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Adoption of smart farm networks: a translational process to inform digital agricultural technologies

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Abstract

Due to natural phenomena like global warming and climate change, agricultural production is increasingly faced with threats that transcend farm boundaries. Management practices at the landscape or community level are often required to adequately respond to these new challenges (e.g., pest migration). Such decision-making at a community or beyond-farm level—i.e., practices that are jointly developed by farmers within a community—can be aided by computing and communications technology. In this study, we employ a translational research process to examine the social and behavioral drivers of adoption of smart and connected farm networks among commodity crop farmers in the United States. We implement focus groups and questionnaires to bring to the fore views on the use of digital technologies in collaborative contexts. We find that participating farmers are concerned with several issues about the potential features of the network (e.g., the ability to ensure data validity while maintaining data privacy) and the nature of their interactions with the various stakeholders involved in the network management. The participatory approach we adopt helps provide insights into the process of developing technologies that are both actionable and trusted by potential end users.

Keywords Smart farm networks · Digital agriculture · Trust · Translational research · Early warning systems · Community of practice

Introduction

The increased rate and severity of changes in weather patterns have led to alterations in the growing conditions of crops, as well as the degradation of soil and water resources (United States Environmental Protection Agency, 2022). https://www.epa.gov/climateimpacts/climate-change-impacts-agriculture-and-food-supply. Since the adverse effects of these climatic changes usually extend beyond the perimeters of individual farms (e.g., pest migration), coordinated responses among farmers may often be required to deal with these challenges. Consequently, information and communication technologies are being developed to assist farmers with timely and collective mitigation and adaptation strategies to cope with current and future agricultural challenges. This study explores the drivers to acceptance and adoption of a smart and connected farm network in the context of early warning systems for pest infestations. Through a participatory approach, we investigate farmers' perceptions of the benefits and risks of participating in a smart and connected network, providing insights on the potential barriers that keep farmers from embracing (digital) tools and practices that could enhance their productivity and profitability.

Previous research has identified technological factors that may hinder the adoption of smart farming, including incompatibility across the technological tools and disconnection

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between the tools developed by the private sector and the services offered by public research and extension organizations (Eastwood et al. 2017; Higgins et al. 2017). This study contributes to the literature by further exploring some of the behavioral factors that may pose a threat to adoption of smart farming, including issues surrounding the aggregation of data across scales and the coordination of decision-making by farmers (i.e., practicing farming within a community context). To do so, we employ a participatory approach as a first step in a translational research process that sheds light on engaging farming communities in the development process of digital technologies within a network context. When done correctly, participatory approaches hold promise in aiding the development and utilization of agricultural technologies (Lengwiler 2008; Biggs and Smith 1998).

Agriculture in the context of climate change

The changes in temperature, precipitation patterns and extreme weather events being observed across the globe are bound to adversely affect agricultural productivity, food security, and overall human wellbeing (Nelson et al. 2009). The impact of climate change on agricultural systems is both substantial and complex. For instance, the effect of a changing climate, as mediated by the development of plant diseases, is itself complex (Garrett et al. 2011). At the minimum, climate change is expected to affect the geographical distribution of hosts and pathogens, as well as transform the physiology of host-pathogen interactions by altering the stages and rates of pathogen development and modifying host resistance (Coakley et al. 1999).

Although an increase in agricultural production and trade have contributed to the rapid spread of crop pests and pathogens, changing environmental conditions have also been responsible for the observed patterns of pest and pathogen emergence and migration globally (Bebber 2015). Moreover, the risk of crop diseases and damages by insect pests is increased by the concentrated nature of many agricultural landscapes (i.e., monoculture farming), especially in a country such as the United States where four crop species account for over two-thirds of croplands (Margosian et al. 2009).

Other menaces such as the dispersal of weed seeds and the diffusion of pesticides by wind also demonstrate that agricultural production is increasingly faced with threats that transcend farm boundaries. Besides, climate change is expected to encourage the proliferation of weeds and pests (Nelson et al. 2009). Consequently, there is a need to respond appropriately to the current agricultural production context with proper management approaches—those that emphasize mitigation efforts and decision-making at the landscape and community level. Although technological advancements may represent only partial solutions to the complex challenges of climate change (Fraser et al. 2016), innovations like rapid computing and communications technologies can aid farmers in exploring response strategies that require them to act collectively.

Digital agricultural technologies, smart farming, and data sharing

The agricultural sector has been experiencing an "information revolution" (Dyer 2016), also known as a "digital agricultural revolution" that is rapidly changing the agricultural management landscape (Weersink et al. 2018). This revolution is characterized by the use of digital agricultural technologies and platforms and is driven by both the low cost of data collection and improved computational capacity in analyzing data (Coble et al. 2018; Weersink et al. 2018).

Digital agricultural technologies are those that "digitally collect, store, analyze and share electronic data/information along the agricultural value chain," while digital platforms are "a group of technologies that are used as a base upon which other applications, processes and technologies are developed" (Runck et al. 2021, pp1-2). Examples of digital technologies used in agriculture are unmanned aerial vehicles (UAVs), sensors (soil, water, light), and location and navigation systems such as the GPS. Among examples of digital platforms are digital tool suites that link data to tools, or a website that aggregates information about digital tools (Runck et al. 2021).

On the other hand, smart farming is a phenomenon that emphasizes the use of information and communication technology in the cyber-physical farm management cycle, thereby enabling farmers to make context- and situation appropriate responses to real-time events (Wolfert et al. 2017). That is, smart farming entails the use of digital technologies to manage farms with the goals of increasing the quantity and quality of products, reducing production risks, and minimizing costs in the long run, while optimizing human labor. Examples include the use of sensors and drones for smart crop management (e.g., pest detection and spraying), and utilizing artificial intelligence and location tracking software in autonomous ground vehicles (e.g., self-driving tractors) to increase field work accuracy. Smart farming is believed to enhance efficiency and productivity, support sustainability, and positively affect rural communities (Regan 2019). However, previous studies have highlighted various concerns around the effects of digitalization on the nature of work, farmer identity and the cultural fabric of rural areas; as well as ethical issues surrounding the distribution of power (Ingram et al. 2022; Klerkx et al. 2019; van der Burg et al. 2019).

As earlier pointed out, the transboundary nature of current production threats necessitates data collection and decision-making at a community or beyond-farm level. However, farmers often express concerns with respect to data sharing across farms. For example, there is the fear of being stigmatized or penalized if worrisome data is traced to a particular farmer's operation (Regan 2019). That is, farmers may be concerned about the practicability of assuring privacy of individual farm-level data and the potential consequences of such negligence. Moreover, even in cases where individual anonymity is guaranteed, concerns about undesirable action being taken against the group or community to which the farmer belongs may be another source of concern (Taylor 2017).

Indeed, many of the concerns with data sharing among farmers revolve around issues of data privacy, data ownership, trust, and control (autonomy). However, it has been noted that the level of farmers' skepticism varies with respect to the stakeholders they must deal with. The type of organization managing the data-sharing platform and farmers' idiosyncratic attitudes towards them have been observed to influence the degree of farmers' willingness to engage in arrangements that require sharing of farm data. For instance, Turland and Slade (2020) found that Canadian farmers were more willing to share their data with university researchers and grower associations than with government officials or equipment manufacturers. Potential explanations for this relate to farmers' fear that the government could generate new regulations or reveal violations of existing regulations based on the shared data, as well as skepticism about the benefit that the government can provide relative to private organizations (Coble et al. 2016).

Farmers also often express skepticism about the ability of current regulations and practices to adequately protect their farm data. Even where privacy and security measures do exist, some farmers are still worried about the risk of potential breaches (Jakku et al. 2019). Furthermore, many farmers believe that they have the right to know what data is being collected, who is accessing it, and how it is going to be disseminated and used (Regan 2019; Ryan 2019). Farmers perceive data as a valuable commodity and are concerned about who will capture the value of accessing and using the data, especially if it will be at the expense of farmers themselves (Jakku et al. 2019; Zhang et al. 2021). For example, farmers fear that by accessing their data, data aggregators could gain an unfair advantage and engage in price speculation in commodity and real-estate markets (Sykuta 2016).

Another concern that farmers have with regards to data governance is the lack of transparency/clarity around contracts with technology providers, and a limited awareness of the terms and conditions regarding data ownership and use (Ryan 2022; van der Burg et al. 2020; Wiseman et al. 2019). Farmers may not be aware of or may not fully understand how much control the contract relinquishes to the service provider, or the extent to which the data will be shared, raising ethical issues around the informed consent that they may provide (Ryan 2019). It is also concerning that many of such license agreements are generally non-negotiable and are presented in a "take it or leave it" format (Wiseman et al. 2019).

Behavioral determinants of technology adoption and the practice of farming

In general, innovations are taken to be the new methods, customs, or devices used to perform new tasks (Sunding and Zilberman 2001). Innovations are usually adopted because of their perceived benefits (Chavas and Nauges 2020). That is, the adoption of a new technology is often the result of calculations that weigh the incremental benefits of adoption against the cost of change, often within a context of uncertainty (Chavas and Nauges 2020; Hall and Khan 2003).

Generally, adoption of new agricultural technologies is affected by several factors such as the characteristics of the technology, agroecological or biophysical factors, economic factors, social networks, and informational factors (Mwangi and Kariuki 2015; Tey and Brindal 2012). At the decision-maker level, individual characteristics and intrinsic behavioral factors have been shown to influence the adoption of agricultural technologies (Streletskaya et al. 2020). These include farmers' risk preferences, time preferences, altruism, social norm compliance (Carter 2016; Wuepper et al. 2023), among others. Osrof et al. (2023) conducted a systematic review on the drivers of smart farming adoption and found that individual perceptions and attitudes towards the functioning of the technologies often act as barriers to farmers adopting these technologies.

The nature of an agricultural innovation may also necessitate a more serious consideration of the behavioral traits of farmers. For instance, in settings that require collective action such as that of a smart and connected farm network, trust in the cooperation level of others plays a vital role in farmers' decision to adopt an innovation. That is, if the innovation in question is of a public good nature and requires the voluntary contribution of individuals within the community, trust is one of the elements of social capital that facilitates the required cooperative behavior (Leonard et al. 2010). For example, Halimatussadiah et al. (2017) find that trust—used as a proxy for social capital—impacts the contributions made by individuals towards an environmental collective action involving the management of waste collection. This highlights the vital role that trust and relationships among farmers play in shaping their views about the innovation (Raedeke et al. 2003).

To explore this notion further, we look to the discipline of Sociology and draw insights from Bourdieu's concepts of "field" and "habitus" that highlight how actors' objective conditions, internal interpretations and social actions can help understand the practices and operating logic of a given social group (Bourdieu 1977, 1984, 1988, 1990; Bourdieu and Wacquant 1992; Raedeke et al. 2003). This framework has been previously used to inform how farmers and entrepreneurs negotiate change and to explore the inherent characteristics that shape their responses (Valdivia et al. 2021; Barbieri and Valdivia 2010; Glover 2010; Raedeke et al. 2003; Shucksmith, 1993).

Under this framework, the *field* of farming entails the social relations that make farming possible (Raedeke et al. 2003). It emphasizes the networks or set of relationships farmers have, as opposed to the individuals and social structures that make up the system. These relationships exert considerable influence on the practice of farming. For example, family members may sway farmers' views of what constitutes "good farming," while the perceived preferences of landlords may play an important role in the farming methods their tenants use (Raedeke et al. 2003). Similarly, farmers' relationship networks often influence their adoption of innovation (Caffaro et al. 2020), and more generally, these networks situate much of their learning since learning is argued to be a social process (Oreszczyn et al. 2010).

On the other hand, the concept of *habitus* has to do with the habitual schemas and dispositions of individuals that operate in their subconscious. Specifically, the habitus of farming refers to the "taken-for-granted, shared meanings and behaviors" utilized by farmers and it works as a "matrix of perceptions, appreciations, and actions [that] makes possible the achievement of infinitely diversified tasks" (Raedeke et al. 2003, p. 69). The habitus of farming could also be described as the "active residue of past action that functions within the present" and allows for a farmer's "efficient negotiation through mundane day-to-day activities on the farm" (Carolan 2005, pp. 389–390). That is, habitus is the internalization of the dominant modes of thoughts and experiences (through social interactions and one's own experiences) that are derived from the subconscious and cumulative assimilation of an established ethos of being a farmer (Shucksmith and Herrmann 2002).

The interrelation of habitus and the constraints, demands and opportunities of a field produces practices (Shucksmith and Herrmann 2002). The practice of farming therefore encapsulates the dialectical relationship between field and habitus, and the interaction of field and habitus is what gives rise to specific attitudes, feelings, and dispositions (Raedeke et al. 2003). Learning about such values and attitudes is inherently essential in the case of smart and connected farm networks because the functioning of such networks is hinged upon collaboration among farmers (which, for example, may be contrary to the competitive nature of commodity farming).

Methodology

Translational research process

This study is embedded in a translational research process (Woolf 2008) that engages potential end-users of a technology in the discovery process by effectively communicating their needs, wants and perspectives about the proposed technology (Valdivia et al. 2014).[1] Within the context of agricultural development, this is a participatory process involving a two-way communication (feedback loop) between actors in the technology development sphere and those in the practice of farming (Valdivia et al. 2014, 2018) (see Fig. 1). Such feedback loop is intended to bridge any differences in knowledge systems and facilitate learning among the different groups of actors, with the end goal of creating a technology that is salient, trusted, and actionable within the context of the end-users. For instance, feedback from potential end users can help developers improve the technology, while information from various sources—including the developers and their own social networks—can help the end users in mastering the technology. Stakeholder participation shares features of co-design in policy research, which has been established as an "effective, democratic, and innovative" approach to research that includes actively involving diverse stakeholders in developing and evaluating responses to shared problems (Blomkamp 2018, p. 731). The community of practice and the process feedback loop in the context of smart, connected farm networks are further discussed in the next section.

Study context and procedures

This study is part of a project that aims to develop novel socio-technical solutions that will create smart, connected farm networks to facilitate rural farming communities with data sharing, knowledge exchange and coordinated responses to production threats. The project intends to promote real-time monitoring of threats and contribute to community-led decisions, with the end goal of improving the management practices and crop yield of farmers in

[1] By including important but often less-dominant voices in the technology development conversation, the translational research process helps in decreasing the risks of exacerbating inequalities and injustices that could potentially be caused by the digital agricultural revolution (Klerkx and Rose 2020). Indeed, such an approach aligns with the notion of responsible agricultural innovation (Bronson 2018).

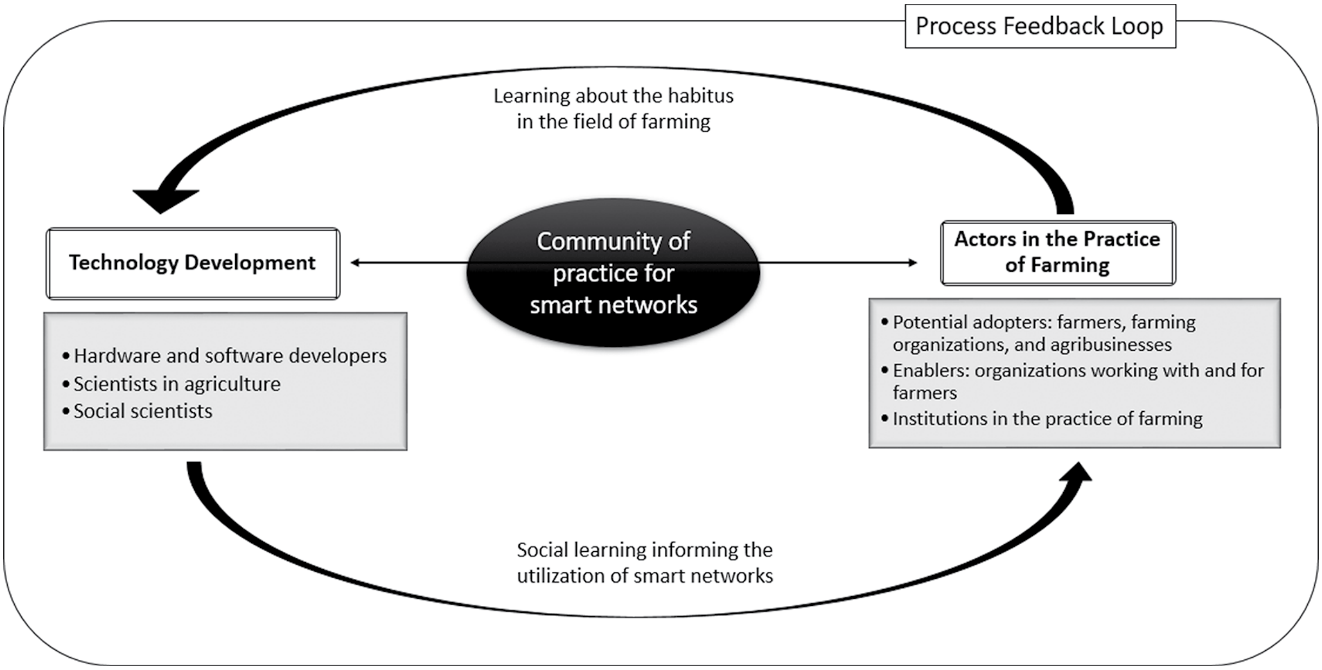

Fig. 1 Translational research process in the development of smart farm networks

an efficient and cost-effective manner. The technology in question is expected to have a network component where farmers can share their knowledge and data, and coordinate responses to potential pest and disease outbreaks. That is, the network in question requires on-the-ground data from farmers' fields—in this case from farms distributed in a region—to provide information beyond a particular farm.

The study was implemented in collaboration with an association that serves farmers in the U.S. state of Iowa. A community of practice (CoP) was formed to engage potential users of the technology from its inception and throughout the development process. Engaging the farmers themselves to learn about their views of the technology represents the first step in the feedback loop process of the innovation pathway (Valdivia et al. 2018). This stage consisted of the scientists sharing the concept of the smart and connected network, what it would take to produce and deploy the technologies to be used within the network, and which issues the network could address (Valdivia et al. 2014). The team of developers consisted of computer scientists creating the software and hardware of the technology (e.g., machine learning models to identify the pests, and white spaces for the wireless transmission of data), agronomists in charge of testing the technology in the field, and social scientists examining drivers of technology adoption. The workshops with the CoP are part of the first step in the study's translational research process. Findings from these workshops served as basis for the design of quantitative instruments to elicit perceptions of the proposed network among a larger number of farmers from around the state.[2]

A group of eight farms with soybean production in common constituted the CoP. The selection of participating farms was made with assistance of the partnering grower association.[3] The nature of the technology – a network – guided the selection of the farms; that is, farms were selected as a function of their location in Central Iowa and the distance between farms. The farms belonging to the CoP were used to test various sensory and networking devices while the innovation process unraveled. Additionally, members of the CoP were selected based on their willingness to participate in this research project.

Two participatory workshops were conducted in August 2021 in the state of Iowa. Participants consisted of farmers representing the eight farms in the CoP and a team of scientists from four institutions involved in the innovation process. The protocols for the participatory workshops were developed with respect to the specific technology and were

[2] Specifically, the tools that were designed based on feedback from the CoP workshops include a discrete choice experiment to elicit farmers' willingness to pay for different attributes of the network and incentivized behavioral games to elicit behavioral drivers of adoption.

[3] We acknowledge a potential selection bias in the formation of the community of practice as the selected farmers were active members of the same grower association. These farms were mid-sized and have been exposed to more advanced digital technologies. However, they were ideal to achieve the goals of the project as they allowed for data collection in their fields using sensors and for the continuous testing of the technologies throughout the project cycle. Furthermore, it was crucial to enroll farmers who were willing to provide feedback to the scientists as the development of the technologies advanced.

designed based on a related literature review and feedback from the scientists involved in the development of the network. The protocols were then pilot tested among the research team prior to implementation. The active involvement of actors from the technology development sphere in the design and testing of the protocol was also an important initial stage of the translational research process employed in this study.

The participatory workshops lasted approximately 90 mins and began with a presentation about the goals of the project and a short description of the network by the scientists. Participants were informed that the smart and connected network would help improve data collection, transfer, and processing, as well as improve connectivity within and between fields. They were told that the communication infrastructure for the network was to be realized with the help of emerging technologies such as dynamic spectrum access, unlicensed radio frequency, unmanned aerial vehicles (or drones), Internet of Things sensors, and mobile crowdsourcing; and that sensors would be the source of information, providing data and images on crops, soil, environment, diseases, etc. The participants were also notified that the collected data would be processed using state-of-the-art algorithms and machine learning approaches; that cloud services would be used to store both raw and processed data; and that drones and novel wireless technologies would be utilized to transfer data to the cloud. Furthermore, they were informed that farmers participating in the network would have real-time access to the processed data to visualize the resulting information from fields and possible recommendations through a dedicated website portal on a tablet, desktop, or smartphone; and that they could also send information and data to the system in a privacy-preserving manner through a crowdsensing paradigm.

After receiving information on the network, participants engaged in a focus group discussion followed by a short questionnaire. At the end of the session, participants received a $50 cash compensation. Approval from the university's Institutional Review Board was obtained prior to conducting the workshops.

Focus group discussions

The members of the CoP participated in a guided focus group discussion to share their impressions, experiences, and vision about how the proposed network could become an actual trusted tool in their hands. The focus groups were designed following Morgan (1997) and they allowed us to observe group interactions around the nature of the innovation, bringing into discussion many more ideas than an individual interview. The interactions and dynamics in the focus groups also presented an opportunity for participants to elaborate on the perspectives and experiences shared by others in the group.

Two focus group discussions were conducted, one with three participants and one with six participants.[4] Each focus group started with a presentation about the proposed network given by the developers and a grower specialist involved in the deployment process. Information about the characteristics of the network was given through a 10-minute video followed by an 8-minute in-person presentation about the potential benefits of the network to the practice of farming.[5] The presenters were the same in both focus groups. Participants then had the opportunity to ask general questions about the innovation and introduce themselves to the group. Both focus groups were facilitated by the same researcher who followed a script to ensure consistency with the content, prompts, and framing of questions. The focus groups were recorded using Zoom and cellphones. Participants used their names during the discussion; however, anonymous identifying numbers (e.g., P1) were used when transcribing the recordings to maintain anonymity of responses. That is, there is no personal identification linked to the responses.

A literature review on the practice of farming concept (field and habitus) informed the design of the questions used in the focus groups. The discussions were structured based on the following four sets of questions (in this order): (1) *What are your impressions of what was just presented to you about the technology? Have you had or interacted with similar technologies before?* (2) *What do you like most about the technology, and what are some problems you are currently facing that this technology may be able to address?* (3) *What concerns do you have about the technology? Why wouldn't you adopt this technology on your farm?* and (4) *What are your thoughts about how the technology could become a reality for farmers in your community?*

Questionnaire

The purpose of the questionnaire was to obtain information on the socio-demographic characteristics of the farmers (e.g., age, income, gender), their farming operations, and behavioral attitudes that may influence adoption of the smart

[4] Although eight farms made up the community of practice, there were a total of nine participants for the workshop sessions. This was because one farm had two representatives (i.e., a married couple), whereas the other farms had only one representative each.

[5] In addition to describing how the technology could be used in the farmers' practice, the presentation also highlighted some of the potential benefits farmers could derive from participating in the network. Since costs or risks of adoption were not mentioned explicitly, participants may have focused more on the positive aspects of belonging to the network. However, the follow-up questions and discussions gave much attention to the potential costs and barriers to adoption.

and connected farm network. Participants were asked questions about their farm specializations, types of digital technologies currently being used, and their current practices for managing pests, diseases, and weeds. Regarding farm networks, participants provided information about the formal and informal networks, organizations, and people they interacted with, as well as the frequency of such interactions. They also responded to various statements regarding the level of trust they had in their neighbors, other farmers, agricultural technology and network providers, and several other stakeholders in their field of farming. The questionnaire also enquired about the farmers' knowledge and use of different services provided by digital agricultural technologies. Furthermore, the farmers were asked about the perceived value and risks they associate with digital agricultural technologies and networking, and the conditions for increased trust in these service providers.

Data analysis

The recordings of the focus groups were transcribed using *Otter.ai* software and the transcripts were then revised by two researchers separately. The three members of the research team engaged in active reading and re-reading of the edited transcripts and independently carried out a thematic analysis (Braun and Clarke 2006). The data was coded manually and the themes for the coding protocol were based on the *field* and *habitus* framework described above.

Since the intent of the focus groups was to capture farmers' impressions about the proposed network, the coding strategy took into consideration both the group and individual level phenomena; that is, insights from both the individuals that make up the CoP and the dynamics of the group were acknowledged (Morgan 1997). An analysis that recognizes the interplay between these two levels of analysis is often recommended because neither the individual nor the group represent a "separable unit of analysis" (Morgan 1997). Furthermore, this approach helps to reduce the potential impacts of omissions by an analysis at only the group level such as the effects of censoring and conformity—situations that tend to occur in group settings (Carey and Smith 1994).

Our thematic analysis followed a more "theoretical or top-down" approach, as opposed to the "inductive or bottom-up" alternative (Braun and Clarke 2006). That is, rather than simply focusing on providing a rich description of the data itself, the theoretical approach was driven by the analytic interest of the researchers and centers more on the specific questions of interest, thereby providing more detailed analysis of relevant aspects of the data. Specifically, the researchers sought to determine the networks of farmers (while identifying those that they trust), the shared values in the practice of farming, and their adaptive capabilities (Glover 2010; Valdivia et al. 2021). The downside to using a top-down approach is that there may be other factors influencing the likelihood of acceptance and adoption of the network that may differ across farmers that are not taken into account in the analysis, for example, differences in the culture of the producers and the nature of the products and markets they participate in. The researchers met multiple times to review their independent analyses of the data and to discuss the emerging themes and sub-themes. Responses to the questionnaire were analyzed using Microsoft Excel.

Results

Description of the community of practice

The community of practice (CoP) consists of nine farmers (8 farms) who are members of the same grower association. Almost all participants are male (90%), with an average age of 51 years and average household income of \$135,000, which is below the average net farm income (cash) of \$153,000 for Iowa in 2021 (Ag Decision Maker 2022). All participants have completed high school and half have at least a college degree. They are all involved in crop production (mainly corn and soybean) and had each planted between 1,000 acres to almost 4,000 acres of cropland in the study year. On average, participants plant 700 acres of soybean and 850 acres of corn per year. About 75% of participants are involved in other farming operations such as beef cattle and/or hog production.

Characteristics of the CoP field and practice of farming

In addition to being members of grower associations, participants are also part of cooperatives. They mostly use these groups as well as other private company networks for sharing information about farming, with the nature of these interactions varying depending on the field of farming. For instance, the participants seem to interact daily with other farmers; whereas, on average, the participants indicate that they meet with university extension agents and representatives of environmental agencies (e.g., Natural Resources Conservation Service) on a quarterly or annual basis. While most participants do not have any contact with scientists, two report interacting with them annually and one respondent indicates monthly interactions. Participants' interactions with independent crop consultants present the greatest variation, ranging from weekly or monthly interactions to annual or no interactions whatsoever. Engagement with policy makers is also seldom or non-existent.

In terms of technology exposure, participants can be considered as relatively technologically savvy as they have previous experience with various types of digital agricultural technologies on their fields such as variable rate technologies (i.e., the use of data and automation to apply varying rates of inputs like fertilizers and seeds in appropriate areas around the field); GPS-based field mapping; and drone/aerial imagery for scouting weed, disease, pest, and nutrient stress plant stand count. However, other technologies such as crop canopy sensors and machine optimization solutions are scarcely being used within the group. The participants also report that they rely mainly on private companies for information and technical expertise on the management of pests.

The information participants shared during the focus group sessions revealed high diversity regarding their farm operations, ranging from part-time to full-time operations; growing of soybean and corn commodities to rearing of animals such as pigs and cattle; and renting of land alongside owning enterprises as a family business. There were varying years of engagement and partnerships with family members, such as parents still owning land and multiple generations being involved in farming: "*I am now at the stage of life, when I'm probably starting to downsize and transfer the operation over to my grandson… So that's kind of a challenge for me. I'm kind of a "I can do it all" kind of guy. And it's hard to even let him take over*" (P2).

Some participants have gone into debt to begin their enterprise. While some participants have farmed for several years and even generations, there are others who are younger and beginning farmers. In addition, some participants have off-farm work experience but still within the practice of farming such as working for an agribusiness firm.

The conversations held during the focus groups were rich and touched on a wide range of issues. However, our analysis focuses on topics related to the adoption of the smart and connected farm network and is split into two main sections: (1) first impressions about the proposed network; and (2) concerns related to the adoption of the network.

Initial impressions about the smart and connected network

Overall, participants find the proposed smart and connected network to be useful for collecting, analyzing, and utilizing data for decision-making. They recognize the need for a technology that can give farmers access to information that they hitherto would not have been privy of: "*If there's certain insects that are moving through an area and this can communicate to others, it's helpful to be aware of this problem potentially reaching your farm, and kind of tracking some of the disease, crop disease or insect problems that can develop along*" (P1). These revelations were further reinforced by the results from the questionnaire where all the respondents agreed or strongly agreed that digital agricultural technologies and networking can help them deal with production-related issues and make more informed decisions.

The timeliness of the information to be provided among the network users is also attractive to the participants; as P3 indicated: "*I've met other growers and so we kind of have this informal network of sharing information on practices and/or management practices, you can say. So, something like this would definitely help us share information, and make it easier and timelier in a quantifiable way.*" Additionally, the necessity for production-related information in participants' own locality was noted. P9: "*And I would say, this fact, is this localized data collection seems like, versus like a climate field view, which is, who knows where that comes from? And how big an area?*"

However, since participants already have existing avenues that they utilize (and trust) for receiving information and for interacting with other farmers, a new technology would have to demonstrate its superiority for it to be adopted.: P6: "*I think the benefit that the technology has to prove is that it's going to be better than what's already out there. If the forums that I'm already looking at or using isn't as good as the new technology, then I'm going with the new one, but if the proposed technology doesn't replace what I'm already using as a better trusted advisor, then I probably wouldn't. You know, it won't catch on*." Indeed, the enduring value of older technologies has been highlighted as a reason why they are sometimes not displaced by emerging technologies (Rose et al. 2023).

Technological factors and behavioral drivers of adoption

Requisite technological infrastructure and network size

Participants feel that there is a need for reliable highspeed internet access for farmers to be able to utilize the technology. P5 remarked: "*That's why the investment needs to be in infrastructure.*" The importance of telecommunication infrastructure to agricultural operations has also been echoed elsewhere (Zhang et al. 2017). Among the participants in this study, individual experiences with quality of internet differed. Unlike some participants who noted that they have only recently gotten access to good internet, others indicated that they have enjoyed quality service for several years. P8 stated: "*I kind of have the impression that most of rural Iowa has pretty good internet, I know I have good internet*," but not all participants affirmed that opinion. "*Yeah, you're extremely spoiled. Live in my place for* *about a week, for about a day and a half and you go crazy*," another participant reacted.

Moreover, participants perceive that the benefits of being in a network such as the one to be provided by the proposed technology will only be harnessed if there are enough people participating in that network: P5: "*So it's good to have a wider base, bigger pool. I think your data is only as good as the environment it's coming out of.*" It is the belief that a larger network—i.e., an expansion in the field of farming—will provide more data points for any potential analysis, thus ensuring that the report produced about any phenomenon taking place in a landscape is more accurate.

Data privacy and data accuracy

Although the issue of data privacy and security are one of the main challenges discussed in the literature on adoption of digital agricultural technologies (Coble et al. 2016; Ryan 2019; Shepherd et al. 2018; van der Berg et al., 2020), our focus group participants seem more interested in evaluating the pros and cons of utterly protecting the identities of the members of the network. During the sessions, they raised concerns about how privacy-preserving features of the network could limit data integrity. Some participants are worried that if complete privacy is guaranteed, it will be difficult to track the source of information provided on the network, which may inadvertently increase one's risk of being exposed to misinformation: "*To keep it anonymous, then you don't know where the information is coming from, but if they don't keep it anonymous, then people can point fingers.*"

In addition, participants fear that total privacy may be a disincentive to engaging on the platform or may prevent those who want to build a reputation of being knowledgeable (or respected contributors) from doing so i.e., it may be at odds with building one's online credibility. P6: "*…all those forums have names on them, you know, and you gain respect for that person from South Dakota that's always posting on the forum because he has 1000 herd feed lot and he consistently has good advice and people respect him. If it was anonymous, you know, someone could also be posting from the sofa and you don't know whether to trust them or not.*"

Due to the prospect of data coming from various sources (e.g., data from different technological devices within the farming network to a central data hub), data quality has been highlighted as a potential challenge for digital agriculture technologies (Tantalaki et al. 2019). Regarding data accuracy, a participant states a preference for information that can be validated. P7: "*The one thing I can see is where if there is bug pressure, or if there is disease pressure, that's something that could be validated. And you can look it up. And you know, if it shows it's more in this area, or they've seen a lot, well, that's something that could be validated, or fact checked.*"

This participant envisages that having information verified by a third party may be beneficial. P7: "*I do like the growers' association because they cater to what I want, and for what I use them for. They can be my third-party independent auditor that makes sure all the data is accurate. So now they can take that information and you have somebody like that, that can make sure that information is accurate before it gets on to [the network].*" This service could fit into the role of a data intermediary as pointed out by Brown et al. (2023). However, the participant is quick to note that this may be a challenge to implement in reality: "*But then there's a lot of puzzles and pieces to make that work. You know who's going to be that fact-checker?*" Again, this may be suggestive of a need to expand one's field of farming, or for the current stakeholders in an existing field of farming to take on additional responsibilities.

Trust

One major component in the habitus of farming as it relates to the operation of a smart and connected farm network is trust. Trust in this context could relate to the data generated and utilized in the practice of farming, or to the stakeholders belonging to the network. For instance, the issue of data validation mentioned in the previous sub-section arises due to worries about where the data may be coming from. A participant clearly states his concern regarding unknown sources of information:

> *The hesitancy to be reading other information on the network and not knowing where it's coming from, and if it's a trusted source. You know, all the time you hear about on Facebook or Twitter, whether this is fake information, false information, and so you want some validation behind it… Before I go invest my money in a new practice, or changing my operation based on what this guy did on his farm, I want to make sure that it is good for me.*" (P6).

The role of previous experience—both with working with a stakeholder, as well as one's personal experience trying out an innovation–was highlighted as a factor influencing trust. As P7 points out:

> *My impression was I think there's a lot of good information out there. But for me, it's a matter of where the information comes from. How do I trust the information? So, if I'm looking for information, I go to the people that I know that have the right information or*

that I trust…We have a lot of trials. And so, I can disprove a lot of information or prove it. So, I trust my information cause I've actually put it to the test.

Clearly, the habitus of farming is seen to be shaped by the stakeholders that make up one's field of farming, and specifically by participants' personal experiences with them. This observed correlation between familiarity and trust is consistent with findings by Mase et al. (2015). The authors report that for information about soil and water quality, agricultural respondents in midwestern United States indicated higher levels of trust for organizations that they were more familiar with, including agencies that had a longer historical presence in their region such as the Farm Bureau and the state natural resources agencies.

As noted earlier, farmers' (dis)trusting attitudes often depend on the stakeholders they are dealing with in their field of farming. For example, regarding data sharing, several participants express higher trust levels toward public universities and grower associations compared to private companies:

"*I think the fact that it's being run or being overseen by a grower association or a university or whatever, makes it more legitimate. If somebody from a for-profit company came and said, "Hey, we want to get farmers to start doing this," I'm always skeptical that they're going to steal my information or want something from it, and either use it against me or use it for their own profit. I trust you guys aren't going to be doing that. So, I have a little more trust in a university."* (P6).

The more positive attitude of farmers towards universities and grower associations relative to other stakeholders aligns with findings among Canadian farmers reported by Turland and Slade (2020). These findings are also supported by the participants' responses to questions regarding their trust level toward different institutions and organizations. The results reported in Table 1 reveal that overall, participants seem to trust agricultural organizations and other farmers the most, followed by land grant universities and financial institutions. The lowest levels of trust are expressed towards the government and public institutions.

Table 1 Farmers' responses to questions on trust in institutions and organizations

Statement: How much do you trust the following?	Mean	SD.
Neighbors	3.6	0.88
Other farmers	3.8	0.44
Landowners	3.3	0.71
Cooperatives	3.1	0.78
Agricultural organizations	3.9	0.92
Commercial agricultural service providers	3.4	0.72
Banks and other financial institutions	3.7	0.50
Land grant universities	3.7	0.87
Government	2.3	0.50
Public institutions-based start-up company	2.7	0.50

Note: Respondents were asked to indicate their level of trust on a scale of 1–5, with 5 being Total trust and 1 being No trust at all

When there are conflicting opinions and participants are torn between choices that seem contradictory, they tend to rely more on recommendations from non-commercial entities:

"*And so it's really a struggle, because you have one side telling you, yeah, you better put it on, because you know, it's just a good thing to do for ensuring your yields. And the other one saying, well, there's no evidence that it is going to ensure your yield, because there's nothing affecting, it's not affecting this product…. So, an independent crop consultant, somebody that is not actually selling a product, or Extension or a grower association, things like that, somebody unbiased, will be the ones that could really use this.*" (P1).

Commercial companies are perceived to mainly care about their margins while trying to take advantage of farmers via the information they provide. A participant repeated those sentiments by stating:

"*But I sometimes think it's, of course the industries that we buy from are senior petrochemicals or fertilizers, they also provide that type of information almost competitive with our universities sometimes. And personally, I trust information from them very little, because they're always biased. They have their own opinion. And that's why this type of a project, can be so beneficial, because hopefully, we weed out all that noise from people that try to make a buck off the information they're sharing.*" (P2).

Another participant added: P5: "…*I feel I'm really interested in this because I would like to see data that isn't biased by anything. Hard to find…*" Low level of trust toward commercial digital and networking providers is also observed in the responses to the questionnaire, where only 20% of the participants agree that these stakeholders are either trusted by them or by other farmers. However, all the participants indicate that their trust in digital agriculture technology and network providers will be increased if they complied with agreements on data access, privacy, and ownership.[6]

[6] Only one respondent indicates that they neither agree nor disagree that complying with an agreement that provides clarity on data access would increase their trust in these providers. All others agree with the statement.

Nevertheless, it appears that trust towards these different types of institutions may not be absolute—i.e., farmers may not show (dis)trusting behaviors to certain stakeholders in all situations—but may be dependent on the service in question. For instance, one participant admits that he does not trust public universities with providing up-to-date information: P7: "*I hope they don't take offence, but the university information seems dated at most times, whether it's our state or Missouri… they'll be teaching me things that we started doing 10 years ago.*" On the other hand, he indicates that he trusts private companies when it came to scouting his fields: "*And so I'm always having my seed company do it…you know, they give me good information, because they've been out scouting other people's fields*."

It is worth noting that in general, there tends to be a relationship between trust attitudes, risk perceptions, and technology adoption. Within the context of adoption of digital agricultural technologies, it is argued that trust lies at the heart of concerns around data ownership, transparency, privacy, and security (Jakku et al. 2019; Shepherd et al. 2018), and as a result, significantly influences the risks farmers associate with a given technology. Therefore, farmers who have lower trust levels towards a technology and/or the entities involved in its management or operation may be expected to have lower adoption rates. For example, Jayashankar et al. (2018) investigate the mediating role of perceived risk and value in the relationship between trust and adoption of Internet of Things (IoT) technologies. The authors find that the perceived risks of farmers have a negative impact on their willingness to adopt IoT, and that trust helps to mitigate such perceived risks.

In our study, participants express some levels of concern about how commercial companies would handle their data. Table 2 below suggests that participants are slightly concerned about the possibility of their data being accidentally lost or deliberately shared by private companies. Participants' perceptions of the risks associated with working with private organizations may also help to explain some of the distrusting attitudes they have towards these stakeholders.

Table 2 Farmers' responses to questions on risk perceptions

Statement: There is a high risk that digital agriculture technology and networking providers will:	Mean	SD.
share raw data from my farm with neighboring farmers without my knowledge	2.8	1.30
share raw data from my farm with land speculators without my knowledge	3	1.32
share raw data from my farm for commodity trading without my knowledge	2.8	1.30
be hacked and lose my personal and sensitive business information	3	1.22
make decisions for me with raw data from my farm	2.9	0.93

Note: Respondents were asked to indicate their level of agreement on a scale of 1–5, with 5 being Strongly agree and 1 being Strongly disagree

Data quantity and data utilization

A concern that was constantly brought up during the focus group is the large volume of data that smart devices tend to collect, and the time demands of using such tools. With respect to the habitus of farming, participants are concerned that they could spend a lot of time reviewing and/or analyzing information in a way that is no longer effective/efficient. P3: "*I might call it the overwhelming factor of information overload. There's just so much information we process and analyze already…I think that could be the challenge. Like well, do I need to be collecting this? Do I even need to spend time trying to read or look at this, or should I, you know, either focus my time on other places?*"

A related concern is farmers' inability to utilize the data that will be generated. The participants indicate that they currently have lots of success collecting various types of data but express dissatisfaction with their capacity to use that data to make informed decisions on their farms. P1 stated:

> "*For five years at least we've been doing aerial imagery stuff studies. So, we've done a lot of data collection there, we've done soil conductivity tests and things like that on that. But as far as putting everything together to help make agronomic decisions or financial decisions, no…We have so many variables and to have information is nice, but it's only nice and valuable if you can make an improvement, or a cost-saving measure with that data. So being able to utilize the data to make me more efficient is the goal.*"

Furthermore, participants anticipate a need in the future to expand their field of farming in order to be able to engage other stakeholders (experts) who can analyze the data. In essence, participants are interested in learning what types of data would be collected in the proposed network, how it would be analyzed, and how it would ultimately assist with decision-making in their practice.

The large volume and complexity of data produced, as well as the models required for computational efficiency, have indeed been identified in the literature as some of the potential challenges of agricultural technologies requiring the use of big data.[7] For instance, Tantalaki et al. (2019) describe the extraordinary techniques required to efficiently process voluminous datasets and suggest that these demands

[7] Big data refers to the "massive volumes of data with wide variety that can be captured, analyzed and used for decision-making" (Wolfert et al. 2017, p.69).

cannot be adequately met by traditional learning models. In addition, they note that advanced visualization techniques and strong multidisciplinary engagement may be needed for appropriate data interpretation; thereby corroborating the views among farmers in our CoP.

Market competition among farmers

A reason to favor privacy in farmers' practice is the competitive nature of farming. Although market-oriented goals are not always the only motivations for farming, they are usually important in influencing farmers' practices. On one hand, participants in the study acknowledge the appeal of privacy to them as farmers; on the other hand, they recognize the need for collaboration to make the network function as it is supposed to: P7: "*I guess it's a fine line between privacy and giving information that can help you… Say you got something good; can you share that information? Maybe you're taking your competitive edge away, you know, so while you want to talk to your neighbors and friends, on the other hand you're still trying to run a successful business.*"

Some participants worry that sharing certain information may impact them negatively. P2 stated:

> "*I think I'm a little concerned about sharing data with my competitive neighbors… We farmers, whether we like to admit it or not, are competitors with our neighbors. And the data sharing will help me grow and hopefully help our agriculture industry grow. But in some respects, I don't want it to put me into a disadvantage with my neighbor.*"

> Another participant corroborated: "*It's unfortunate that we have to compete against one another, and we cannot compete against another industry. We need to work together, as opposed to against.*" (P5).

Discussions in the focus groups were corroborated by participants' responses to the questionnaire. Table 3 shows that participants are indeed least willing to share information

Table 3 Responses to questions on willingness to share information

Statement: I will be more willing to share information generated on my farm with:	Mean	SD.
Farmers who are my neighbors	3	0.71
Farmers who live in my county	3.3	0.50
Farmers that have similar farming operations like mine	4	0.71
Farmers who I know personally	3.7	0.50

Note: Respondents were asked to indicate their level of agreement on a scale of 1–5, with 5 being Strongly agree and 1 being Strongly disagree

from their farms with their neighbors and other farmers living in the same county.

There is an obvious tension between sharing data to improve the resolution of the collected information and the inherent competition of the market, such as the competition for renting land: P7: "*I think a lot of the sharing just goes back to even just the land you farm, you know, I mean it's a dog-eat-dog world out there for cash rent. And so I mean, any information you share, I feel can be misdirected and be, you know, either used against you…*" This point was expounded by another participant (P1):

> *The guy that farms within 50 miles of you is really almost your competitor, cause people will travel to farm land if it's a lot of viable, larger chunk of land. If they know something about your farm, that they think oh, I can find out who owns that land and give them more money because I know what they're getting as a return or whatever. There are concerns about that.*

These revelations clearly point to the need for data categorization as it is evident that farmers deem some types of data as private and personal, whereas other types are considered to be for "the common good" and could therefore be shared (Brown et al. 2023, p.11).

Costs of adoption

Since farmers are interested in their enterprises being profitable, it is no surprise that they would undertake a cost-benefit analysis before adopting a new technology into their practice, and only those technologies perceived as yielding a net-benefit would eventually be adopted. As P5 expressed: "*I got to get at least as much out of it as I'm putting into it.*" Also, considering that the farmers in the CoP are relatively small, they worry about the average cost of taking up a new technology and the ability of their operations to justify such an investment. P1 noted: "*…an operation of his size, he's 1200 acres, I'm 1100 acres, so basically the same size, and so the number of acres that we cover per year is not so great to spread the cost over, you know. It's a higher cost per acre investment.*"

Furthermore, participants would like to be able to sync new tools with existing infrastructure or would prefer a machine that can perform multiple tasks: P1: "*I have a planter that plants beans, one does the corn, the tracker, everything's older equipment. But I can't afford to buy five or six different devices to collect GPS location and analyze data as we go through the field. I'm going to have to be able to quick switch it from one to the other, or how's that going to work? That's a big concern to me.*"

Participants acknowledge the additional costs associated with adopting a new technology such as the time it would take them to familiarize themselves with the technology and the possibility of not receiving the expected returns, particularly in the short run. For instance, the ability of big farms and big agribusinesses to cover some of the upfront costs associated with running data-driven operations—as well as their ability to access the required skills and advice to efficiently utilize such technologies—have led some farmers to posit that big data is for "big farming" and not for everyone (Fleming et al. 2018). Even those with a contrary opinion felt that the potential benefits to farmers may take some time before they are actualized (Fleming et al. 2018).

Discussion and implications

While digital agricultural innovations have the potential to enable farmers mitigate and respond to current and future production threats in a collective and efficient manner, our findings point out issues that need to be resolved to actualize this possibility. This study set out to investigate farmers' impressions and concerns about participating in a smart and connected farm network. Our results shed light on the participants' engagement in the field of farming and bring to the fore considerations that should go into the design of digital agricultural innovations that are trusted and actionable. Guided by the theoretical framework of field and habitus, we identify alignments and conflicts between the needs, beliefs, and trust attitudes of potential end users. Furthermore, the framework helped in learning about the attitudes of participants in relation to the technical requirements of a smart and connected farm network (e.g., data sharing).

The interest of the CoP in the attributes of the proposed smart and connected network was accentuated, encompassing matters related to the feasibility of enlisting the required number of participants onto the network (i.e., an expansion of the field of farming), as well as its capacity for quality assurance (i.e., the ability of the network to operate in a way that minimizes errors). A good starting point in confronting the former challenge could be to streamline farmer recruitment efforts by drawing insights from existing models of successful farmer networks (Chapman et al. 2016). On the other hand, effective strategies for ensuring data accuracy and consistency within the practice of farming will need to be developed, as claims of precision in digital agriculture often appear to be speculative (Visser et al. 2021). It will also be crucial for these strategies that guarantee data reliability not to be at odds with the data privacy goals of farmers—to the degree possible—since farmers are also interested in protecting the confidentiality of their data. Resolving such potential tensions in different needs and values of farmers would be an important step towards realizing the gains of the digital revolution.

Similarly, participants also raised issues of data quantity and data utilization, and these challenges correlate with the widely acknowledged characteristics of big data, referred to as the "4 V's of Big Data"—volume, velocity, variety, and veracity (Lokers et al. 2016). Smart farming is bound to generate very large amounts of data that will require data analytic techniques (Bacco et al. 2019). The frustration of farmers in the CoP about their inability to utilize both currently available and future datasets suggests that they do not possess the skills needed to analyze them. This implies the need for technicians to transform these raw data into meaningful information; thus, giving rise to the demand for an additional service or technology.

Moreover, it was evident from the discussions that the potential costs participants would have to incur could severely restrict their adoption of digital innovations. Economic constraints are among the factors often identified in the literature as limiting the adoption of agricultural innovations (Shiferaw et al. 2015; Ruzzante et al. 2021). All things being equal, higher costs could translate to reduced profit margins for farmers, which implies that some technological advancement may in reality be at odds with their habitus of profitability. Consequently, the possibility for developers to manufacture devices that are compatible with existing farming technologies would need to be explored. Success in this regard would help maximize the net-benefits of farmers' investments by lowering the setup and operation costs associated with such new technologies.

Likewise, there is a need for increased investment in rural broadband deployment to provide the requisite telecommunications infrastructure that digital agriculture and networking technologies can ride on. Evidence suggests there is a positive impact of rural broadband initiatives on high-speed internet use among farmers, as well as on farm sales and expenditures (Kandilov et al. 2017). However, these gains presently appear to have a spatial gradient and are mainly confined to counties adjacent to densely populated urban areas. There is therefore an opportunity to further harness the overall gains of the digital agricultural revolution by expanding quality internet access to currently underserved rural communities.

In addition to the specific attributes of the proposed network, participants were also particularly interested in the stakeholders that will be involved in the operations of the decision support system. Many of the participants echoed skepticism towards the roles of for-profit entities in different aspects of the innovation apparatus, ranging from the management of the information being collected from farmers to the recommendations that will ultimately emerge from the analyzed data. Some of these pessimistic attitudes mirror those acknowledged by previous research (Jakku et al. 2019; Wiseman et al. 2019; Zhang et al. 2021). As a result, it may be pertinent to explore the practicability of non-commercial organizations and institutions managing such networks, and the ramifications of such arrangements.

On the other hand, it will also be worth the effort from a regulatory and policy standpoint to address the specific concerns that farmers have with private companies, such as the opaqueness in how data is collected, stored, processed, utilized, and shared. It will be crucial to promote greater transparency in agreements involving farmers and agribusinesses, as well as to address the existing asymmetry in power relations between various actors in the industry (Bronson 2019; Avelino and Wittmayer 2016). However, it is also important to state that farmers' attitudes towards different actors in their field of farming could also be shaped in part by the inherent behavioral characteristics of farmers themselves, such as their general trust levels and risk preferences—which are themselves determined by other idiosyncratic characteristics (Nielsen et al. 2013).

Some other concerns raised by participants in the focus groups that relate to their farming habitus have received relatively limited attention in the literature on digital agricultural technologies. For instance, during the sessions, attention was directed to the way the competitive nature of farming could act as a hinderance to the willingness of farmers to share their data. From our results, it appears that farmers may have to be assured that the data they share will not hurt their competitive advantage. The dilemma and mechanisms of knowledge sharing in relationships that are simultaneously cooperative and competitive (or "coopetition") have been more formally developed and addressed in the fields of management and organizational science (Bengtsson and Kock 2000; Hackney et al. 2005; Tsai 2002; Walley 2007). This kind of business arrangement allows for the use of shared knowledge to pursue common goals, as well as to outperform competitors.

Within the context of digital agriculture, the challenges that are bound to arise from operating such "*coopetitive*" knowledge-sharing platforms will necessitate a need to better understand how to effectively instigate and sustain network participation. It will be important to know if, and to what degree, factors such as the size, nature, and exact location (or relative proximity) of farmers' operations will influence their desires to participate in these types of network arrangement.

Conclusion

In this paper, we provide a discussion of the various factors influencing farmers' perceptions and acceptance of digital agricultural innovations, highlighting the role that trust and cooperation play in the likelihood to participate in a smart and connected network. Findings from our study highlight the gains to be harnessed when farmers are involved in the discovery process of an innovation. This study is part of the initial step in the translational research process of the development of a smart and connected network. Results from the analysis of the focus groups and questionnaire were presented to the scientists involved in the development and deployment of the technology with the goal of informing them about the participants' habitus and concerns highlighted at the initial stages of the innovation pathway. This round of discussions is to be followed by subsequent focus group sessions with members of the community of practice, as well as with the technology developers who will inform us about the types of additional information they would like to learn from potential users. The multiple interactions between scientists and potential end users in this participatory process allows for the creation of a feedback loop that shapes the stakeholders' values, constraints, needs and likely responses. Furthermore, insights from these interactions are being utilized in designing research instruments that will be used on a wider and more representative sample of commodity farmers across some states in Midwestern United States.

In situations where the effectiveness of the innovation depends on the willingness of users to collaborate (e.g., sharing quality data to produce high resolution information for an early warning system to production threats), scientists involved in the creation and deployment of the new technology have a higher likelihood of developing an innovation that is trusted and actionable by engaging farmers in networks early in the innovation pathway. This engaged and continuous dialogue will help uncover the issues farmers anticipate having within the network or with the stakeholders that will be involved in some part of the technology's functioning. Addressing these concerns in a timely and cost-effective manner will ultimately lead to the provision of the appropriate tools farmers need to effectively respond to both current and emerging agricultural challenges in a coordinated way.

Due to the relatively small sample size and specific characteristics of the participating farmers, conclusions from our findings should be carefully drawn. For example, our CoP was composed of farmers who have experience participating in projects to test new technologies, meaning they are potential early adopters and more technologically savvy than the average farmer. Although several potential factors that could constrain participation in a novel smart and connected farm network were highlighted during the focus group discussions, the views expressed may still be more optimistic than those that would have come from farmers who are late adopters. Future studies could seek to use a more diversified sample of farmers (e.g., with respect to farm size or farm operation) to capture a wider range of views and experiences relating to the use of digital agricultural technologies in collaborative contexts.

Appendix

[Participant Question 1] Please tell me, what are your impressions of what was just now presented to you about the network?

- Have you heard or interacted with similar technologies before?

[Participant Question 2] What do you like the most about the network?

- What are some problems you are currently facing that the network may be able to address?

[Participant Question 3] What concerns do you have about the network?

- Why wouldn't you adopt this technology in your farm?
- Privacy preserving.
- Time involvement.
- Addressing issues.

[Participant Question 4] What are your thoughts about how the network could become a reality for farmers in your community?

- How does the network become a tool in your farming operations and decision-making?
- How to operationalize a network? Previous experiences?
- What types of existing networks or organizations would work well with this network? (e.g. xxx)

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Declarations

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