% of respondents either strongly or somewhat agreed with the statement (see Figure 7).

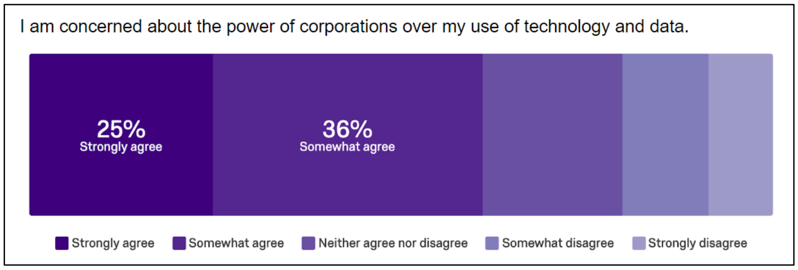

Figure 7: Concerns regarding the use of farmer data (Questionnaire)

As illustrated above, most farmers express some level of concern about corporate power with respect to technology and data. When comparing across the dataset, I see that each possible response to the question above is represented by one or more farmers in the interview. I was able to take a deeper look at the 'big data question' in interviews, revealing interesting contradictions. While the other three challenges are prevalent across the sample, there are opposing beliefs regarding data among study participants.

When taken collectively, participants demonstrate a wide diversity of attitudes and beliefs. In the interviews, I asked each participant: "Do you have control over your information and digital farming technology? How much do you trust the companies that handle your data?" Some farmers are reasonably optimistic and see the companies collecting and analyzing data as service providers, with their best interest at heart. Given the prompt above, Farmer #7 responds:

> "I guess I would *trust* them for the most part. [hesitates] *I am not too concerned about the companies that have the data, because the data is to some extend meaningless it's more the interpretation of the data*. If the data is on an individual basis it has limited risk to coming back to be detrimental to an individual farm. *And from the standpoint of the companies, it provides them some feedback so that they can position themselves to better serve the customers*." (Farmer #7)

Farmer #7 feels that he can trust the companies supplying and servicing the digital farming technology that he uses because there is little perceived risk of sharing data. Some participants believe that the companies are offering a service and access to farmer data can improve their products, which has the potential to help their customers. A few farmers are keenly aware that the access to data is of tremendous value to digital farming companies. In addition to access to data, the accumulation of data for analysis and predictions changes the nature of data concerns. Farmer #9 says, "It's not necessarily that I am worried about my information, but they *seem to have a big advantage by having everyone's information*." However, there are other participants with very different perspectives. When asked about risks of big data in agriculture, Farmer #8, who is an enthusiastic adopter, answers honestly:

> "*I don't know*. I'm very blind on that. Probably, I'm very naïve on that. Well, I always sit back and think *'why would somebody else want my data?' and 'what value is it to me?'*" (Farmer #8)

For some participants, the implications of data collection are not something that they know very much about, even if they 'agreed' to the questionnaire statement regarding data concerns. The general sentiment is that farmers feel like data issues might be important, but that they are not deserving of much of their time and attention.

Given the other pressures and challenges facing farmers every day, thinking about all the possible risks and problems of big data is simply *'beyond their scope.'* Some participants express acceptance or are dismissive of the potential risks.

> "If you're doing something that is going to benefit you, *you are giving up some right to your data* somewhere along the supply chain. *You don't get things for free and expect to have total control over everything*. It's like Google, you know, if you have a Gmail account, they are gathering data about you." (Farmer #1)
>
> "*And are we at risk? Absolutely*. Do we need to worry about it? Yep, we should put what safeguards we can in place. *But I don't know. I think you'll drive yourself batty if you worry about that*. (Farmer #11)

There are too many other challenges and changes for farmers to be able to keep up with the new technology and the potential implications. There is a sense of acceptance in the perceptions of farmers; it might be a problem, but there is nothing really to be done about it. In response to the increasingly vulnerability of farmers in the age of big data, Farmer #9 explains that farmers are *"forced to accept it and drive on,"* much like the many terms and conditions or user agreements that people accept in everyday life. The acceptance and lack of control of farmers concerning data aligns with other challenges of digital farming, such as the economic risks. Participants explain that they do not have a choice but to buy into the new farming equipment and practices.

4.6 Chapter Summary

This chapter covers a wide range of topics in an overview of the empirical results to address the second research objective and prepare the results for further discussion. The research sample is reasonably representative of the population of Ontario grain farmers, though participants are somewhat older and more educated than the average farmer in the province. The majority of respondents operate farms over 350 acres and own the land on which they work, suggesting a certain level of economic stability and cash flow. Moreover, 73% of respondents currently use some form of digital farming in their operations, where cellphone applications, GPS, and GIS are most common. The descriptive statistics and summary of contextual information positions the interpretation of farmer perceptions. Ontario grain farmers experience tension in their sense of self as producers, stewards, and business people. Several participants also feel a responsibility to feed the world. As previously established, Ontario grain farmers face complex problems as actors in local and global food systems. The results demonstrate widespread concern regarding increasing costs, unpredictable weather, and labour constraints, as key challenges to grain farming. The perceived challenges illustrate priorities and values of participants, as well as the continuous compromise of *profit*, *yield*, and *stewardship* in agriculture. Furthermore, tensions in farmer interactions with non-farmers were a recurring theme in the interviews. Farmer relationships with government officials, environmentalists, industry actors, and consumers, present challenges and elicit attitudes of *frustration*, feeling *misunderstood*, and lacking *trust*. Collectively, these results describe the landscape of Ontario grain farming and the context in which farmers experience digital farming.

Overall, there is a congruent understanding in the population of Ontario grain farmers that they are experiencing a digital agricultural revolution. The data analysis of questionnaires, interviews, and fieldwork observations revealed emerging themes of challenges and opportunities from the opinions and experiences of participants. Many participants are optimistic about the potential of digital technologies and big data applications to help farmers. Opportunities of digital farming present in two categories: operational benefits and improvements to decision-making. Many participants believe that new technologies can support more efficient, productive, and profitable farm operations. In addition, digital farming relies on data collection and analysis that can offer more information on which farmers can base their decisions for business and stewardship. As a result, agriculture becomes more modern and data-driven.

Presently, the challenges outnumber the opportunities, but many farmers feel that they have 'no choice' but to adopt. First, participant unanimously agree that digital farming technology and services are extremely expensive, in the context of already tight margins. Despite the economic disincentive in the cost of the machinery and the skepticism regarding potential benefits, participants explain that adoption is necessary in order to survive in an increasingly competitive sector. Second, digital farming poses challenges in relation to the new skills and capacities required in order to operate and benefit from the technology. Likewise, the new skills affect the availability and cost of additional labour on the farm. Third, the risks and consequences of unreliable equipment or timelines of technological obsolescence are critical, particularly for expensive equipment. Even small delays or malfunctions can compromise the yield and result in significant economic losses. In summary, Ontario grain farmers understand that digital farming is a complex phenomenon, affecting many aspects of their lives in diverse ways. The results in this chapter indicate that digital farming is changing the realities of the participants, with the potential to address some of their existing concerns while causing new challenges.

Chapter 5
Discussion

5.1 Introduction

This discussion analyzes the evidence presented in the preceding chapters to explain the findings, consider their significance, and make comparisons with existing literature on digital farming. I consider the study results holistically to answer the research question: *How do Ontario grain farmers perceive digital farming, and how do their perspectives compare to public debates and academic research?* Building on the evidence on farmer perceptions above, I discuss the two other parts of the question. To begin, I return to the first research objective to revisit the key narratives in public debates and compare farmer perceptions with those of proponents and critics. Specifically, farmers respond to economic promises and the proposition of digital farming as a solution to food insecurity. The following section brings the analysis together to address the third research objective. Emphasizing political dimensions and farmer experiences, the discussion will centre on the implications of digital farming for power relations, data concerns, agricultural labour, and environmental impacts.

5.2 Comparing Farmer Perceptions with the Promises of Digital Farming

In the second chapter, I described the central promises of digital farming, according to proponents: *Digital farming promises to improve agricultural efficiency, productivity, and profits, while addressing the challenges of a growing population and a changing climate*. Recall that affirmative and negative arguments for digital farming in public debates come from two dominant perspectives, espoused by diverse populations. In this section, I will discuss whether farmer perceptions align with the dominant proponent narrative and its promises. As discussed in the previous chapter, there are diverse and conflicting perspectives within the population of Ontario grain farmers, some of whom would identify steadfastly as proponents or critics of digital farming. In contrast to the binary narratives of proponents and critics in public debates, however, this study finds that Ontario grain farmer perceptions of digital farming are more nuanced and complexity-informed. Farmers must juggle complex and uncertain factors in their decision-making, which inform a much more nuanced opinion of digital farming. Participants make judgements of digital farming and its proponents grounded in tensions in their identities as both stewards and business people. Furthermore, just because a farmer adopts the new technology does not necessarily mean that they agree with all aspects of the proponent narrative.

Generally, farmers agree that digital farming could be a solution to some of the problems in the food system, but they remain *skeptical*.[33] Even the most enthusiastic adaptors with whom I spoke, like Farmer #5, understand the limitations of digital farming and the importance of how it is applied.

> "*I don't think that digital technology is the answer or the solution to everything.* I do hope it's just *another tool in the toolbox* that we can have to make farming more positive [better]" (Farmer #5)

Farmer #5 is hopeful that digital farming may live up to some of the promises of proponents, but she appreciates that the tools are limited. The participants explain that the effectiveness and potential benefits of digital farming depend on the individual farmer and the conditions of their operation, including economic stability, debt, education, and comfort with the technology on adoption. Situated in the contextual perspectives of Ontario grain farmers, as represented in the data generated in this data, this section reconciles farmer experiences with the digital farming promise. More specifically, I will evaluate participant responses to two key claims: digital farming will improve profits and economic wellbeing for farmers, and digital farming address food system challenges such as food security.

5.2.1 Improving Efficiency, Productivity, and Profits

Proponents promise that digital farming will make food production more efficient, productive, and profitable for farmers, regardless of the size or approach of their operation (Bayer, 2018b, 2019b; Proagrica, 2018b; Real Agriculture, 2017; The Climate Corporation, 2017; Trimble, 2018; van Rijmenam, 2013). Bayer asserts that technological innovation can "make agriculture more efficient and also more sustainable at the same time" (Bayer, 2019b), appealing to farmers' identities as "both business owners and stewards of the land" (Bayer, 2019a). Similarly, Lawrence MacAulay, Minister of Agriculture and Agri-Food, claims that government support for biotechnology and digital farming "will contribute to Canada's place as a world leader in agricultural clean technology, helping farmers… while also protecting our environmental resources and mitigating climate change" (Government of Canada, 2018b). Proponents argue that the economic benefits will not compromise other social or environmental gains.

The results presented in the previous chapter reveal the majority of participants perceive themselves as producers. As such, farmers pay careful attention to the risks and opportunities of digital farming on their ability to produce food. According to the empirical data in this study, participants believe that digital farming has the *potential* to increase efficiency, productivity, and profits for farmers. Operational improvements are the most prominent opportunity of digital farming in the empirical data.

[33] The 'single quotation marks' signify an *In Vivo* code (see Chapter 2). "Double quotation marks" indicate that I am quoting a farmer directly. *Italics* are to mark emphasis and important codes in the text.

However, economic benefits are conditional. Some participants believe there may be small economic gains of digital farming, but there is *'no guarantee.'* Farmer #11, speaking from experience in digital farming research and working in the media, reports the following:

> "When you look at the meta-analysis of the studies out there, it suggests that the *profitability was 1.5% and that really did not cover the increase in costs...* Individual components I think are economical, but the system as a whole as it stands today has *not made many farmers much money*." (Farmer #11)

In the quotation above, Farmer #11 refers to evidence presented at a recent farming conference that he attended. He goes on to explain, "Most of the time the answer is that they have been *spending a lot of money* and so far, have *not seen outstanding return* on that investment." For now, there is little evidence to support the economic promises of digital farming on the ground.

Taken collectively, there is a prevalent belief in the potential of digital farming in the empirical results on farmer perceptions. Some participants are adamant that they are already reaping financial rewards of adopting the technology. However, farmer perspectives are polarized. In the interviews, I asked, "Businesses and governments claim that digital farming will increase the profits and economic wellbeing of farmers. Do you agree?" While a few participants responded to this question with neutral or uncertain views, most are at either extreme. Some are hopeful:

> "*Yes. As a general statement, I think it absolutely does*. Focusing in on what the grower knows about their *land and the equipment* that they have and the *technical knowledge* that they have will drive the key products that will allow them to have a bigger *ROI [return on investment]*. (Farmer #1)
>
> "*Very much so*. What it likely will do though, and the trend has been going on now for a couple generations, it will allow them to *farm more farms*." (Farmer #2)

Participants who are amenable to the proponent narrative rationalize the potential for digital farming to improve efficiency, productivity, and profits based on the specific characteristics of the operation and the individual farmer's capacities, as stated by Farmer #1. Furthermore, the ways in which participants perceive digital farming promises relates to their views of broader trends. Farmer #2 believes that digital farming will improve the economic wellbeing of some farmers, but that it will also continue the consolidation of farms and increase competition.

At the same time, many participants disagree with the economic promises of proponents. In response to the question above, some participants respond:

> "*No, absolutely not*." (Farmer #4)
>
> "*The companies are out there to make a dollar for themselves*. We have to remember that they're not out there to help me, they're out there to help themselves." (Farmer #8)

> "*No. Not for farmers*. The data that we are going to reap will be harvested by the *government or large corporations*. Farmers will *not make one cent. Not in the long term*." (Farmer #10)

Participants who are skeptical of the promises point to other non-farmer groups who will see the benefit of digital farming, in line with their perceptions of relationships in the food system. Not only are participants skeptical of digital farming's promises, but they also believe that the proponents who make such promises, namely governments and TNCs, are likely to benefit at their expense. Although the initial responses appear to be binary, the interviews provided rich descriptions of farmer perceptions. Each of the three critical farmers listed as examples above explain that farmers may be able find ways to profit from digital farming technologies. Farmers can hold conflicting truths and find ways to make the most of the conditions in which they live.

As outlined above, the proponent narrative says that digital farming will benefit everyone, not only big industrial farms. In the emerging scholarly literature on digital farming, most scholars take the opposite stance (Bronson, 2019; Bronson & Knezevic, 2019; Fleming et al., 2018; Mooney, 2018; Morena, 2018; Rotz, Duncan, et al., 2019). In some ways, the views of farmers in this study align with the proponents. Participants argue that digital farming *can* help any farmer. However, they insist that some are more likely to benefit than others. Many participants believe that farmer with large conventional operations have an advantage in the digital agricultural revolution, which aligns with theory in academic literature reviewed above and the narratives of critics. Participants believe that farmers with diverse operations can experience benefits of digital farming. As Figure 3 illustrates in the previous chapter, 73% of respondents disagree with the statement that digital farming only helps big industrial farms. Digital farming refers to a diverse suite of technologies and changing farming experiences. Many technological innovations, like smartphone applications, are well suited for smaller farms or non-conventional operations; indeed, some participants are enthusiastic adaptors with organic or agroecological farms. Furthermore, the diversity of digital farming applications – such as the use of GPS and sensors on Farmer #2's organic soy operation – may become an important leverage point for change toward more sustainable agricultural practices. Much like farmer interviews for digital farming studies in Australia and Ireland (Jakku et al., 2018; Regan, 2019), empirical data in this study suggests that it would be an oversimplification to say that digital farming will only benefit large conventional operations.

Overall, participants are skeptical of proponents and economic promises of digital farming, even if they agree with some of their claims. Although participants highlight the potential for digital farming to benefit any farmer, there are considerable challenges associated with digital farming, which are less likely to harm farmers with large conventional operations. The cost of the new equipment and services causes farmers to doubt the possibility of realizing economic promises of digital farming. Given the economic challenges of grain farming in Ontario and the volatility of grain prices, it is difficult to justify such a large expense with any sense of a reliable return. In the literature, the cost of digital farming is one of the most prevalent barriers to adoption (D'Antoni et al., 2012; Reichardt et al., 2009; Silva et al., 2011; Tey & Brindal, 2012). Like the participants in this study, farmers interviewed in Europe and Australia assert that costs of digital farming present significant financial risks (Barnes et al., 2019; Fleming et al., 2018; Regan et al., 2018). Still, many farmers in Ontario and elsewhere are choosing to adopt.

5.2.2 Solving Food System Problems and Feeding the World

The proponent narrative claims that digital farming can overcome complex challenges facing the future of food, such as ensuring food security in a future with a growing population and shrinking arable land (Bayer, 2019b; Proagrica, 2018a; Wolfert et al., 2014). This message is prevalent in public debates and the media, where many articles and blogs open with the challenge of feeding the growing population or include it in the title – e.g., "How big data is going to help feed nine billion people by 2050" or "How Smarter Technology Will Feed the Planet" (Gilpin, 2014; Karmi, 2019). Global agricultural production presumably already produces enough food for the future population (Holt-Giménez, Shattuck, Altieri, Herren, & Gliessman, 2012).[34] However, a large majority of conversations about digital farming begin by explicitly stating the opposite assumption: we need more production to feed the world. The Climate Corporation asserts, "rapid [population] growth translates to an urgent need to find more efficient, sustainable ways to grow substantially more food" (The Climate Corporation, 2019). This narrative influences the ways in which various actors perceive and experience digital farming. In Carolan's study of digital farming perceptions in the US, "everyone interviewed from the 'farmer' and 'big data industry' groups made some reference to a growing population that needs to be fed, with the assumption that current alternative practices (agroecology, organic agriculture and the like) are insufficient to achieve this end" (2016, p. 142). As introduced in the literature review, discussions of food security in the digital agricultural revolution align with patterns of productivism and the dominance of

[34] Whether global agricultural production could feed all of humanity today (or in the future) is an extremely controversial question. This is likely due to the methodological challenges of such an evaluation, as well as the political assumptions on the causes of food insecurity embedded in the statement. Those studying food systems conclusively prove that food insecurity is not due to a lack of food; it is a complex interaction of ecological, social, political, and economic systems (Ericksen, 2008; McKeon, 2015; Sen, 1981). Moreover, there is extensive research to support the assertion that there is already enough food to feed up to 10-12 billion people, depending on estimates (D'Odorico et al., 2014; Foley, 2011; Foley et al., 2011; Godfray et al., 2010; Holt-Giménez et al., 2012).

industrialized agricultural practices (Bronson, 2018; Carolan, 2018b, 2019; D. C. Rose et al., 2018; Rotz, Gravely, et al., 2019).

To understand whether farmers agree with the promise that digital farming is essential to feed the world's growing population, the underlying assumptions and understanding of food security in farmer perceptions must be clear. Therefore, I included multiple questions in the interviews that explored food security from different directions. For instance, I read the following prompt to each farmer:

> The UN Food and Agriculture Organization explains, 'Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (FAO, 2006). What does food security look like to you, and what role does farming play in establishing food security?

I chose to use this definition from the FAO's 1996 World Food Summit, for its clarity, prominence in food security discussions, and perceived neutrality. Responses to this question varied widely, providing meaningful insights for the study of farmer perceptions. Definitions of food security are fluid and changing in their socially constructed realities (Williams, 2009). While there are elements of farmer perceptions that aligns with the productivist paradigm, the interviews revealed much more nuance in their understanding of food security.

Although feeding the world is central to the proponent narrative, it is not relevant to the experiences of all Ontario grain farmers. Recall that, while 82% of interview participants expressed that *'the role of a farmer is to produce food,'* only 45% believe that *'the role of a farmer is to feed the world.'* To some participants, food production does not relate to feeding the world; the farmer's responsibility ends when the crop is sold. Interview questions on food security surprised many participants because it did not seem relevant. There are two important contributing factors to farmers' lack of concern about food security. First, many participants believe that there is already '*enough'* food, especially in Canada. Participants believe there is an '*abundance'* of *'cheap'* food, which it is and *'accessible'* to most people.

> "*There's enough food in the world right now*. In fact, we are in a surplus situation. It's *distribution and affordability*. That is part of the problem, and the other part of the problem is just because we have enough food, *if you give it to people that actually doesn't solve the issue*." (Farmer #11)

Farmer #11 explains that current food insecurity is not the result of an insufficient supply of food, but rather a problem of distribution and accessibility. Many other participants echo this perspective. The quotation also points to the second contributing factor. According to participants, increasing production will not ensure food security; farmers do not have the power to feed the world.

> "*It's not an issue that's the responsibility of the farmer. It's more of a responsibility of society and the government that can reach them*. Because the food is obviously available, it's just not in the right people's hands." (Farmer #9)

When considering who bears the responsibility of addressing food insecurity, it was common for participants to point to social services or the government, which suggests that farmers diverge from the productivist understanding of food security when contemplating local or national food systems. Farmers also have a clear sense of power relations in the food system.

In contrast with the general lack of concern regarding local food security, other elements were more important to participants. According to the interviews, most farmers do not consider food security to be a Canadian issue or one that is relevant in the short term. However, the beliefs and problem frames change when participants discuss food security in the future and at a global scale. Digital farming proponents often make sweeping declarations that digital technologies and big data applications in the food system are essential to food security because they will increase food production in line with the demands of feeding the world. In the interviews, I asked farmers to respond to this claim. There is a unanimous agreement that digital farming alone will not satisfy future global food security. Most of the participants understand the complexity of food security beyond increasing supply. Yet many still believe that the global population, particularly in the future, requires more food than is produced today and that digital farming will play an important role. Farmer #9 asserts that "we *definitely have to increase production* in order to feed 10 billion people," and many participants share this belief. Still, the comparison between the *'feeding the world'* theme and farmer perceptions is not clear-cut.

The interview responses are varied, but there is a potential connection to broader worldviews. For farmers who embrace the economic priorities and faith in science and technology from productivist paradigms, digital farming is an essential tool for future food security. This subset of participants explains that more data leads to better decisions, which can maximize yield and address food insecurity by increasingly production. For example, when asked if he agrees with the food security promises of digital farming proponents, Farmer #1 says:

> "No. *I don't think that digital farming alone will close the gap of food insecurity* related to the individuals who don't have food. Those are economic driven decisions… I think that *digital farming will help us grow more food per acre on a global basis, which will allow us to feed more mouths internationally*." (Farmer #1)

He does not agree with the proponent narrative, but he still believes that it is important to increase agricultural production to feed the world. When asked if he had any final thoughts at the end of the interview, Farmer #1 returns to this point: "We are going to have to make *smarter decisions to feed the world* and it's [digital farming] going to play a big role." The participants understand that the causes of the problem are complex, even if part of the solution (i.e., grow more food) corresponds to the reductionist frame of food security in the dominant productivist paradigm. According to participants, meeting the needs of a growing population is not a discussion of techno-fixes or a binary of adoption versus business as usual. Farmers are able to hold multiple, potentially conflicting truths, and to understand compromise in the food system.

5.3 Comparing Farmer Perceptions with Themes in Scholarly Debates

In this section, I will compare the empirical data from the interviews, questionnaires, and fieldwork observations with the themes in the related academic discourses. Chapter 3 presents the existing academic literature on digital farming in transdisciplinary social sciences along four main themes: power, data, labour, and environment. While the narratives and claims of proponents and critics in public debates provide the structure for the first half of this chapter, the remaining discussion addresses each theme to reconcile the experiences and perspectives of Ontario grain farmers with the theory and empirical results from existing research, addressing the study's final research objective.

5.3.1 Power Relations: Farmer Autonomy and Corporate Power

The digital agricultural revolution takes place in the context of existing power asymmetries in the global food economy, but the impact of digital farming on power relations remains uncertain. To date, the majority of the literature reviewed argues that digital farming risks reproducing uneven power relations in the food system (Bronson, 2018; Bronson & Knezevic, 2016b; Carbonell, 2016; Carolan, 2018b; Rotz, Duncan, et al., 2019; Rotz, Gravely, et al., 2019). Researchers exploring the possible 'winners and losers' of the digital agricultural revolution claim that corporate actors are most likely to find big gains at the expense of producers and consumers (Carolan, 2018a; Fleming et al., 2018; Regan et al., 2018). Concerns for the impacts of corporate power in digital farming on justice and sustainability are prevalent in the narratives of critics in public debates, as is represented in civil society reports (e.g., Bassetti et al., 2017; ETC Group, 2016; IPES-FOOD, 2017; Mooney, 2018; Morena, 2018). Interestingly, the participants in this study not particularly concerned about corporate power, although they do perceive a growing power differential between famers.

In this study, there are counterintuitive tensions between corporate power and farmer autonomy. As previously discussed, industrialization, neoliberalism, and corporate concentration in the food system can compromise farmer autonomy. Much like the literature on digital farming suggests, empirical data from this study reveals that farmers are aware of several ways in which the rise of digital farming threatens their autonomy, including economic pressures to adopt expensive technology, challenges for labour and new skills required, and the lack of control over equipment. But there is limited sense that TNCs or other industry actors developing digital farming are to blame for these challenges. A small number of those interviewed feel that corporate power is a concern, as illustrated in the earlier discussion of data ownership and access. The majority of participants were much more concerned about the power of governments, activists (e.g., environmentalists and the "anti-science"), and the whims of the public as determining the conditions of their livelihoods.

Implications of corporate power in the global food economy include shaping farmers' sense of self, subjecting farmers to economic risks, and eliminating choice by reinforcing industrial agriculture and the products that it requires, namely the agrochemicals and GM seeds sold by agribusiness (Clapp, 2017; Rotz & Fraser, 2015; Stock & Forney, 2014). As previously discussed, TNCs exert power in shaping the frame of digital farming as a solution to food system challenges. Further still, beyond discourses and norms, corporate power also determines the structure of the digital agricultural revolution and the farming practices that are likely to persist in the future, namely large industrial monocrop operations that rely on the ag-inputs and equipment sold by corporate digital farming proponents. For example, in a recent study of digital farming developers in Canada and the US, interview analysis reveals that "decisions about data collection and the building of infrastructures [for digital farming] reproduce historic relationships of power by serving already powerful food system actors and the current dominant food system model" (Bronson, 2019, p. 3).

Generally, farmers are acutely aware of the symptoms of corporate power to which the academics studying power are referring, namely an increasingly competitive market, shrinking margins, and lack of choice. Ontario grain farmers are witnessing the transformation of agricultural land to fewer, larger farms as a result of economic pressures. In response to this trend, Farmer #10 explains, "the reason they [farmers] are big business is because *they got pushed into being big business,"* but most farmers would likely prefer to farm smaller operations if they "had a decent life." However, most farmers with whom I interacted did not feel threatened by corporate power. As illustrated in Figure 8, when asked if digital farming TNCs are the only beneficiaries of digital farming, only two respondents strongly agree, but 58% of respondents either somewhat or strongly disagree.

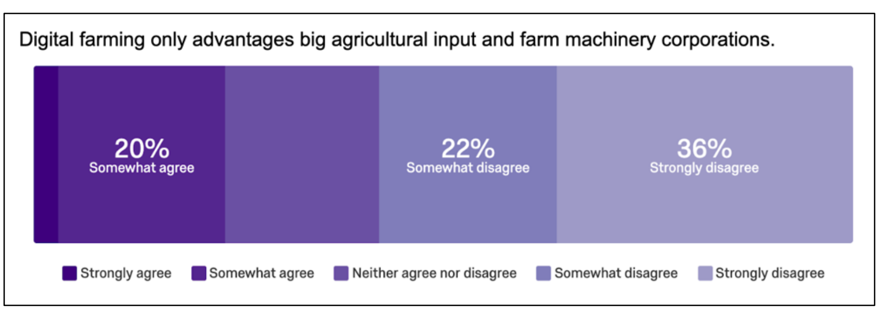

Figure 8: Digital farming only helps big industry actors (Questionnaire)

The statement is intentionally polarising to reveal a range of opinions in the questionnaire, but it remains useful in understanding the rationale of farmers. Even if TNCs will profit from digital farming, they are not necessarily benefiting at the expense of farmers. This result is surprising considering the analysis of scholars in the field, who outline the many ways in which the rise of corporate power compromises farmer autonomy (Bronson & Knezevic, 2019; Carbonell, 2016; Eastwood et al., 2017; Regan et al., 2018). In contrast with the academic literature, the large majority of farmers in this study do not think that TNCs are clear 'winners' of the digital agricultural revolution.

There are many possible explanations for this surprising finding, though it demands further research. It may be that most participants are not concerned about digital farming corporations due to the impact of corporate power on farmer autonomy. Ontario grain farmers face complex challenges, both related to digital farming and pre-existing issues; power relations in the food system download risk onto farmers and erode farmers' control over their operations. Increasing costs, changing weather, labour shortages, and technological change inundate farmers. Thus, the conditions of participant experiences are a barrier to understanding the implications of corporate power. Even if farmers know that there might be risks involved the digital agricultural revolution, because they have so many other things to worry about, they must, as Farmer #9 puts it, *"accept it and drive on."* However, the empirical results suggest that many farmers also actively buy into the proponent narrative. A few participants currently work with developers and academics in entrepreneurial or research ventures for digital farming innovation. Across the dataset, there is a persistent optimism that digital farming can help farmers by improving efficiency, productivity, and profits, in line with the productivism of the proponent narrative. Most of the farmers who participated in the study demonstrate a faith in science and earlier biotechnology innovations, including GM seeds. Therefore, corporate power in the digital agricultural revolution could influence a lack of concern from participants because the economic conditions of digital farming obfuscate the power of TNCs over the experiences of farmers or because farmers, like TNCs and other digital farming proponents, are already embedded in the productivist worldview of agriculture.

Overall, while the loss of autonomy is a prevalent topic in the discussion of digital farming challenges, the majority of participants do not perceive TNCs or other industry actors as a threat. However, the economic conditions driving farmers to expand their operations interact with the digital agricultural revolution. Some participants believe that digital farming will accelerate these trends, while other think that farms will continue to get bigger with or without the new technology. In the context of highly competitive markets and other challenges, farmers who do not adopt digital farming are disadvantaged and may not be able to continue, as discussed in the previous chapter with Farmer #9's prediction of a *"two-tiered farm community."* Research of Ontario farmer-retailer relationships presents a similar interpretation of economic factors driving digital farming adoption (Duncan, 2018). While I did not ask farmers about their debt levels, Rotz et al. find that "farmers in Canada today carry a debt of 23 dollars for every dollar of income, which is largely fuelled by both land and equipment purchases" (2017, p. 1). Digital farming may add on to the debt farmers carry, exacerbating the economic barriers of adoption and eroding economic resilience in complex and volatile food systems.

A 'digital divide' usually pertains to barriers to technology or internet access, such as education and socioeconomic status. As discussed in the context of technological difficulties, the 'digital divide' for digital farming includes challenges and obstacles to adoption, such as a lack of knowledge about digital farming or poor satellite reception or broadband communication, which are required to make use of the technology and its data capabilities (Bronson & Knezevic, 2019; Carolan, 2019; Rotz, Gravely, et al., 2019; Wolfert et al., 2017). Moreover, participants perceive a divide in the community of Ontario grain farmers between those who are able to adopt and those who do not. Bronson comes to the same conclusion: "the market for smart farming technologies is bifurcated between large, commodity farms whose managers are adopting these tools, and smaller-scale, unconventional growers whom are not adopting at equal rate" (2019, p. 2). In line with the productivist priorities of digital farming developers and proponents, most social sciences literature on digital farming argues that these power dimensions will reinforce industrialization of agriculture (Bronson, 2019; Carolan, 2016). This thesis finds that there are important implications of digital farming on power relations in the food system, not only in terms of corporate power and farmer autonomy, but also for growing inequities among farmers. Reflections on power dimensions will also inform thematic analysis of data, labour, and environment.

5.3.2 Data and Knowledge: Accumulation, Control, and Co-Production

Big data is the cornerstone of the digital agricultural revolution. While diverse proponents are optimistic about the power of data to transform food systems for the better, critics express serious concerns for the implications. According to those researching digital farming, data concerns are of utmost importance, but the literature needs catch up with the pace of innovation (Bronson, 2019; Eastwood et al., 2017; Pham & Stack, 2018; Rotz, Duncan, et al., 2019). Especially, the integration of data in the food system gives pause to those studying ethics, justice, and governance (Bronson, 2018; Carbonell, 2016; Eastwood et al., 2017; Rotz, Gravely, et al., 2019; Weersink et al., 2018). In particular, farmers ought to be concerned about those who have access to their data and in what ways they might benefit from its application (Bronson & Knezevic, 2016a; Carbonell, 2016; Mooney, 2018). However, the consequences of farmers engaging in data exchanges with industry is surprisingly not a central challenge or concern in this study.

The questionnaire, interviews, and fieldwork observations all yielded results regarding data concerns, but they were not a consistent risk or challenge in the view participants. Many participants confess that they feel confused and uninformed regarding the data dimensions of digital farming, even if they are adopters. There are several factors that make it difficult for farmers to understand what happens with their data and the implications of data access, ownership, and control. For instance, digital farming companies can obscure data governance in user agreements, which are notoriously complicated documents filled with legal jargon. In addition, farmers have limited time and energy to invest in learning about big data because they already face many complex challenges that already demand their attention.

Contrary to the predictions of theoretical literature cited above, participants in this study generally do not perceive risks of start-ups or TNCs accessing and using their data through digital farming. More research is needed to understand the causes and whether this level of understanding and lack of concern is unique to the study's sample. Many start-ups and organizations are encouraging farmers to realize the value of their data; Farmobile states, "From Big Ag to Silicon Valley and back again, the race to gather farm data is on. Some genetics companies, equipment manufacturers and freemium startups want an informational edge to target your margin. It's time to protect your data like the significant asset it really is," offering a farmer-led alternative data storage platform (2019). Yet most of the farmers who participated in this study are not aware of the value of data that they are freely giving away to digital farming companies, sometimes paying those same companies to have access to the data that their equipment generates. Nonetheless, many participants convey knowledge of digital farming and the relationship with big data. Many have views at either extreme when it comes to trusting the companies that have access to their data, as presented in the previous chapter.

While some farmers think that data ownership and access is a nonissue, others "have *significant concerns about ownership of the information* that is generated using some of these technologies" (Farmer #4). Data collection and analytics compromises farmer autonomy. Regarding the position of farmers in the age of big data, Farmer #11 asserts,

> "*I don't really have control of the data* per se because it ends up, most of the time, where *other people that have access to that data*… I think anybody who thinks they have control is *probably kidding themselves*." (Farmer #11)

Control over the data primarily relates to who has access to the information. Responding to resistance movements and public pressure, many digital farming companies have shifted to user agreements that explicitly state that farmers own their data. However, farmer ownership does not level the power imbalances because corporate power structures the conditions of data collection and can still accumulate and use the data for their own purposes (Carbonell, 2016; van der Burg et al., 2019). Ownership does not guarantee control or autonomy.

In the digital agricultural revolution, to accumulate data is it accumulate power. Digital farming gives agri-food TNCs unprecedented access to the intricacies of each farm where their products are in use. According to Farmer #10, this takes away power from farmers:

> *"The problem is, the large corporations of the world today, and government especially, have too much access to what we do on the farm*. And they know with too much certainty, how much it's going to cost us to grow an acre of corn or an acre of beans or whatever. So, when that happens, *they automatically know exactly what they can charge us, and we'll still buy it*. That is the curse of Big Data." (Farmer #10)

Farmer #10 is acutely aware of the power of those who have access to his data. Farmers lose their bargaining power. Data governance as it currently exists furthers the imbalances of power between TNCs and farmers. Not only can access to data influence the prices of agricultural inputs that farmers are locked into buying, but it might also influence the farmers' income because of changes to grain prices.

Power asymmetries in digital farming are related to the legacy of corporate power in the food system, as previously discussed. In light of the evidence presented in the thesis, the wave of megamergers in agricultural input companies (Bayer-Monsanto, Dow-DuPont, ChemChina-Syngenta) and corporate concentration more generally become increasingly problematic (Mooney, 2018; Pham & Stack, 2018). Vertical and horizontal integration supports the accumulation of data and capital across the food system, and the control to use the powerful big data analytics for their own gain. Mooney (2018) also views technological developments as inevitably reinforcing the power relations in the food system and the political power of 'objective science' in justifying technological innovation. Carbonell (2016) discusses the ethical implications of digital farming and the rise of big data in agriculture, focusing on the power relations between farmers and TNCs:

> There is no doubt that a massive restructuring has occurred within industrial agricultural production since its mechanisation, especially with the introduction of patented seeds. *This reorganisation has tended towards an increasing dispossession of farmers' autonomy and control over their production process, rendering them as glorified sharecroppers or at best contract labourers*… Industrial farmers thus have to create uneasy alliances with mega-agribusinesses such as Monsanto or DuPont to be able to access and process this type of high-level technology, which comes at the *paradoxical cost of losing control over their data*. (2016, p. 5)

Farmers are facing increasing economic pressure to adopt expensive digital farming technology but buying into digital farming usually means accepting the terms of TNCs who are controlling and benefiting from the digital agricultural revolution. The data concerns add another layer of complexity to earlier discussions of economic factors in digital farming.

Moreover, digital farming and big data influence the co-production of food and knowledge (Bronson, 2019; Jasanoff, 2004, 2016). Data collection in agriculture is not new, but the capacities of big data can lead to farming becoming more 'data-driven' and changing agricultural practices and farmer identities (Pivoto et al., 2018; Regan et al., 2018; Zhang, 2016). Proponents are enthusiastic about the use of digital farming to make agriculture more scientific and data-driven (Climate Fieldview, 2018; IBM, 2018c; Proagrica, 2018b). There is also a repeated claim that data-driven or scientific agriculture is an improvement compared to existing farmer decision-making (Proagrica, 2018a; The Climate Corporation, 2018; Trimble, 2018). Bayer explains, "Digital tools like Climate Fieldview provide data-powered recommendations that inform farmer decisions, like exactly when to spray fungicide for a developing disease, or when, where and how much nitrogen fertilizer to apply, helping to maximize harvests, reduce waste and improve sustainability" (Reiter, 2019). As discussed in Chapter 4, participants are embracing these claims and internalizing the normative perspective that (big) data leads to *'better'* or '*smarter decisions.'* In this study, Farmer #7 states, "agriculture has been driven by *gut feel decisions* and information on what has been done in the past," but digital farming is the "basis for making *better decisions*." Likewise, Farmer #8 explains that his operation is based in data and science, improving his farm management because "decisions will be made on the *result of numbers* that I am looking at, *not just on a gut feel*." Much the same, Carolan's interviews with US farmers reveal that "good farmers do not follow their gut, they follow data" (2016, p. 145). When interviewed, farmers in the US, Ireland, and Australia use similar normative language (e.g., 'smarter farming') when discussing the implications of digital farming (Carolan, 2016; Fleming et al., 2018; Regan, 2019). The empirical evidence in this study corroborates the findings of earlier studies: digital farming is changing what it means to be a 'good farmer' (Shepherd et al., 2018). However, there are participants in each of these studies that resist these claims, arguing that the knowledge and expertise of farmers is irreplaceable, as I will discuss in the context of labour in the next section.

Finally, there is also growing attention to alternatives or more ethical data governance in the digital farming literature and critical data studies more generally (Bronson, 2019; Carolan, 2018b; Eastwood et al., 2017; Guston et al., 2014; Iliadis & Russo, 2016; Lyon, 2014; Newman, 2015; Rotz, Duncan, et al., 2019). While this study did not include farmers involved in resistance movements, there are two particularly interesting examples from the interviews explaining how farmers might use data to reclaim power form other non-farmer actors. First, there is the matter of crop insurance. Farmers can purchase insurance for their crops to receive financial support in the event of losses beyond their control, including weather. Farmer #2 explained that insurers will refer to regional weather data to validate claims, which is not always true to each farm, but digital farming can provide farmers with tools to advocate for themselves. Farmers have evidence for the date and conditions of planting, as well as weather and agronomic data throughout the season, to prove that the losses are beyond their control. Second, farmers feel blamed by government institutions and public for environmental issues. Many participants were particularly sensitive about the algae blooms in Lake Erie, which are often attributed to fertilizer runoff (CBC, 2019). Farmer #10 felt assured by the power of data because he would be able to prove to non-farmers that he is already doing his part, with suspicions that the accumulation of data would reveal that the problem is not farmers at all. In further research, it will be essential to study alternatives modes of data governance and to learn from the farmers and organizations taking leadership in this space (Ag Data, 2019; Farm Hack, 2018; Koebler, 2018; Whale & Hand, 2019).

5.3.3 Agricultural Labour: 'We Will Always Need Farmers'

In the existing literature on digital farming, there are conflicting opinions on labour implications. Some of the central scholars in the discourse present arguments that digital farming poses risks to farmers for their labour and expertise to be replaced by new machinery and big data analytics (Bronson & Knezevic, 2016a; Carolan, 2016; Rijswijk et al., 2018; Rotz, Gravely, et al., 2019; Wolfert et al., 2017). More pointedly, there is an uneven distribution of risk for technological unemployment for those who are already marginalized in agriculture, namely temporary migrant workers and 'un-skilled' labour (Rotz, Gravely, et al., 2019). Admittedly, migrant workers are much more common in vegetable production and animal agriculture than in commodity crops because the large, capital-intensive monocrop practices have already minimized labour requirements through earlier technological change. More generally, the digital agricultural revolution presents risks for marginalized groups in the food system (Rotz, Gravely, et al., 2019). In contrast, other academics argue that digital farming is a solution to the challenges of an aging work force, rural depopulation, and labour shortage in Ontario (Canadian Agricultural Human Resource Council, 2016; Collins, 2018; D. C. Rose & Chilvers, 2018; Weersink et al., 2018).

The farmers who participated in this study provided a nuanced understanding of labour in agriculture and the implications of digital farming. While participants understand that digital farming means that there will be less labour required in the future, it is a perceived benefit because it improves efficiency and alleviates the challenge of labour shortages. Farmer #1 explains his understanding of digital farming's implications for agricultural labour.

> "I think from a labour standpoint there is a *tremendous opportunity to increase productivity* on Ontario farms. Labour is one of the challenges for agriculture in general, the *shortage of affordable workforce*... I think digital farming and …scientific data-based agriculture is going to play a huge role in the development of the technology and the *improvement of economics for the grower*. We will be able to *do more with less human interactions*." (Farmer #1)

Farmers are aware of the employment gap challenges in Ontario and Canada more broadly because it is an important issue their communities, but also because many of them have direct experience of not finding the labour support that they need. Many participants shared frustrations in unfilled farm labour positions or hiring someone only to have them quit shortly after because of the demands of farm labour and the challenges of working in rural areas. In the short-run, the labour savings of digital farming will not be replacing the humans because of the labour shortage in agriculture, which aligns with the interpretation of other scholars (D. C. Rose & Chilvers, 2018; Rotz, Gravely, et al., 2019). However, as Farmer #1 also explains "digital farming will make it *harder and harder to find qualified individuals*, and it will also make the ones that you can find, more *expensive*." Thus, the changes to agricultural labour are not clear-cut.

Considering longer-term implications of digital farming on labour, participants are undisturbed. Interestingly, the majority of questionnaire respondents do not believe that digital farming threatens their labour or expertise, as illustrated in Figure 9.

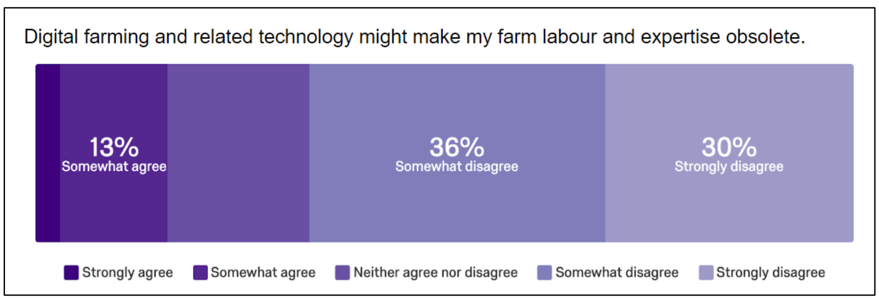

Figure 9: Risk to farmer labour and expertise (Questionnaire)

This unexpected finding presents an important contribution to digital farming literature in the context of growing concern for technological unemployment. In the interviews, I was able to ask participants about their questionnaire responses and I asked them to speak to the labour question in particular.

> "*I think we will always need farmers…* There's still a connection with the land and you have to know the land. And understand what the h-maps are telling you what your vegetation maps are telling you." (Farmer #9)

Mostly, there is a sense that farmers have unique knowledge of the land, which technology and data analytics cannot replaced. Participants are confident that a human being will always need to be at the decision-making centre of agriculture, and farmers will safely maintain this role. As presented in Chapter 3, other digital farming scholars make similar predictions (Regan, 2019; Wolfert et al., 2017, 2014). One study on the perception of digital farming in Ireland's grain sector, explained that some participants felt that "digital technologies did not replace the farmer; rather than technology dictating to the farmer, the farmer would still remain at the heart of farm operations" (Regan, 2019, p. 6). An ethnographic study of English farmers and their perceptions of early digital farming equipment (e.g., yield monitors) includes similar findings (Tsouvalis et al., 2000).

Digital farming also affects the quality, demands, and structure of agricultural labour. Most participants who are digital farming adopters express that the technology makes farming more enjoyable and convenient: "Digital farming makes it a lot *easier*. We *don't have to work as hard* as we used to" (Farmer #9). As discussed in Chapter 4, adopters enjoy operational benefits of digital farming that makes their work more flexible and less physically demanding, which can improve their mental health, but that there are additional labour burdens for learning new skills and planning for the season through the new platforms. The new capacities and skills required to *'keep up with the technology'* are a primary digital farming challenge, according to participants. Much like the empirical data from a study of crop and dairy farmers in Ontario, participants felt under-prepared and a lack of support for meaningful adoption (Duncan & Fraser, 2018). Many other studies are calling attention to the changing nature of farm labour in the digital agricultural revolution and the need for farmers to adjust (Eastwood et al., 2017; Rotz, Gravely, et al., 2019; Tsouvalis et al., 2000; Weersink et al., 2018).

The discussion of labour presents another interesting finding regarding farmer autonomy. Participants are aware of the increasing reliance on digital farming companies and the associated risks in the case of technical difficulties. As farming continues to change with the introduction of new technology, there may be a 'deskilling' or a loss of skills and capacities because they are no longer required in the digital agricultural revolution. In researching the implications agricultural technology, many food scholars examine 'deskilling' (Chopra, 2012; Eastwood et al., 2017; Howard, 2016; Mcmichael, 2009; Stone, 2007). In this study, Farmer #10 makes an astute observation on this topic.

> "The problem I'm seeing is that *everybody knows how to play video games and no body actually knows how to fix anything*. So, my newest tractor, it's an '03. It's got a computer on it. When things are broken, *I've got to call a guy with a computer to fix it, and that's the only way to fix it*." (Farmer #10)

User agreements prohibit farmers from repairing their machinery or, in some cases, freely accessing their data, which compromises their autonomy and increases the dependency on powerful TNCs. In their review, Shepheard et al. make a similar argument "perceived risk of increasing reliance on technical experts and the technology resulting in a loss of tacit knowledge and that farmers may become ever more reliant on the technology for decision-making" (2018, p. 5). Likewise, in an Irish digital farming study, some farmers were concerned that "over-reliance on technology would impair farmers' ability to think intuitively," finding that digital farming could "change the nature of decision-making away from the inherent skills and heuristics that farmers pride themselves on having" (Regan, 2019, p.

6). Moving forward, it will be important to pay attention to the digital agricultural revolution's effect on agricultural labour.

5.3.4 Environment: Sustainability Concerns and 'Caring for the Land'

Sustainability – or, more accurately, maintaining production in the context of limited agricultural land, a growing population, and a changing climate – is a central promise of digital farming proponents (AAFC, 2018a; Bayer, 2019b; Proagrica, 2018a; The Climate Corporation, 2019; Yara, 2019a). There is also a growing body of research in STEM to investigate the potential economic and environmental benefits of digital farming (Balafoutis et al., 2017; Bongiovanni & Lowenberg-Deboer, 2004; Kamilaris et al., 2017; Plant et al., 2000; Schieffer & Dillon, 2015; Yost et al., 2019). The simplest example is more targeted use of agricultural inputs, which could save money and reduce environmental impacts, but there is optimism that much more is possible. In response to sustainability promises in public debates, there are some mentions of environmental dimensions in the transdisciplinary social sciences literature on digital farming, but they are mostly at the periphery (Regan, 2019; van der Burg et al., 2019; Weersink et al., 2018; Wolf & Wood, 1997). Still, impacts of digital farming on stewardship are quite important to farmers. In this study, 72% of participants view *'caring for the land'* as central to their identity and consider the environment in their perceptions of digital farming (see Chapter 4).

In general, participants are optimistic about the environmental impacts of digital farming. As illustrated in Figure 5 in the previous chapter, 85% of respondents either strongly or somewhat agree that digital farming and the data it yields inform better decisions for the environment. Farmers are most enthusiastic about VRA, as it presents opportunities to mitigate environmental problems such as fertilizer run-off and Lake Erie's toxic algae blooms. In technical terms, this is not yet well reported, and there are cases where variable rate technology actually increases the use of agricultural inputs through the rebound effect (Schieffer & Dillon, 2015). Proponents also claim that digital farming can help farmers facing the volatility of a changing climate. Farmers are much less convinced of this promise, as illustrated in Figure 10.

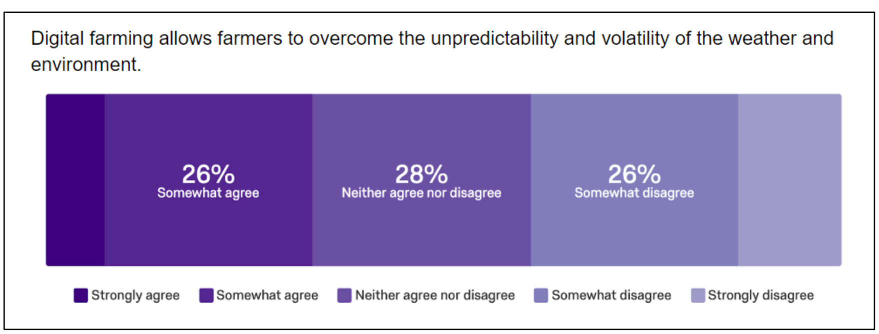

Figure 10: Digital farming helps to overcome environmental problems (Questionnaire)

Participants generally believe that the environmental challenges facing agriculture are much more complex than the ways in which proponents describe them. While farmers are hopeful that digital farming might reduce the environmental impacts of agriculture, they do not subscribe to the narratives of proponents that technology could overcome risks and unpredictability of environmental problems.

In the earlier discussion of perceived opportunities of digital farming, the empirical results illustrate the importance of farmer values for decision-making. Several participants explicitly stated that the priorities of farmers influence their farm management, especially when there is conflict between profit and stewardship. Farmer #7 explains that even if digital farming can provide the data to inform *"better decisions,"* it still "comes back to the *individual person* themselves and *how that information is used*." Therefore, the ability of digital farming equipment to collect information that could support more sustainable agricultural practices does not guarantee any environmental benefit. Participants experience digital farming in the context of conflicting identities as business people and stewards, simultaneously. There is a normative sense of being a *'good farmer'* and *'doing the right thing'* as a steward of the land across the interview transcripts, which also interacts with the changing notion of being a *'good farmer'* in the age of big data. According to participants, a good farmer produces food for society and can find balance between economic and environmental factors in agriculture. When I asked Farmer #11 if he perceived pressure on non-adopters, he said, "I'd sure hope that they are going to feel some pressure, because it's the *right thing to do,"* in relation to the *"easy wins"* for the environment in adopting VRA. Participants place the responsibility on the individual farmer, when discussing 'good' farming practices. However, this problem frame omits other factors degrading farmer autonomy.

Farmers view themselves as stewards, but also as producers and business people, placing their identities in constant tension. Drawing from the broader debates and academic literature, it is also important to consider the political and economic factors that condition the farmer's experience. Several participants explained that their decisions are necessarily tied to *'ROI'* the *'bottom line.'* Predominantly, farmers are adopting digital farming to survive in a competitive industry and the environmental impacts are a side benefit. In the context of the complex systems and pressures, a farmer's decisions of what to do with the information that digital farming provides is not entirely their own. For instance, research in Canada demonstrates how industrialization and financialization limit farmer autonomy with detrimental consequences for sustainability because farmers are unable to make decisions in the interest of long-term environmental goals, such as agroecological practices (Rotz & Fraser, 2015; Rotz et al., 2017).

The material realities of digital farming shape kinds of agriculture that are feasible. The development of large farm equipment and dominance of monocropping are intertwined, just as digital farming platforms and the new machinery are designed to support conventional farming (Bronson, 2019). Moreover, Zundel and Ribeiro point out that digital farming "can theoretically be set to just-about meet technical organic standards without deeply improving the health of soil and building resilience to climate change" (2018, p. 30). Digital farming might reinforce the existing trends of industrialization in agriculture, perpetuating the many known environmental consequences (IPES-FOOD, 2017; Morena, 2018). Technology also has unknown or unintended consequences (Huesemann & Huesemann, 2011a; Jasanoff, 2004). However, neither farmer perceptions nor public discourses considered the environmental impacts of digitalization in agriculture, such as e-waste and energy use. Considering the complex systems in the digital agricultural revolution, it is possible that the ecological footprint of intensified industrial agriculture and digital technologies outweigh the incremental gains of digital farming, though significantly more research is needed to make such an evaluation.

5.4 Chapter Summary

In this discussion, I interpret the empirical results on farmer perceptions and explore their significance in the context of broader debates. The findings of this study suggest that the experiences and realities of Ontario grain farmers are much more complex and nuanced than the public debates and academic theory would lead us to believe. In public debates, proponents claim that digital farming will improve efficiency, productivity, and profits for farmers. Participants in this study believe that there is the potential for economic benefits, but that there is *'no guarantee.'* In response to the promises that digital farming will ensure food security for a growing population, some participants are more optimistic than others. Most participants believe that addressing food insecurity is much more complex that increasing production. Certainly, there are a few participants in this study who would identify as firm proponents or critics of digital farming, but the findings support the conclusion that Ontario grain farmers to not fit into the binary of public debates. Farmers are skeptical of the promises made by proponents, but many participants still believe that digital farming can benefit their operations in some ways and serve as tool in addressing food system challenges.

The remainder of the chapter compares farmer perceptions to themes in emerging academic literature on digital farming. First, this study finds that digital farming has important implications for the distribution of power in the food system. The literature suggests that digital farming corporations are likely to be the 'winners' of the digital agricultural revolution, at the expense of farmers and citizens. While the study's empirical results offer evidence to show that digital farming compromises farmer autonomy, participants are not particularly concerned about corporate power. Instead, farmers are more preoccupied by inequities in the farming community, noting that digital farming might lead to a bifurcated grain sector where large industrial operations that can afford the technology continue to grow and accumulate power, while smaller and non-conventional farms are at risk of obsolescence. Second, there are important findings regarding agricultural (big) data. Although the literature suggests that data accessibility, control, and ownership should be at the forefront of farmers' minds, participant responses are varied. Many confess that they are uninformed or untroubled by the role of data in digital farming. In addition, the interview data confirms that big data in agriculture alters farming practices and the ideal of a 'good farmer.' Third, the study provides insights for the scholarly debate on the impacts of digital farming on agricultural labour. Participants are enthusiastic about the labour saving potential of digital farming and do not feel that their labour or expertise is at risk. Analysis of labour implications also suggest that farmers are increasingly reliant on digital farming companies in a process of deskilling. Fourth, the environmental implications of digital farming are uncertain. Proponents claim that digital farming improves sustainability; participants agree that digital farming might support better decisions for stewardship, but they are skeptical of promises that it will address environmental problems or help farmers face the pressures of a changing climate. Moreover, social, political, and economic factors influence farmer decision-making such that, even if digital farming can provide the tools or information to farm more sustainably, they may not have the autonomy or security needed to make changes to their operations. These findings lay the groundwork for further research on the environmental implications of digital farming, as well as the three preceding themes.

Chapter 6
Concluding Thoughts

6.1 Introduction

Digitalization and big data are revolutionizing agriculture, with complex implications across ecological, social, political, and economic systems. As technological innovation accelerates with growing public and private investment, digital farming's unknown and unpredictable implications are increasingly problematic, especially in the context of the wicked problems facing the future of food. There are growing pressures on agriculture due to environmental degradation, climate change, a growing world population, and rampant food insecurity, as well as the risks that these problems pose for the resilience of food systems. In response, proponents frame digital farming as a solution to food system challenges. It is true that many technologies improve quality of life and productivity; however, the paradigm of technological innovation as the solution to humanity's complex problems typically strips the issues of their fundamental political dimensions and denies their existence in complex, interactive, and adaptive systems. Although digital farming might play an important role in establishing more sustainable and equitable food systems, it is it is improbable that food system challenges could be reducible to 'techno-fixes' alone. Instead, digital farming, as a complex phenomenon, will more likely have uneven and contradictory implications. The massive volume of real-time data collected by tractors may liberate farmers from environmental pressures and the risks of climate shocks, while simultaneously undermining their privacy and agency, as corporations limit access to data to inform insurance and investment (Carbonell, 2016; Morena, 2018). Structural realities of digital farming, as designed by developers and executives, might reinforce the dominance of industrial agriculture, but the diversity of technologies and proliferation of startups could also support agroecological approaches (Bronson, 2019; Weersink et al., 2018).

In this final chapter, I will briefly return to the aims of the research project to discuss key findings and make recommendations for further research. This study set out to investigate the experiences and perspectives of Ontario grain farmers in the context of the digital agricultural revolution. More specifically, the thesis addresses the following research question: *How do Ontario grain farmers perceive digital farming, and how do their perspectives compare to public debates and academic research?* Three objectives guide the research design: (1) Identify key narratives in digital farming debates, focusing on proponents and critics; (2) Describe the perceptions of farmers regarding challenges and opportunities of digital farming; and, (3) Compare farmer perceptions with key themes in digital farming debates. This thesis is exploratory and contextual in that it focuses on a topic about which little is known and offers a description of phenomena as it is experienced, to direct more refined and systematic questions for further research (Neuman, 2014; Ritchie et al., 2014).

Social scientists, particularly from political economy and sociology, are drawing attention to ethical implications of digital farming, some of whom point to justice movements and alternative uses of technology (Carbonell, 2016; Carolan, 2017, 2018b; Kamilaris et al., 2017; Rotz, Duncan, et al., 2019; van der Burg et al., 2019). This research responds to the scholars raising concerns about the lack of research and discussion of the social, political, and ethical dimensions of the digital agricultural revolution (Bronson & Knezevic, 2016a; Eastwood et al., 2017; Regan, 2019; Rotz, Gravely, et al., 2019; van der Burg et al., 2019). Furthermore, while there is growing attention to the implications of digital farming, scholars maintain that there remains a dearth of empirical studies (Carolan, 2018b; Regan, 2019). The thesis offers empirical contributions and proposes directions for theory development to an emerging area of scholarship exploring the implications of digital farming on the food system.

6.2 Summary of Findings

This study yields original empirical data on farmer perceptions of digital farming and offers novel insights on the implications of the digital agriculture revolution for power relations, data concerns, agricultural labour, and environmental impacts. Two chapters offer evidence to satisfy the first research objective. Chapter 3 presents a diversity of digital farming proponents and critics, summarizing dominant claims and concerns. Chapter 5 returns to the key narratives for further analysis and to compare the promises with farmer perceptions. Permeating the contentious conversations on digital farming, there is a dominant narrative crafted by proponents. TNCs developing digital farming equipment and services, like other proponents, make promises that these technologies improve efficiency, productivity, and profits, while also being essential for feeding the world and addressing environmental problems (Bayer, 2018a, 2019b; IBM, 2018c; Trimble, 2018). While the narrative presents digital farming as an innovative and novel solution, the argument is that food security, environmental pressures, and other challenges can be solved by efficiencies and increased production. Furthermore, an unquestionable faith in science and technology buttress the value of productivity and the dominant narrative of proponents. There is a consensus among most social scientists that the dominant narrative on digital farming is embedded in the productivist paradigm, which includes most academic research from STEM perspectives (Bronson & Knezevic, 2016a; Carolan, 2018b; Rotz, Gravely, et al., 2019).

The majority of the empirical results in the study are to address the second research objective. Chapter 4 is devoted to unpacking the empirical results on Ontario grain farmer perceptions of digital farming, focusing on perceived opportunities and challenges. The online questionnaire reveals that 73% of respondents presently employ digital farming technologies, where smartphone applications, GPS, and GIS are the most prevalent uses. Unlike the uniformity of past technological innovations in agriculture, such as packages of GM seeds and agrochemicals, there is currently diversity in the adoption of digital farming. Study participants illustrate diverse combinations of digital farming hardware and software. Interviews demonstrate the individual decision-making required to ensure that the technology adopted suits the needs and capacities of the individual farm. Although the sample size limits the generalizability of findings, the study joins other research projects on digital farming to understand the state of adoption in Ontario (Duncan, 2018; Mitchell et al., 2018). Furthermore, the findings caution against generalizing farmer experiences. Even if smaller or non-conventional farmers are not necessarily adopting at the same rate as large conventional farmers due to a variety of factors, digital farming adopters and enthusiasts are diverse.

Next, the study of Ontario grain farmers provides contextualized results on perceived challenges and opportunities in the digital agricultural revolution. Farmers experience digital farming in the context of their multifaceted identities as producers, stewards, and business people. Additionally, existing challenges identified by participants influence their perceptions, namely increasing costs, unpredictable weather, and labour constraints. Among participants, there is growing enthusiasm for digital farming and the potential benefits it offers to farmers. Participants are primarily excited about the operational benefits of digital farming, especially the *potential* to increase yields while decreasing inputs and impacts. The use of VRA for more targeted fertilizer application, for instance, could support more productive and sustainable farming, although benefits of digital farming depend on the technology in use, conditions of the operation, and farmer capabilities. Moreover, participants also perceive an opportunity for digital farming to support *'smarter'* agronomy and *'better decisions.'* Improvements to agricultural data can assist farmers in addressing the many complex challenges that they face, such as unpredictable weather and shrinking margins; however, these conditions and farmer values will influence how operators make use of this information.

At the same time, the rise of digital farming presents an assortment of new challenges for farmers. The empirical data illustrates that the challenges of digital farming presently outnumber the opportunities, but the conditions still may lead to increased adoption. First, economic challenges are simultaneously drivers and barriers of adoption. Participants explain that digital farming is *'phenomenally expensive.'* The expense of most digital farming technologies is a significant challenge in the context of already increasing input costs. Yet it may be necessary for farmers to '*adopt in order to survive'* in an increasingly competitive sector. According to farmers, such conditions may continue the trend of increasingly large farms, potentially creating a digital divide, or a *'two-tiered farm community,'* where the adopters thrive and non-adopters decline. Second, digital farming poses challenges in relation to the new knowledge and capacities that must be developed in order to operate and benefit from the technology, changing the skills needed to be successful. Likewise, the new skills affect the availability and cost of additional labour on the farm. Third, participants have concerns about technological difficulties and the risks of digital farming, which is less reliable than older technology and will need to be replaced more frequently. Agreements with digital farming companies, combined with the changing skills and capacities of farmers, make many participants feel more dependent on third-parties. Finally, data concerns are important to consider in the rise of digital farming, but they did not present a persistent perceived challenge in the empirical data. Many participants think that farmers should probably be concerned about data ownership, access, privacy, or use by third parties; however, they have a limited knowledge of their own data agreements and the broader implications. There are too many other important things for farmers to be worrying about, so they are *'forced to accept it and drive on.'* Even so, a few participants have pointed concerns about the use of their data by third-parties who can aggregate farm data and are deeply critical of the companies that control their data.

Finally, Chapter 5 discusses the findings systematically to address the third research objective and answer the research question. Returning to the public debates introduced in Chapter 3, a comparison of participant views with the narratives of proponents and critics reveals that Ontario grain farmer perceptions of digital farming are more nuanced and complexity-informed than the polarized debates. Although there are some participants who are well aligned with the key narratives in public debates, farmers are able to consider digital farming as a complex phenomenon and consider the compromises of conflicting priorities. Participants understand that digital farming may offer economic gains, but that they are conditional. Similarly, digital farming might be a tool to increase global agricultural production, but participants understand that food security is a much more complex problem.

The second part of the research question pertains to the themes in the existing academic literature on digital farming; the study contributes to scholarly debates on power relations, data concerns, agricultural labour, and environment. First, the findings in the thesis are consistent with theory that digital farming has the potential to reproduce uneven power relations in the food system, with negative implications for farmer autonomy (Bronson & Knezevic, 2016a; Carbonell, 2016; Rotz, Duncan, et al., 2019). In addition to the rise of corporate power, there may be a 'digital divide' with inequities among farmers (Bronson & Knezevic, 2019). Second, the findings also accord with the theory that digital farming alters agricultural ideals: namely, there is a new sense that "good farmers do not follow their gut, they follow data" (Carolan, 2016, p. 145; Regan, 2019). However, the findings are in conflict with the literature in terms of farmers level of concern about corporate power and the implications of big data. In addition, the labour implications are complex. Surprisingly, participants do not feel that their labour or expertise are threatened by digital farming, despite growing concern for technological unemployment. Moreover, changes to agricultural practices may lead to a loss of skills and knowledge and dependence on digital farming companies (Carolan, 2018b; Eastwood et al., 2017; Shepherd et al., 2018). Finally, the findings on environmental implications of digital farming join a conversation that is mostly at the periphery of digital farming literature in the social sciences. Participants explain that farming demands an ability to make difficult decisions and find compromises, in line with their identity as both stewards and business people. Digital farming might offer information and equipment to support more sustainable agriculture, but the complex social, political, and economic factors may not support the farmer's environmental priorities. While there may still be some flexibility, as illustrated by the enthusiastic organic farmer using digital farming, the findings broadly support earlier analysis that technological innovation reinforces industrial agriculture, along with its known environmental consequences (Bronson, 2019; Morena, 2018).

6.3 Recommendations for Further Research

Although the research design of the thesis presents some limitations, the findings provide numerous starting points for the further research on the digital agricultural revolution. There is a need for further empirical study of farmer perceptions of digital farming and big data to make generalization and prediction about their experiences and opinions. Choices of recruitment and sampling methods, as well as the sample size, restrict the conclusions that can be made from the results. A more expansive sample of Ontario grain farmers and a temporal analysis would be valuable in mapping digital farming adoption and changing conditions of agriculture in Ontario.

Despite its exploratory nature, this study offers some insight into the realities of Ontario grain farmers. In contrast with the literature, participants were not concerned about data implications or corporate power. The findings on farmer perceptions of corporations and developers prompts the need for educating farmers on the risks and implications of digital farming. However, more research is needed to explore whether participants' lack of concerns is representative of the general population of Ontario grain farmers and to investigate the reasons for this belief. Moreover, the study is limited to applications of digital crop farming, although there are bourgeoning advances from dairy and aquaculture, to fruits and vegetables, which require attention. In addition, the thesis focuses almost exclusively on the more industrialized world, emphasizing Canadian food systems, although the digital agricultural revolution is a global phenomenon.

Moreover, there are several other methodologies that could provide important insights on digital farming. In particular, there is an established scholarship exploring discourse analysis of biotechnology in the food system to inform future research on digital farming (e.g., Brooks, 2005; Fleming et al., 2018; Rotz, 2018; Tourangeau & Smith, 2015). It would be extremely useful to take a deeper dive into the discourses of digital farming, in terms of the 'naming and framing' and emerging truths in the digital agricultural revolution. There are many important questions about the co-production of technology and ways of knowing or being, including effects on mental health and feminist analysis of familial labour. For instance, Farmer #5 says, "We talk so much about the technology, but *no one talks about how it makes us feel,*" in response to the changing roles and relationships on her family farm following the adoption of digital farming technology. Evidence from this study also suggests that the rise of digital farming alters the ideal of a *'good farmer,'* a concept that is ripe for further analysis. Ethnographic methods could be useful in these respects (e.g., Singleton & Law, 2013; Stone, 2007; Tsouvalis et al., 2000).

Building on the discussion of power relations, this study positions future research on power dimensions in the relationship between corporate actors and farmers, among farmers, between farmers and other agricultural labourers, and between farmers and non-human life. It seems that the digital agricultural revolution, as it is currently structured, is likely to benefit already powerful actors in the food system. Research on power relations might inform theories of change or policy recommendations to remediate power asymmetries and find leverage points for system change. While most research focuses on the relationships of farmers and corporate actors, the study's findings motivate further research on the implications of digital farming on various forms of agricultural labour, especially in the context of fruits and vegetable farming, which rely on migrant labour and other precarious workers (Carolan, 2019; Rotz, Gravely, et al., 2019).

The relationships between farmers and the environment in the context of uneven power relations and technological change are currently unexplored in digital farming research. As of now, the emerging discourses on digital farming are embedded in an anthropocentric ethic. Because the dominant paradigm assumes that humans are more important than other life (e.g., non-human animals) and non-life (e.g., water and air), it is difficult to avoid such a foundational assumption. However, it will be essential to consider intergenerational, intersectional, and interspecies justice perspectives in understanding the role and implications of digital farming. New ways of collecting information about the land affects the relationship between framers and the environment. For example, by making the land into something that farmers can *manage*, there is a reinforced idea that humans are *separate* from nature. This denial of interdependence is a central topic of study in STS and ecological feminisms

(Haraway, 1991; Jasanoff, 2004; Merchant, 1980, 2006; Mies & Shiva, 2014; Plumwood, 1993; Puis de la Bellacasa, 2017; Salleh, 2017; Sikka, 2018).

Transdisciplinary research on digital farming can evaluate and inform policy and development for more equitable and sustainable food futures, but it will also be important to make space at the table for those who are most directly affected farmers, agricultural labourers, migrant workers, citizens, and the voiceless. There are exiting movements for equity and sustainability in the digital revolution of agriculture globally and locally. A study on the identity and experiences of Ontario farmers revealed that, "through practices of open data sharing, farmers are using capital and technology to push back against corporate control in agri-food" (Rotz, 2018, p. 453). In particular, farmers are finding community and solidarity on social media platforms like Twitter. I heard similar things in my interviews with farmers, especially with smaller groups like organics and women in agriculture. The sharing and co-creation of knowledge in farm communities can help farmers to be informed and to reclaim autonomy. There are also farmer-led digital farming ventures across the globe with explicit social and environmental aims (Ndubuisi Ekekwe, 2018; Reyes, 2017). Locally, Ontario Agri-Food Technologies is developing a data platform called AgBox that will be owned and governed by those who generate the data, much like a cooperative or credit union (Whale & Hand, 2019). In this model, farmers can choose to grant access to third parties of their choice, which could include agronomic support to improve environmental sustainability. There are several open-source technologies and data sharing initiatives to empower farmers; for examples, FarmHack is a global community where farmers can support one another in repairing and controlling their equipment and the data it generates (Farm Hack, 2018). Although the digital agriculture revolution is already underway, the future of food is undetermined. These initiatives make space for alternatives to the corporate industrial agriculture model and could offer leverage points for change.

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Appendix A

University of Waterloo Office of Research Ethics (ORE#23305)

UNIVERSITY OF WATERLOO

OFFICE OF RESEARCH ETHICS

Notification of Ethics Clearance of Application to Conduct Research with Human Participants

Principal/Co-Investigator: Jennifer Clapp — **Department: School of Environment, Resources and Sustainability**

Principal/Co-Investigator: Andrea Collins — **Department: School of Environment, Resources and Sustainability**

Student Investigator: Sarah-Louise Ruder — **Department: School of Environment, Resources and Sustainability**

ORE #: 23305

Title: Perspectives of Ontario Grain Farmers on Digital Farming & Big Data in Food

☑ *Human Research Ethics Committee (HREC)* ☐ *Clinical Research Ethics Committee (CREC) is pleased to inform you the above named study has been reviewed and given ethics clearance.*

Approval to start this research is effective on the ethics clearance date which is: 09/12/2018 *(m/d/y)*

University of Waterloo Research Ethics Committees are composed in accordance with, and carry out their functions and operate in a manner consistent with, the institution's guidelines for research with human participants, the Tri-Council Policy Statement for the Ethical Conduct for Research Involving Humans (TCPS, 2nd edition), International Conference on Harmonization: Good Clinical Practice (ICH-GCP), the Ontario Personal Health Information Protection Act (PHIPA), the applicable laws and regulations of the province of Ontario. Both Committees are registered with the U.S. Department of Health and Human Services under the Federal Wide Assurance, FWA00021410, and IRB registration number IRB00002419 (HREC) and IRB00007409 (CREC).

The above named study is to be conducted in accordance with the submitted application (Form 101/101A) and the most recent approved versions of all supporting materials.

Ethics clearance for this study is valid until: 09/12/2019 *(m/d/y). Multi-year research must be renewed at least once every 12 months unless a more frequent review has otherwise been specified by the Research Ethics Committee (Form 105). Studies will only be renewed if the renewal report is received and approved before the expiry date. Failure to submit renewal reports by the expiry date will result in the investigators being notified ethics clearance has been suspended and Research Finance being notified the ethics clearance is no longer valid.*

Level of review:

☑ *Delegated review*

☐ *Full committee review meeting date:* ______________ *(m/d/y)*

Signed on behalf of: ☑ *HREC Chair* ☐ *HREC Vice-Chair* ☐ *CREC Chair* ☐ *CREC Vice-Chair*

Vanessa Buote (signature)

- Julie Joza, Director, Research Ethics, jajoza@uwaterloo.ca, ext. 36005
- Heather Root, Senior Manager, heather.root@uwaterloo.ca, ext. 30469
- Karen Pieters, Manager, kpieters@uwaterloo.ca, ext. 30495
- ✓ Vanessa Buote, Research Ethics Advisor, vanessa.buote@uwaterloo.ca, ext. 30321
- Joanna Eidse, Research Ethics Advisor, jeidse@uwaterloo.ca, ext. 37163
- Erin Van Der Meulen, Research Ethics Advisor, ervandermeulen@uwaterloo.ca, ext. 37046

This is an official document. Retain for your files.
You are responsible for obtaining any additional institutional approvals that might be required to complete this study.

Additional notes on ethics: I received consent from willing farming organizations to disseminate my research information letter and the address of the online questionnaire. The farming organizations disseminated the information on my behalf, and I did not have access to the personal information of their membership. Organizations were each given the opportunity to keep their participation confidential. Involvement in any and all parts of the study was entirely voluntary. Participants were informed that they could decline to answer any questions that they did not wish to respond, and they could withdraw participation at any point, up until the publication of this thesis. Questions were skipped in some of the online questionnaires, but only one interview participant asked to skip a question. Contact information was used to match questionnaire responses to interview transcripts and then deleted. The online questionnaires included the research information letter and conditions of consent on the opening page. Participants expressed verbal consent for all interviews, after I read an informational script and consent questions aloud. Eleven of the twelve interview participants consented to audio recording and the use of anonymous quotations. I am grateful for the trust of all participants. I received positive feedback from the population of participants and my engagement with the broader Ontario agri-food community.

At the end of every interview, I offered time for the participant to return to any previous topic or offer additional insights that were not addressed in the questions. One participant volunteered the following comment:

> Farmer #4: "I'll fill out a lot of online surveys and some of them, well they [annoy me] because they are worded in a way that you get to question and you know that they are fishing for a very specific response and the way that its worded within the context of the survey. They are trying to weed out or manipulate the outcome of the survey based upon some of the questions. And I think part of the reason that I was willing to speak to you on the phone was because I didn't feel that your survey was tilted that way. So, good job in writing it out in an open and honest manner."

Appendix B

Online Questionnaire and Semi-Structured Interview Guide

Online Questionnaire

Demographic Questions

1. In which Ontario County or municipality is your farm located? ___________________

2. How old are you?
   - ☐ 18-24
   - ☐ 25-34
   - ☐ 35-44
   - ☐ 45-54
   - ☐ 55-64
   - ☐ 65-74+

3. What is your gender?
   - ☐ Female
   - ☐ Male
   - ☐ Non-binary or third-gender
   - ☐ Prefer to self-describe: ____________
   - ☐ Prefer not to disclose

4. What is the highest level of education that you have completed?
   - ☐ Elementary school
   - ☐ Secondary school (No diploma)
   - ☐ Secondary school diploma
   - ☐ College
   - ☐ Undergraduate
   - ☐ Graduate
   - ☐ Other (post-secondary)

5. Where is your country of origin?
   - ☐ North America (Canada)
   - ☐ North America (Not Canada)
   - ☐ Africa
   - ☐ Asia
   - ☐ Australia
   - ☐ Central America
   - ☐ Europe
   - ☐ South America

Digital Farming and Big Data in Ontario Grain Farming

6. Please select any and all forms of digital farming used on your farm.
   - ☐ Unmanned aerial vehicles (UAV) or drones
   - ☐ Farm Information Management Systems (FIMS) software
   - ☐ Smartphone applications
   - ☐ Geographic Information System (GIS) mapping or software
   - ☐ Grid zone soil sampling
   - ☐ Global Positioning System (GPS) software
   - ☐ Sensors (e.g., moisture, temperature, etc.)
   - ☐ Smart spraying of agrochemicals (e.g., precision farming)
   - ☐ Soil electrical connectivity mapping
   - ☐ Other: ____________________________

7. I have been using precision agriculture or digital farming for ____ years.

8. Digital farming technologies are included in my business plan….

   ☐ Presently ☐ Next 5 years ☐ Next 10 years ☐ Distant future ☐ Not at all

Perspectives and Opinions

Please selection the option that best suits your perspective or opinion.

9. We are experiencing a digital revolution of agriculture.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

10. I have little or no knowledge of recent developments in digital farming.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

11. Digital farming only advantages big agricultural input and farm machinery corporations.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

12. Digital farming only helps big industrial farms.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

13. Adopting digital farming technology is necessary to remain competitive and essential to the success of my farm and business.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

14. Digital farming improves farm productivity.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

15. Digital farming can help me to reclaim power in my production and decision-making.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

16. I am concerned about the power of corporations over my use of technology and data.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

17. Digital farming can help farmers make better decisions for land stewardship.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

18. Digital farming allows farmers to overcome the unpredictability and volatility of the weather and environment.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

19. Digital farming technology can solve environmental problems faced in agriculture.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

20. Digital farming is the solution to food insecurity in Ontario.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

21. Digital farming and related technology might make my farm labour and expertise obsolete.				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

22. Digital farming addresses the challenges of Ontario farming (e.g., an aging and indebted labour force).				
☐ Strongly agree	☐ Somewhat agree	☐ Neither agree nor disagree	☐ Somewhat disagree	☐ Strongly disagree

Farm Demographics

23. What's the primary crop on your farm?
- ☐ Soy
- ☐ Corn
- ☐ Wheat
- ☐ Other: _____________

24. How big is your farm?
- ☐ Less than 50 acres
- ☐ 50-99 acres
- ☐ 100-149 acres
- ☐ 150-199 acres
- ☐ 250-299 acres
- ☐ 300-349 acres
- ☐ 350 acres or more

25. Is your farm currently growing grain under a contract with a corporation?
- ☐ Yes
- ☐ No
- ☐ Unknown

26. The majority of your grain is grown for:
- ☐ Human consumption
- ☐ Animal consumption
- ☐ Biofuel
- ☐ Other or unknown

27. Does the farm where you work follow any ecological practices (i.e., sustainability priorities, procedures to minimize environmental impact)?
- ☐ Certified organic
- ☐ Organic practices, without certification
- ☐ Agroecological practices
- ☐ Other ecological practices
- ☐ No set practices
- ☐ Other: _____________

28. How many years have you been farming? ______

29. …on this land? ________

30. Select the option that best describes the land tenure of your farm.
- ☐ Own and operate
- ☐ Leased from an individual
- ☐ Leased from corporate owner
- ☐ Leased form government
- ☐ License
- ☐ Profits-à-prendre
- ☐ Memorandum of understanding
- ☐ Other or unknown

31. How many people work on your farm (including you)? __________

32. Is any of the labour on your farm done by volunteers?
- ☐ Yes
- ☐ No
- ☐ Unknown

33. Are any of the people working on your farm migrant workers (e.g., Seasonal Agricultural Worker Program or Temporary Foreign Worker Program)?
- ☐ Yes
- ☐ No
- ☐ Unknown

34. Does your farm rely on family labour?
- ☐ Yes, with pay (e.g., wage or allowance)
- ☐ Yes, without pay
- ☐ No
- ☐ Unknown

Optional: If you would like information about the study or to **volunteer for an interview (phone or in person),** please enter your contact information below.
Email: ____

<u>Semi-Structured Interviews</u>

Introduction
1. What does a typical day on the farm look like for you?
2. How would you describe your farming operation?

Values and Assumptions
3. What is the role of a farmer?
4. What do you consider to be the big challenges of gain (soy, maize, and wheat) farming in Ontario?
5. How would you describe the relationship between a farmer and the land or the environment? Are there any big areas of environmental concern for you?
6. The UN Food and Agriculture Organization explains, “Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and. healthy life.” What does food security look like to you, and what role does farming play in establishing food security?

General Questions about Digital Farming

7. Digital farming, smart farming, clean tech, precision agriculture, and Big Data are becoming buzzwords in agri-business and the media. Are you familiar with these terms? What do these concepts mean to you?
8. Generally speaking, how do you feel about the recent emergence and use of digital farming technology and Big Data in farming?
9. Is digital farming part of your current farm management or future business strategy?
10. What role might digital farming play in addressing the challenges in Ontario agriculture?
11. Is technology good for agriculture, bad for agriculture, or neither?
12. Do you feel pressure to use digital farming technologies? If so, from where?

Theme Questions about Digital Farming

13. What risks do perceive when considering the use of digital farming technologies on your farm?
14. Businesses and governments claim that digital farming will increase the profits and economic wellbeing of farmers. Do you agree?
15. Do you have control over your information and digital farming technology? How much do you trust the companies that handle your data?
16. How does the use of digital farming affect your decision-making and farm management?
17. Does digital farming change the way that you understand and interact with the land? How so?
18. How will digital farming affect the environmental problems faced in agriculture and Ontario grain farming specifically?
19. Businesses and governments claim that digital farming will address food insecurity. Do you agree?
20. How does digital farming affect the time and quality of labour on the farm?
21. Are all farm workers affected equally by the implementation of digital farming? Consider both paid and unpaid labour.
22. Do you have any other concerns of the risks involved in digital farming such as employment, environment, and the impacts on farming communities? Or is there anything else that you would like to add?

In Chapter 4, I indicated that some questions in the online questionnaire and interview guide were influenced by a study of digital farming in the Australian grain industry. I have listed below the specific questions from which I drew inspiration (Fleming et al., 2018, p. 4):

- "When people talk about digital agriculture and big data, what does that mean to you?"
- "How much is big data part of your current business or future strategy?"
- "What benefits or opportunities do these digital technologies and big data applications provide?" and "What problems or risks do they present?"
- "What do you think are the main challenges or changes in relation to digital agriculture and big data that are likely to impact on the grains industry in the next 5–10 years?"

Appendix C

Qualitative Interview Analysis: Example Codes

Table 5: Coding methods used in data analysis with examples - Appended

Coding method	Definition	Examples from my codebook
	First Cycle	
Open Coding	Constructing prolific descriptive codes in an exploratory fashion; focus on context and meaning over content	- Challenges of digital farming - When things go wrong - Labour shortage - Return on investment - Rural population - Soil health
In Vivo	Key words or phrases in the voice of participants, copied verbatim form the transcript (and coded over other text with the same words or meaning) ** Employed in Open Coding*	- ‘Smart decisions’ - ‘Keeping up with technology’ - ‘No choice’ (adoption) - ‘Right thing to do’ - ‘Data vs. gut-feel’ - ‘Enough food’ (food security)
Values Coding	Codes for participants *attitude* (way we think and feel), *values* (priorities, what is important), *beliefs* (system of values, attitudes, and knowledge) to understand their worldviews and perspectives; requires reflexive positionality as it is an interpretive exercise (i.e., not always explicitly stated)	- Optimistic - Frustrated - Values: Profit - Values: Knowledge - Farmers are stewards - Farming is a business first
	Second Cycle	
Axial Coding	Development of node hierarchies for organization and theorizing; abductive analysis working iteratively to reconcile emerging trends from data (inductive) with theory and literature (deductive) to develop themes in analytic memo writing	- *Beliefs (Values Coding)* > Impact of digital farming >> DF makes farming more efficient >> DF doesn’t change anything … - *Environmental dimensions* > Impact of agriculture >> Soil >> Water …

Table 6: Full list of codes in NVivo

Farmer Perceptions (Affective Coding)	**Attitudes and emotions**	*Negative*	General; Blamed or attacked; Concern; Confusion; Disappointment; Frustration; Misunderstood; Overwhelmed; Skeptical; Unappreciated
		Neutral	General; Cautious; Dismissive; 'lukewarm'
		Positive	General; Confidence; Excited; Hopeful; Pride
	Values	Community; Convenience; Efficiency; Family; Knowledge; Pleasure; Profit; Progress; Reliable; Stability; Stewardship; Tradition; Transparency; Trust; Wellbeing; Yield	
	Beliefs	*Role and identity of a farmer*	Collaboration is in farmer's interest; Farming is a business first; Farming is hard work; Farmers are stewards of the land; Role of farmer is to produce food; Role of the farmer is changing; Role of the farmer is to care for the land; Role of the farmer is to feed the world
		Relationships and conflicts	Environment = economics; Environment vs. economics; Farmer vs. consumer; Farmers vs. government; 'my neighbour is my competitor'
		Perceived pressure	Farmers on other farmers; Improving env impact is the 'right thing to do'; Labour shortage motivates DF adoption; Pressure to adopt because you can't avoid DF tech; The environment or weather is changing; 'We have to change our attitude'
		Impact of DF	DF adds onto labour burden; DF and BD benefit big corporations (not farmers); DF and BD benefit farmers; DF changes my decision-making; DF = better decisions; DF doesn't change things; DF improves environment; DF is not delivering on the promises; DF makes farming easier and more convenient; DF makes farming more efficient; DF makes farming more profitable + productive
		Perceptions of future	Agriculture is changing due to DF Labour 'micro-scale' or 'target management' Agriculture is changing with or without DF Bigger farmers and smaller communities Farmers are still important for decision-making Farmers who do not adopt will struggle People will experience DF in different ways
	Challenges	Challenges (DF); Challenges (general); Future challenges	
	Risks	Risks (DF); Risks (general); 'When things go wrong'	

Digital Farming and Big Data (Descriptive Coding)	**Adoption**	Adoption stories; Barriers to adoption; Different experiences of DF; Digital divide; 'Keeping up'; 'no choice'; Non-adopters; Older-younger; Resistance
	Benefits of DF	Environment; General; Information; 'Optimize'; Productivity; Profit
	Data	Acceptance; Access to information; Big Data; Collection; Financial information; Handling; Interest; Ownership; Security; Sharing; Trust
	Knowledge of DF	Conferences; Different levels of use and understanding of digital; Digital technology in everyday life
	Transition	General; Technology is changing
	Adoption	Ability to afford technology; Banks; 'Bottom line'; Competition; Corporations; Costs; Debt; Efficiency of farm operation; Farm size; Food system or supply chain; Insurance; Investments; Land Tenure; Loss; Margins; Marketing; Markets; New industries in agri-food; Price of food; Price of land; Productivity; Profit; Quota; Return on investment; 'Speculation'; Taxes; Trade
	Potential of DF	
[Econ.]	*Economic Dimensions* (Descriptive Coding) Ability to afford technology; Banks; 'Bottom line'; Competition; Corporations; Costs; Debt; Efficiency of farm operation; Farm size; Food system or supply chain; Insurance; Investments; Land Tenure; Loss; Margins; Marketing; Markets; New industries in agri-food; Price of food; Price of land; Productivity; Profit; Quota; Return on investment; 'Speculation'; Taxes; Trade	
Environmental Dimensions (Descriptive Coding)	**Earth-human relationships**	Balance; Improving; Intensive; Knowledge of the land; Next generation; Stewardship; To be managed
	Impact of agriculture	Air and atmosphere; Fertilizers; Fossil fuel; Habitat; Soil; Water
	Matters of concern about the environment	Pests and disease; Urban sprawl; Weather or climate
Social and Political Dimensions (Descriptive Coding)	**Food security**	Accessibility; Availability; 'Enough food'; Production; Social factors; Social programs; Traceability; Waste
	Farmer-eater relationship	
	Public perception	
	Power relations	
	Environmentalists and activists	
	Government	
	Politics	
	Family	
	Rural population	
	Mental and physical health	
	Quality of life	
	Gender	
	Labour (Descriptive Coding)	
	Capabilities	
	Cost of hiring labour	

	Custom or hiring out	
	'Get them to work'	
	Jobs	
	Migrant labour	
	Off-farm jobs	
	Precarious	
	Quality of labour	
	Shortage	
	Time	
Other	**Decision-Making**	Autonomy; Compromise; Data and 'numbers' vs. 'gut feel'; Factors in decision; Planning for the season; Science; 'Smart decision'
	Current events	Ag Inputs; DON; Food guide; GMO; Huawei; Lake Erie; Other; Politics; Trade
	Farm operation	Agronomy; Changes in ownership; Changing farming practices; Crops; Digital; Machinery
	History	
	'Other parts of the world'	
	Quotes and anecdotes	

Appendix D

Study Participant Demographics

Table 7: Distribution of questionnaire respondents by demographics and farm characteristics

Farmer Demographics								
Age	100%	n = 73	**Gender**	100%	n = 72	**Education**	100%	n = 72
18-24	1.37%	1	Female	15.28%	11	Elementary	0	0
25-34	20.55%	15	Male	83.33%	60	Secondary (no diploma)	2.78%	2
35-44	28.77%	21	Non-binary	0%	0	Secondary diploma	15.28%	11
45-54	9.59%	7	Prefer to self-describe:	0%	0	College	31.94%	23
55-64	26.03%	19	Prefer not to say	1.39%	1	Undergraduate	31.94%	23
65-74+	13.70%	10				Graduate or professional	13.89%	10
						Other (post-secondary)	4.17%	3
Farm Operation Characteristics								
Crop	100%	n = 65	**Size**	100%	n = 65	**Land Tenure**	100%	n = 65
Soybeans	24.62%	16	< 50	1.54%	1	Own and operate	87.70%	57
Corn	50.77%	33	50-99	76.92%	5	Leased from individual	7.69%	5
Wheat	3.08%	2	100-149	3.08%	2	Leased from corporate owner	0%	0
Other:	21.54%	14	150-199	4.62%	3	Leased from government	0%	0
			200-250	4.62%	3	License	0%	0
			250-299	6.15%	4	Profits-à-prendre	0%	0
			300-349	12.31%	8	Memorandum of understanding	1.54%	1
			> 350	60.00%	39	Other	3.08%	2

Table 8: Descriptive information for each interview participant

Farmer #1	2018-10-25	35-44 years old, man, farming 350+ acres, undergraduate degree
Farmer #2	2018-10-31	65-74 years old, man, farming 300-349 acres (certified organic farm), undergraduate degree
Farmer #3	2018-11-05	55-64 years old, man, farming 300-349 acres, secondary diploma
Farmer #4	2019-01-10	35-44 years old, man, farming 350+ acres (agroecological practices), secondary (no diploma)
Farmer #5	2019-01-16	35-44 years old, woman, farming 250-299 acres, graduate degree
Farmer #6	2019-01-18	65-74 years old, man, farming 350+ acres (agroecological practices), secondary diploma
Farmer #7	2019-01-21	55-64 years old, man, farming less than 50 acres, undergraduate degree
Farmer #8	2019-01-24	55-64 years old, man, farming 350+ acres, graduate degree
Farmer #9	2019-01-31	35-44 years old, man, farming 350+ acres (agroecological practices), graduate degree
Farmer #10	2019-02-04	54-54 years old, man, farming 350+ acres, secondary diploma
Farmer #11	2019-02-08	man, otherwise unassigned

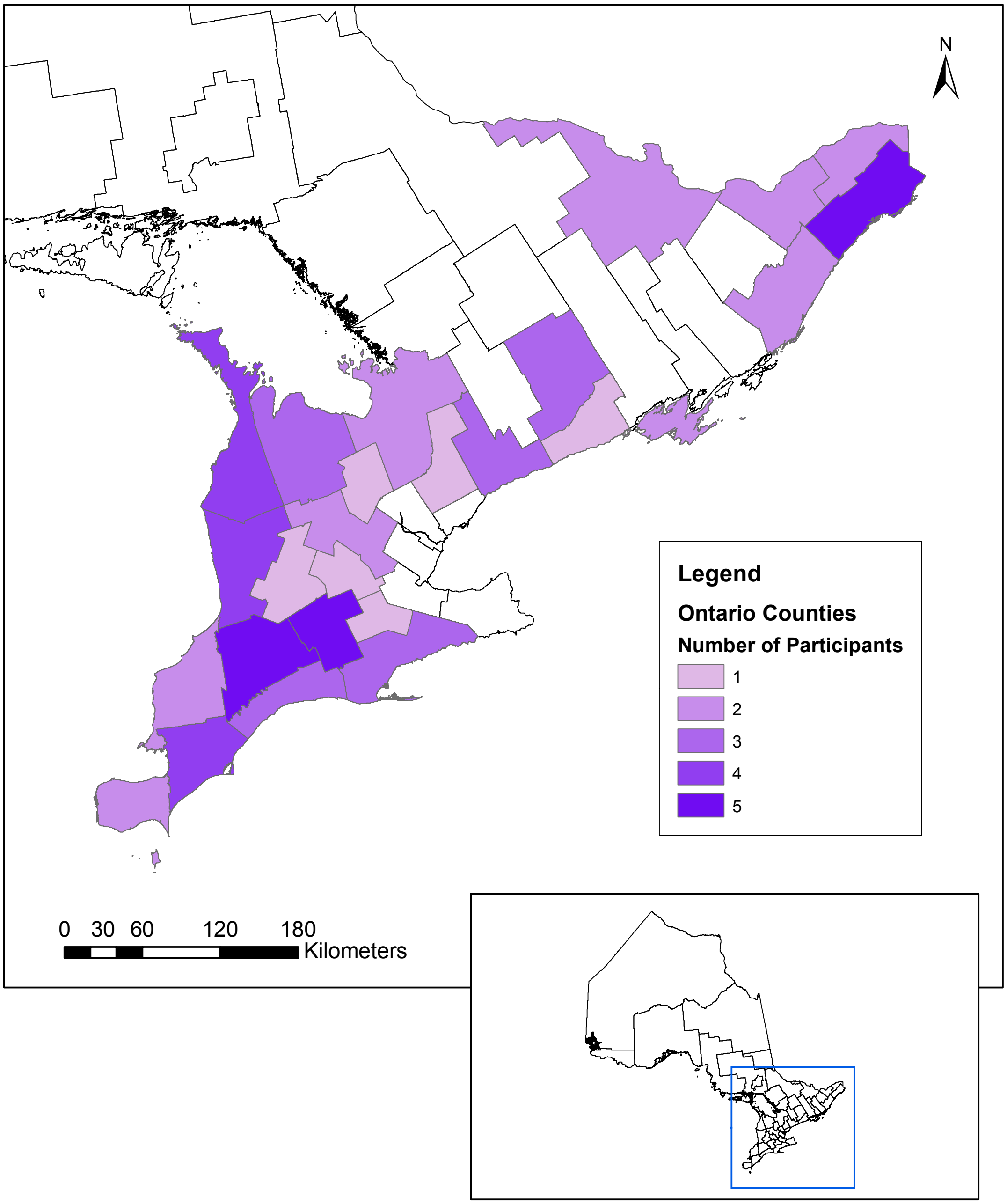

Figure 11: Questionnaire respondent demographic map by Ontario counties - Full Size