Understanding Farmers' Data Collection Practices on Small-to-Medium Farms for the Design of Future Farm Management Information Systems

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Fig. 1. Farmers and interviewers walking on a farm tour after the interview

Farm Management Information Systems (FMIS) integrate data from a variety of sources, including sensors, to enable farmers to interpret past activity and predict future performance. FMIS is traditionally designed for and used by large farms, given their capital and need for automation and scale-up. This paper examines the current data collection practices on small and medium farms so that FMIS systems can be better designed to their needs. Our empirical research comprises interviews conducted during 10 farm visits. Our semi-structured interviews incorporated questions about daily activities, points of decision-making, data sharing, and incentives for data collection. We analyzed the interviews by focusing on possible obstacles to adopting expanding digital data collection practices and how expanded data collection might help fulfill farmers' goals and motivations. We found that farmers use their own bespoke data collection techniques instead of or in parallel to more formalized methods and often hold key observations and hypotheses in their heads rather than committing them to any data collection system at all. Key barriers to FMIS adoption include technology skepticism, technical

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hurdles, lack of support, and self-doubt in technical skills. Based on this empirical work and analysis, we recommend that FMIS systems can best address the needs of small and medium farms by 1) accounting for the farmers' different approaches to memorizing vs. storing data, 2) integrating rather than trying to replace existing practices, and 3) considering the economic and political motivations driving farm decision-making and practices.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: Data collection, agriculture, interviews, farm management information systems, human-computer interaction

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1 INTRODUCTION

Farmers collect a wide variety of data to support their everyday work. They collect data records related to farm management (e.g., farm records, labor costs), context (e.g., weather conditions), and output (e.g., crop yield), and then analyze the data to improve their decision-making. Often, on small and medium farms, these data are siloed on different platforms and never consolidated for comprehensive data analysis. In larger farms, digital agronomy has been applied to manage input placement, resource use, and timing of operations to improve crop productivity and environmental stewardship. Efforts are underway to bring similar systems to small- to medium-sized farms [61, 67]; however, there is a gap in the understanding of the current needs, barriers, and practices around data collection on small-to medium- farms. Thus, our research seeks to better understand current data management operations on small-to-medium farms, so that new digital agronomy services being designed for these farms help rather than hinder these farmers.

Curating management data on these farms for digital agronomy applications requires committed time, skill, and attention from farmers beyond what is needed for their current practices. By profiling the gap between current data practices and what is needed for digital agronomy, we can help inform ways that FMIS systems can better address the needs of small and medium farmers, helping them to maintain their competitiveness and meet expanding environmental standards.

We set out to better understand small and medium farmers' data collection practices, barriers, and incentives. To do so, we performed ten semi-structured on-farm interviews, averaging 1.5 hours in length, in Spring 2022 in the region of Upstate New York on small and medium-sized farms. Our interviews focused on both systems of data collection and management practices and also the challenges faced by the farmers in collecting, sharing, and using data for their everyday work. As part of the interviews, we asked farmers to show us their physical and digital records and their data storage systems employed in their current practice, including tablets, printed reports, binders, file cabinets, folders, maps, online interfaces and repositories, spreadsheets, charts, tables, and scattered notes.

Our results will help FMIS designers build systems for the needs and constraints of small and medium farms by addressing the gap in understanding how such farmers currently collect data, and what obstacles and incentives exist with regard to FMIS systems.

2 BACKGROUND

Because we are interested in current data collection practices for better design of FMIS systems, we must turn to the field of digital agronomy. Digital agronomy can be defined as the collection and use of data in everyday farm tasks and decision-making, such as crop planting and animal disease detection [46]. These farm data are often centralized, analyzed, and visualized with farm management information systems. Digital agronomy has the potential to support farm productivity and efficiency goals as well as sustainability objectives by helping farmers analyze and optimize crop yields, monitor and control carbon emissions, and identify opportunities to reduce inefficient pesticide and fertilizer applications [2, 3]. In this section, we briefly review the agronomy and social science literature on such systems and the data collection practices on small and medium farms. We also discuss computing research conducted specifically in the CSCW and HCI realms.

2.1 Farm Management Information Systems (FMIS)

Digital agronomy and Farm Management Information Systems (FMIS) largely came of age in the mid-1990s, with the rise of the Internet and the ability to share data across computer-based systems. Their recent growth has been buoyed by technological developments related to the Internet of Things (IoT) and the capture and digitization of crop, soil, weather, animal, building, and other data [49]. FMIS serves as a hub for data to be integrated from various sources, including sensors on equipment and in fields, which allows farmers to interpret past data and predict future performance (e.g., crop yield, dairy production) while improving efficiency and lowering costs [26, 36]. Although farm-level data entered into FMIS have some value for individual farms, aggregation of data across farms promises high-level insights for a broader spectrum of stakeholders (e.g., agribusinesses, government agencies, equipment manufacturers) and is often the focus of such systems [11]. Critics of this data aggregation raise concerns about privacy, surveillance, and data governance [50, 59].

Extant studies on farmers' reluctance to adopt FMIS highlight that - for these smaller farms - the main benefits of such systems do not accrue to them, whereas the cost and time commitment for data collection, analysis, and interpretation do accrue [55, 65]. Notably, whereas the discourse around FMIS often refers to the promises of "precision" agriculture, Visser et al. note that data collected from smaller farms may be noisier and less inaccurate, requiring extensive effort from farmers to clean them before interpreting them for decision-making [59]. Beyond issues of who benefits and data-cleaning effort, other factors affecting FMIS adoption by farmers include technology issues (e.g., ease of use, timeliness, and relevance of results), organizational issues (e.g., farm size and budget, farmer's technological capabilities and computer literacy), and social or economic factors (e.g., peer recommendation, incentive programs, perceived ROI) [27, 51, 55, 64]. Reticent farmers may prefer their "intuition-based" decision-making processes over the algorithmic recommendations of FMIS [44].

In general, large farms are more likely to adopt digital agronomy and FMIS than are small farms [39, 45, 48], prompting some concern about an emerging digital divide in agriculture. Government policies to regulate the business environments, promote farmers' skill development, and develop rural communications infrastructure are among the mechanisms that may serve to lessen that divide [5]. However, small and medium farmers may have different information needs or capabilities than their larger counterparts; this likelihood motivates our interest in the current-day data collection practices on small and medium farms.

2.2 Data collection practices on small and medium farms in the USA

According to USDA 2020 data, 98% of all farms in the U.S. are family-owned [57]. In particular, small family-owned farms, defined as having a gross cash farm income of less than $350,000, constitute 89% of all farms; these farms typically rely on off-farm sources for the bulk of their household income. Large family farms, with gross cash farm incomes of over $1M, rely on farming for most of their household income. Large family farms constitute only 3% of all farms but generate 46% of total farm production. This difference in income may explain why small farms tend to operate at a lower level of technological sophistication than larger farms. Economics researchers Hennesey, Läpple and Moran studied farm owners' access and engagement in technology and found that the probability of simply owning a computer for business reasons increases with farm size [21]. In general, large farming operations, with more cash available for building a computer-based infrastructure, have better access to advanced digital technologies such as FMIS that support digital agronomy [31].

These differences in technological infrastructure by farm size point to at least two specific disadvantages that smaller farms have with respect to data collection practices and the creation of reliable FMIS. First, the lower computer adoption rate means that owners of small and medium-sized farms are also less likely to be data literate; they might not know how to access data or might not be aware of their rights to data and lack confidence around privacy and security issues. As a consequence, they may struggle with collecting and analyzing data, especially big data [32]. Second, FMIS systems often have high fixed costs [25], so small and medium-sized farms do not realize the economies of scale that large farms do to support the human resources and infrastructure needs of a well-developed FMIS infrastructure [58].

Whether FMIS is ultimately beneficial to small and medium farms or detrimental to them remains unclear [48]. In this context, understanding small and medium farmers' current data collection practices (and the beliefs, concerns, and goals that drive them) may help promote a beneficial outcome.

2.3 The gap in the agricultural research in CSCW and HCI

While US-based research on the practice of farming and agriculture has been championed to be part of "rural HCI" [20], Steup et al. note that HCI research on food and sustainability has largely focused on small-scale urban farms and community gardens [52]; they argue that far more attention should be paid to commercially available data-driven farming tools for smaller farmers in rural environments. Fieldwork from Steup and colleagues [53] has examined the ways that small farmers have built social networks to develop sustainable farming practices in the local food production arena.

There is a gap in the research literature at CHI and CSCW regarding understanding the needs of small and medium farms; CSCW has far more research looking at the needs and practices of farmers in contexts than in the US. Internationally, due to the highly contextual nature of agriculture, the tools and services developed for low-literacy and low-information farmers in India [38], rural Tanzania [61] or Sri Lanka [60] cannot be easily cross applied to small farms in more industrialized contexts. For the farmers in the US, the key needs have less to do with having *information access* and more to do with having less contribution to data repositories which are used to estimate yield, regulate fertilizer and water use, and inform critical farming decisions.

U.S. rural areas face higher poverty, unemployment rates, and brain drain (emigration of highly trained people from a particular area) [14, 19]. According to the USDA, the median income of U.S. farm business households in 2020 was $62,402, compared to $89,492 for self-employed households [56]. While more than 39.4% of all farm households had high wealth, they spent on significant capital assets necessary to run the business (i.e., farmland and equipment). A turn to the information needs and data practices in small and medium farms can then help to address populations who are chronically underserved even in the context of so-called "highly developed" countries like the US. Data about their farm in the context of other farms can help these farmers understand what aspects of their practice can be improved and optimized: for example, data can help inform farm management decisions, such as precisely where to water or perform cultivation [23] and help them adapt to dynamic factors such as climate change [4, 35]. While researching and responding to the practices, motivations, and needs of small and medium farms can help FMIS designers to address the needs and values of such farms [28, 37], which differ from those addressed by the "Big Ag" and

"Big Data" that are being driven by mega conglomerates such as Monsanto or John Deere [8, 52]. Such work can also address challenges in privacy and access that smaller-scale farms face in the age of agricultural big data [7]. For these reasons, we focus on FMIS for the rural farming community to learn about commercially available farming tools, consequential data collection practices, and concerns that people on small and medium farms face.

While the CSCW literature has not yet directly addressed the needs of US rural computing, the issues faced by farmers are akin to the issues faced by other communities studied by CSCW. Beyond the related work in international farm data information systems noted previously, the transition to the farm management information system has parallels to the paper-to-electronic records transitions for example in healthcare [16, 30, 66], or in the practices of individuals collecting and sharing their own health data [10, 17]. CSCW researchers Pratt et al. noted lessons in three key areas that the 2000's era medical informatics field could gain from CSCW to increase the adoption of data technologies, specifically electronic medical records: incentive structures, workflow, and awareness [43]. These also echo issues faced in the farm informatics arena.

The issues in aggregating data from these farmers also bear similarity with the collection, storage, and logistics of other field science efforts, such as biodiversity [6] or ocean informatics [1]. For that reason, we believe findings on the data collection of current-day farm data collection practices and potential challenges to farm management information systems will be informative to other CSCW researchers as they consider transitions in data practice to modern, networked data collections.

3 METHOD

This empirical research comprises interviews conducted during 10 farm visits. Each farm visit included an interview of 1-3 people. In total, there were 15 interviewees, who included farm owners, managers, and extension agents. Interviews were conducted in person. With IRB approval, video and audio recordings were taken during the interviews. Farmers would also give the researchers a tour of their offices and farms after the interview (see Figure 1). The interview covered topics like tasks on the farm, adoption of digital technology, decision-making for data collection, data sharing, and missing data. We used a semi-structured interview protocol [13]; we started by briefing the farmers on the larger goals of our research and let the farmers help to guide the conversations toward those ends. The agronomist on our research team helped to mediate the conversation between the CSCW researchers and farmers, providing clarification and definition of methods and terms. We found that this brought a more fluid conversation between the researchers and the farmers.

3.0.1 Author positionality. We are a team of three communications researchers, two HCI researchers, and one agronomist. The social science researchers approach the interview with the lens of design based on observations and articulated needs. The agronomist approaches the interview with knowledge of the existing farming hardware and software solutions and the realities of seasonal variables. Together, we approach the topic of digitalization of small and medium farms with an understanding of the challenges and opportunities that farmers are facing in the current agricultural context where profit margins are small, governmental and consumer expectations are high, and the industry explodes with proposed solutions for farm digitalization. Through this research, we want to understand better the challenges and opportunities of farm digitalization beyond the agronomic perspective. We recognize that digital agriculture offers tremendous potential for improving the way we farm and transition towards sustainable food systems, and we also recognize that farm management is an amalgamation of a plethora of considerations, agronomy being only one of them. Overall, we prioritize the perspective of field crop farmers unknown to the researchers. We strive to support the digitalization of small and medium farms and prevent them from accumulating a delay in progress compared to large farms.

3.1 Demographics

Our on-site interviews were conducted at small and medium field crops and dairy farms. We defined the farm size to reflect farms producing commodity crops such as maize and soybean on the rationale that this is the market that these New York farmers are operating. For similar reasons, Thompson et al. [54] uses the following four categories: less than 1000 acres (405 hectares), 1235 - 2000 acres (500 to 809 hectares), 2000 - 5000 acres (809 - 2023 Hectares), and more than 2023 Hectares. For the purpose of this study, we used the following definitions: a small farm is less than 2000 acres (809 hectares), a medium farm is 2000 - 5000 acres (809 to 2023 hectares), and a large farm is more than 5000 acres (2023 hectares). Because this study was conducted in the United States, we will use acres as the local unit of measurement but have included hectares for understandability for international audiences. We recruited subjects through three extension agents, one of whom was present at the interview, who translated between the two parties and contributed to the responses. (Extension agents are part of the U.S. Federal Government's Cooperative Extension Program and are employed by land-grant universities and serve the citizens of that particular state by serving as an expert or teacher on a topic relating to economics, community development, agriculture, family, animal production, diet, and nutrition. [28].) Our farmer interviewees (N = 14, 13 males, 1 female) covered diverse farm cropping systems and regions. Farmers were also contacted based on their level of digitalization (i.e., not only farmers who are advanced in their digitalization level based on the perspective of the extension specialists). "Digitalization" can be defined as integrating multiple technologies into daily processes [18], like data collection, organization, and use. For consistency of understanding of digitalization, we provided this definition to every farmer. Table 1 overviews our study participants, farm size, location, cropping system, and whether or not they use yield mapping.

Farm ID*	NY Region	Area (Acres)**	Size Category**	Cropping System*	Yield Mapping
F1 (P1, P2)	Finger Lakes	2396	Medium	M-S-W	Yes
F2 (P3, P4)	Finger Lakes	2988	Medium	M-S-W	Yes
F3 (P5, P6, P7)	Finger Lakes	1704	Small	H-M-S-W	No
F4 (P8)	Mohawk Valley	445	Small	H-A	No
F5 (P9)	Mohawk Valley	592	Small	M-A	No
F6 (P10)	Mohawk Valley	494	Small	M-S	Yes
F7 (P11)	Central NY	2495	Medium	M-S-W	Yes
F8 (P12)	Central NY	1704	Small	M-A	Yes
F9 (P13)	North Country	1507	Small	M-A	Yes
F10 (P14)	North Country	2001	Medium	M-A-H	No

Table 1. Demographics of interviewees' farms, including their Farm ID, the New York Region, area, cropping system, organic, and yield mapping

*"F" indicates farm, while "P" indicates participant

**As described in Section 3.1, a small farm < 2000 acres (809 hectares), 2000 acres < medium farms < 5000 acres (809 to 2023 hectares), and a large farm > 5000 acres (2023 hectares).

***M: Maize; S: Soybean; W: Wheat, H: Hay, A: Alfalfa

Three extension agents from three field crop production NY regions helped us recruit our participants. The first region comprised Wayne, Ontario, and Seneca counties which are part of both Central NY and Finger Lakes regions and where large non-dairy grain production is located. The second region was the Mohawk Valley, comprised of Ostego and Scholarie Counties located south of the Adirondacks. The area is hilly, woodland containing small farms conducting dairy and forage production. The third region is the North Country, which is located in Jefferson County. This region contains some of the largest dairy concentrated animal feeding operations farms in the state, and most large farms tend to have enough land to supply feed and spread the manure generated by their herd. These regions contain an array of field crop production farms within NY State.

In addition to this range of operations and locations, farmers of varying levels of digitalization were contacted and selected. This allowed for the evaluation of variations in farmers' capacity to collect, organize, and utilize data on the farm.

3.2 Materials

Interviews were simultaneously recorded using a lightweight action camera, a handheld audio recorder, and the recording/automatic transcription features of online meeting software. This setup provided redundancy and backup. It also allowed remote researchers to participate in interviews in addition to the in-person interviewers. Researchers also took notes on paper and digital note-taking applications on tablets.

3.3 Approach

Our research was motivated by the research team's desire to understand better the data collection needs of small and medium farms. Hence, our approach is best characterized as *needfinding* rather than ethnography. Needfinding is a design methodology that uses interviews [40] or interaction observation [33] to understand what people need in order to generate design insights toward intended outcomes.

While the needfinding approach is more targeted than ethnographic approaches, a primary principle of needfinding practice is to look for needs rather than solutions to avoid prematurely limiting design possibilities [40]. In this study, we use a combination of observations of files and semi-structured interviews to allow the farmer to steer the conversation as they saw fit while remaining on the topic of their data collection needs.

3.3.1 Recruitment. After an agent from the local extension program introduced us to the farmers, we contacted farmers directly via phone or email, explained the concept of data collection practices, and asked if we could come to their farms for an interview.

3.3.2 Semi-structured interview. A group of two to three of our researchers met with the farmers, depending on availability, and all participated in the conversation. One agronomist researcher consistently attended all sessions. Other researchers work in the field of design and communications.

In the semi-structured interview format, all questions operate as starting point for a conversation on needfinding for data collection practices. The rationale behind the semi-structured interview method was to provide room for the range of farmers' data collection practices. After we described the nature of the interview and received consent, we turned the microphone and cameras on and began.

We began with open-ended questions to get farmers thinking about their day-to-day tasks and decisions. We started with two open-ended questions: (1) "Walk us through a normal day in the planting season in terms of your main tasks, actions, and interactions.", Based on parts of their answers that mentioned data collection, we asked (2) "What kinds of decisions are you making as

Semi-Structured Interview Questions
Walk us through a normal day in the planting season in terms of your main tasks, actions, and interactions.
What kinds of decisions are you making as you go through this time of your day?
Where are you physically when you make each decision?
What tools or devices do you use or are you surrounded by as you make them?
What time of day is it when you make this decision: morning, afternoon, evening, weekend?
What kinds of data or information about controllable factors do you use to inform these decisions?
How do you manage data or information on controllable factors?
How good (valid, timely, complete) is the data and information about controllable factors?
What specific data and information are missing?
Would you like more and better data and information about your farm?
Is there any data that you share between geographically close farms?
Do you see your operation as cooperative or competitive?
To what extent do you use data and information about controllable factors as compared to other data, including data about non-controllable factors?
Can you think back to the last time you needed to bring someone new onto the farm, what tools and data collection practices you had to teach them, and what that new person found confusing?
Was there anything that you maybe forgot to mention or that we failed to ask that would help us understand your data practices this season?
Were there other decisions we did not cover?

Table 2. Questions in the semi-structured interview.

you go through this time of your day?" When we noticed that farmers were not mentioning data collection, we asked about missing data: "What specific data and information are missing?" Please see Table 2 for the complete list of interview questions.

3.4 Analysis

All video, image, audio, and written interview data were stored in a password-protected server, with no personal identifying information linked to the interviewees in the online files. We analyzed the interview responses using qualitative coding software (Dedoose) [63]. For the first round of analysis, three coders used the open coding method to allow new codes to emerge [12]. We use Strauss and Corbin's definition of open coding, which is, "The analytic process through which concepts are identified, and their properties and dimensions are discovered in data."

Next, the coders shared their codes with one another and agreed on a common code list and how these codes would be applied, along with written definitions. The coders analyzed the interviews by focusing on possible obstacles to adopting expanding digital data collection practices and how expanded data collection might help fulfill farmers' goals and motivations. Examples of these codes were data collection and management tools, farming tools, and social/learning tools. A definition, for example, of social/learning tools was, "Mention of any tools/devices/methods used for learning; including trade shows, magazines, online forums, word of mouth."

For the rest of the analysis, the ten interviews were divided between three coders, each referencing this common code list. Finally, the coders met to discuss commonalities across the coding and grouped these codes into themes. Examples of themes included farming tools (code group: data collection and management tools, farming tools, and social/learning tools) and data (code group: issues, security, and use). Next, coders together selected prototypical quotes within each theme for this paper.

4 FINDINGS

In this section, we present our findings on the digitalization of data collection in small and medium farms. Because our interest in existing practices is motivated by the desire to design future farm management information systems in a manner that is better adapted to the needs of small-to-medium farms, we have organized the findings into three themes: current data collection practices, incentives for adoption of digital data collection, and barriers to adoption of digital data collection.

4.1 Current data collection practices

In this section, we will explore the current practices and tools used for data collection, storage, management, and recall. To the extent that some of the farmers were using existing FMIS-related systems, we noted what issues they mentioned about them. However, we were particularly interested in the ways that farmers were using more general-purpose computers and data-keeping tools. These less-structured tools currently in use support a wide variety of use patterns, and observing those patterns might help us understand the existing workflow of small-to-medium farms which future FMIS systems should adapt to.

We found that most farmers relied on collecting data from a variety of software applications and stored data through memorizing, writing down, or digitizing. Farmers memorized data at many stages of farming, including everyday status checks, short-term experimenting, and long-term planning. The effect of this is a convenient awareness of most processes on the farm, with a risk of forgetting and a lack of centralized visualization of operations. We must note, that memorizing and writing down data would only be possible at the scale of a small or medium farm.

4.1.1 Current FMIS tools and practices.

FMIS adoption. Some amount of FMIS adoption was evident amongst our interviewees, although the adoption of farm data management seemed somewhat piecemeal. Among the existing farm management tools in use amongst our interviewees are John Deere's GPS and RTK (provides and records a tractor's location in a field), John Deere's Apex (basic agricultural data management), My Field Crops (agricultural software that helps farmers keep track of what ground preparation, planting, fertilizer, chemicals, inspection, harvest, trucking/selling, and water precipitation/irrigation, occur in each of their fields), and Granular (an online record-keeping system which enables tracking of seeding and yield). These software packages are intended to be used on a desktop office computer and, for the most part, rely on data being manually input into the software by the farmer. It is possible for people who are in the fields to communicate data from the fields in real-time over the radio or mobile phone, but it seems that people mostly input data after coming into the office from the fields.

When P1 uses John Deere's Apex, she can not view her data unless she is connected to the Internet:

> Interviewer: *What if your Wi-Fi went down? How would you get all your information?*
> P1: *Probably won't.*
> Interviewer: *So, are you able to have a local copy of your data? Are you able to download*

> *or have you tried that or?*
> P1: *[We used to have it locally]. Now, everything goes to the cloud,* and yeah, there's no real way to download it because there's nothing to put that data into to view it. The only way to view it is on the cloud.

This demonstrates the issue of not having access to your own data unless connected to the Internet, which is not always available on the field. Fortunately, in the last 20 years, she has improved her networking on the farm, and most of her equipment. Many other farmers in rural areas are not so lucky, as "unstable wireless links are often the only way to access the Internet" and the bandwidth on many farms cannot handle several devices at once [24].

Precision agriculture. "Precision agriculture" is online sensing and adaptive response in order to manage spatial and temporal variability. Its general goal is to improve crop performance and environmental quality [41]. While it is most common in larger farms, it has some presence in small and medium farms as well. Farmers we interviewed mentioned using Rogator and Airmax, precision applicator systems for seeds or fertilizers, which help these farmers plan and execute the distribution of seeds and fertilizers to their fields and precisely record how seeding occurred. P1 describes how these more affordable precision agriculture technologies are not modular or "interchangeable," like the software and hardware systems made by John Deere, which can be used interchangeably with one another. A larger farm might be able to afford integrated systems (i.e., John Deere machines and software) for different purposes, while small and medium (P1 is a medium farm) farms likely do not.

4.1.2 General purpose information tools and practices.

Spreadsheet accounting tools. Farmers adapted general-purpose spreadsheets and accounting tools to farming. For example, during harvest, P1 uses Excel to enter his analog scale data in order to measure yield: "When we are doing the harvest, all of the crops that we take out of the field, all those come across the scale here. So we have all those weights, and we take those weights, and they're all put on an Excel spreadsheet." Here, P1 demonstrates the use of two tools, a "reliable" (P1) analog scale and "reliable" digital Excel software on a computer. More specifically, by using an analog scale and local software, participants won't be concerned that their data will get lost. While P1 is recording his scale data on a spreadsheet, P2 is comfortable with doing advanced computation in Excel in order to make purchasing decisions:

> *This time of year ... I'll use Excel to figure out how much fertilizer to buy. If we know roughly how much fertilizer per field, then it kind of tabulates how much we need to 'cause we buy all of our nutrients and seeds ahead of time. So, right now is when we need to know quantities on that kind of stuff, so that's pretty much what I use "Excel" for still.*

P2 uses Excel for this customized computation yearly and comments that he is unsure if his calendar could have "any kind of planning," which demonstrates his mental model of what his calendar could do. While Excel isn't explicitly an FMIS, it has a flexible interface that FMIS designers could learn from when designing for this demographic.

Mobile phones. Most of the farmers have mobile phones with them at all times, and they use the camera on their phones to record, share, and discuss issues that come up in their fields. For example, P1 uses his phone to take pictures of crop issues on the field to compare with field guides and share at a meeting with the other farmers: "We'll bring the photos back here to the shack or get our textbooks or field guide books out. I sometimes will use [the photos] as well...if we're holding a meeting, I will use those pictures for meetings." Here, we see photos being used for

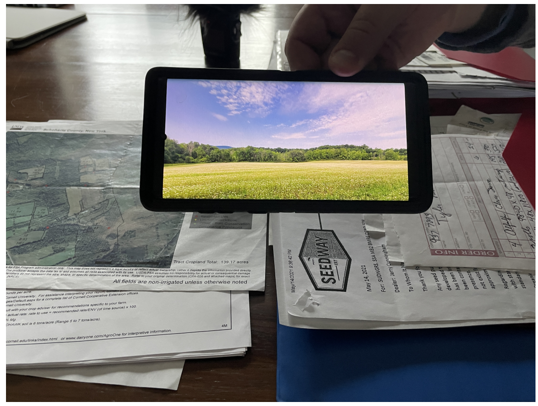

Fig. 2. In addition to all of the records kept for practical purposes; the farmers also record how their field looked very nice on a particular day for sharing.

cross-referencing with field guides, textbooks, and with the knowledge of other farmers in which the phone and photos become both a social tool and a data collection device.

P5 uses his phone to take a picture of the triticale, a hybrid of wheat and rye, on a beautiful day, as shown in the below Figure 2. When asked why he took the picture, he responded that he wanted to show his brother a picture since it looked nice. Again, the phone becomes a tool, not only for recording data but also becomes a social tool in the relationship between him and his brother.

Social Networking. The interviewees mentioned tools for social networking amongst farmers and tools for farming, which we also see as tools for data collection. We notice that these findings align with the results of [61], as they found that farmers in Tasmania were accessing information through business and local social networks. Our farmers used magazines from the business sector while some of our farmers spoke with neighbors about their practices. Additionally, P5 uses an international Facebook group to learn about Hay:

> *Facebook, there's a group called "Hay Kings" on there. It has like 40 or 50,000 members. Every now and again, if somebody has something on there, like, "Hmm, that's interesting. I might try that," and then I'll take it and maybe adapt it in my own way...They are from all over the world. There are people from Australia on there.*

P5 was comfortable with experimenting and therefore sought out information to help him with his experiments. Similarly, farmers are producing information for other farmers on mediums like Youtube, which is how P6 gets to "know what is out there" and describes the information as "cutting edge." P9 receives "The Progressive Dairyman" magazine for information about what is going on in his community, while P8 uses the site, "Pro Farmer" for agricultural news. While these forms of communication are informative for these farmers, there also might be value in a local social network, which shares regional information about growing in local conditions. This could be an implication for design for future FMIS.

Paper notepads and other analog media. There were many moments when farmers showed they were most comfortable working with pen and paper. P1, for example, first records data on a table on a legal pad and saves one legal pad for each year:

> Interviewer: *Okay. I want to know, when you're making a decision with your legal pad, do you only sit there with the legal pad, or do you have other systems open, and you're*

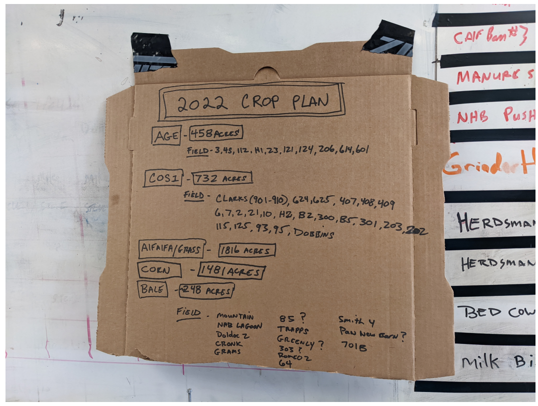

Fig. 3. Pizza box with a written 2022 crop plan, taped onto a whiteboard in the central office.

> *working with them at the same time?*
> P1: *I have one legal pad sitting next to another legal pad.*
> Interviewer: *Sorry. What's on legal pad one?*
> P1: *Old data from last year.*
> Interviewer: *So you get a new legal pad every year?*
> P1: *It's like starting a new file.*

P1 compares starting a new legal pad to starting a "new file," which demonstrates his mental model of how information should be sorted yearly. Later in the interview, he describes replicating the data in an Excel worksheet for reliability.

Farmers also frequently mentioned printing out charts and tables from the farm management software to physically store as a file; they did not entirely trust data recorded online to be available when they needed it, and they felt more secure having hard copy: "I do write down...yeah, and I don't necessarily trust this stuff all the time" (P7). This shows skepticism about this particular technology in its ability to save data.

P6, who didn't digitize any data (because of his distrust for someone potentially making money off of it), prints out templates with places to fill the field number, the date planted, the current crop, the crop variety, maturity, population, the fertilizer order number, rate, and more. These sheets go in binders on a shelf in his home office, dating back to 1997 (one binder per year), which he references as great for seeing what works and what doesn't, and refers to these binders at least once a week. While P6 is distrusting of others profiting off of his data, we can see that P6 has high-tech literacy: he has made a template on Microsoft Word with all the information that will be necessary for him and uses these data often.

One of the artifacts from our interview, a 2022 crop plan written in pen on a pizza box, shown above in Figure 3, demonstrates their value of convenience of materials, centralized office space to reference, appropriate for all levels of tech literacy. In this image, we also note that the pizza box is taped to a whiteboard. We hypothesize that the farmers didn't write the crop plan onto the whiteboard with erasable markers because they did not want an important point of reference to get erased.

4.1.3 Memorization.

Memorized data in farming practice. Many farmers rely on their memory to store and recall important farming information, such as field conditions and crop data, instead of using data recording tools. While this memorization is a deeply ingrained practice for farmers and remains useful, it presents scaling challenges, highlighting the need for more efficient data capture methods in agriculture.

Perhaps the biggest competition for farm management information tools is no tools at all. In the interviews, many farmers reported that they were relying on their memory to store and recall information for farming, including which fields have weeds in them (P5) and which fields are wet, out of 48 fields (P1). From a data collection perspective, this is done instead of recording data. They remember impressive amounts of their data, but to the farmers, this is an unremarkable routine practice that is part of the job of being a farmer.

P1 makes an analogy to memorizing details about his fields:

> Interviewer:*I can barely remember three or four things. So I'm thinking, you know, 48 fields, who's dry and who's wet, just in your head, do you?*
> P1: *Pretty well.*
> Interviewer: *You do?*
> P1: *If you have had five kids, you know what each kid likes and what each kid [does not].*
> P1: *Every one of those fields has a field name and, yeah, a field name. So, if somebody says you need to come pick me up from that field name, we all know what those field names are.*

On the whole, farmers' capability to remember large amounts of data about their farms is useful, and FMIS is not intended to replace farmers' use of their own memory in the assessment and management of their farm experimentation or planning. Perhaps storing and managing data in the mind is the quickest method, but it has some unsustainable elements. In the next sections, we will discuss reliance on the mind for various farming stages.

Memorization in data capture. Farmers tended to view FMIS-generated maps demonstrating yield, soil quality, and elevation but would correct map mistakes (e.g., trees hiding information or purchase of new land) in their heads. This recognition of mistakes is valuable, and it is troubling that the farmer's corrections are merely mental and not recorded anywhere for collaborators or system designers to be aware of. Therefore, making it easier for farmers to input their observations and annotations on the data would be valuable.

Memorization in experimentation. When asked about experimentation, P5 described some experimentation with co-planting buckwheat and radishes on the same field as corn and buckwheat. When asked if he records these data, he replied, no - he drives down the road to check on the fields often and remembers which grains are on each field and their status. The reliance on spatial triggers and internal monitoring of crop status in experimentation has the convenience that the farmer does not have to rely on external devices to store or recall his data. The proximity of the test locations to the farm, and the frequency with which these are passed, keep these experiments top of mind. Any data management system would have to compete with the intrinsic practices currently used by farmers.

Memorization in long-term planning. In describing how he uses both yearly field records and his memory for long-term planning for each year during the winter, P6 belies some uncertainty about whether he will remember details about the fields from springtime:

> *[We get an] integrated pest management plan in place...going over field records from the previous year. Whether we wrote it down or whether you just remember that, hey, there's a wheat issue in this corner of the field, you got to pay attention to that in the spring and, hopefully, you remember, sometimes, you don't...I've done it better in the past - is actually*

write the yield down, we have a yield monitor on our combine, so we can get an average yield throughout the field.

Here we see P6 allude to the fact that writing the yield down is “better.” Relying on memorization leads the authors both to think about how the advancing age of the farmer, the distribution of farming activity, and the growth of farm size would make the intrinsic practice of "recording through the eyes and storing in the brain" no longer suffice. These practices also establish a baseline; however, farmers can perform their existing farm practices with largely intrinsic data recording and memorization, and these practices are felt as part of what it means to be a farmer. As mentioned later in section 4.2, Financial Incentives, any additional work for recording or recalling data would have to be justified in terms of additional payoff. But again, we must emphasize that memorizing and writing down yield data only would apply at a small or medium-scale farm. If the farmer wanted to continue with this “better” habit and also, scale up, it would be challenging.

4.2 Incentives for adoption of digital data collection

Our interviewed farmers collected data for several financial reasons. These include 1) financial incentives, like national contests, tax purposes, chemical companies' compensation, and state program recommendations, 2) understanding crop yield, and 3) the shared benefits of data collection. We discuss these incentive structures and the technology involved with them.

4.2.1 Financial incentives. Each of the motivations came back to improving business and financial compensation. For example, P1 was interested in winning a wheat yield national contest and, in participating, had to deliver his data. Similarly, P7 keeps data about his equipment finances for tax reasons. He collects data to receive compensation from Syngenta (Syngenta AG, Basel, Switzerland), a chemical company, for using a certain level of their herbicides, fungicides, or other crop treatments.

P10 was interested in data collection to improve efficiency in labor and fuel, which can reduce costs. Also, because his operation is qualified as a Concentrated Animal Feeding Operation (CAFO), he must provide data to the U.S. Environmental Protection Agency to remain compliant with the regulation.

Lastly, in exchange for his chemical data, P6 receives recommendations to enhance his natural resources and reduce chemical applications for the health of the environment from the Conservation Stewardship Program created by the Natural Resources Conservation Service (NRCS). P6 explains, “Yeah, you gotta make time to [collect the data] because you gotta have the information at the end of the year. Yeah, to satisfy the program.” We can see that P6 has made the time to collect his data to satisfy the program, and perhaps having his own data is a nice consequence.

On the whole, these themes indicate that financial incentives do motivate farmers to collect data, but also the disparate nature of the data collection shows how piecemeal the current data collection schemes are. In some ways, a unified data collection strategy that enables farmers to then make decisions about which data to share in exchange for different types of compensation could be useful.

4.2.2 Understanding yield. Yield maps, as shown in the figure 4 below, were found to be farmers' principal decision-making tools during planning/planting decisions. Yield maps are a simple, visual tool, that provides a heuristic for farmers, informing them of which areas are thriving and which portions of their crops need increased attention. In our sample, eight out of ten farmers mentioned yield maps. Yield maps are reliable, generationally grounded, and provide an easy approach to reviewing production. Such qualities seem to appeal to farmers directly.

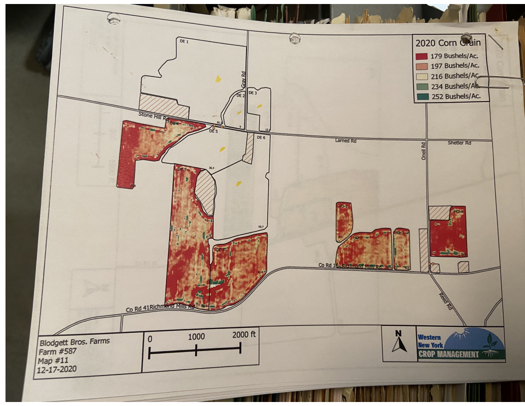

Fig. 4. Field map with a colored overlay showing 2020 corn harvest yield in bushels per acre, split into quintiles

Farmers value reliability, especially because their work is often dictated by uncontrollable factors. Such factors affect when farmers can perform specific tasks. Thus, farmers cannot stumble over their systems' applications & controls and instead need their technology to work in a given moment. P9 encapsulates this shared sentiment in the following excerpt:

> *If you guys have ever—or can picture yourself *pause* you've been through a long winter, the weather's startin' to turn, you gotta get the corn in the ground. You gotta do your new seedlings. We do them in the spring as well. Uh, you gotta get your manure out, you've got all this stuff going on. Is there anything more frustrating now that you need your corn in the ground before May 20 to get the biggest yield [increase], and you're sittin' in the field *pause* and the damn computer screen [for entering data] doesn't work — or [the computer] is not talking to my [farm] planter [machine]* —and here it is, the nicest day in the world, and I can't—do anything because of that?

We can see here the importance of the reliability of a yield map. Yield data have been an integral decision-making tool across generations of farmers. P8 describes,

> *"In 1988, [my dad and grandfather] started growing soybeans, from in the mid-70s, we used to grow vegetable crops, snap beans, and sweet corn and stuff into there...So the planting season really starts with a Microsoft Excel sheet where I do my rotation to figure out what I'm going to plant and where to come up with acreage from that to there. We've been collecting yield data since 1993."*

From this quote, we can see that the yield data are a vital tool for the operation. Yield maps, traditionally, are in paper form with their field and crop boundaries and yield quantities depicted on them, as shown in the above figure 4.

Yet, today yield maps are generated digitally, consisting of a matrix (color, location, yield). Crop yield maps are considered a significant enabler of digital agriculture and a valuable tool for understanding and addressing spatial variability existing on farms, as demonstrated by agronomist researchers studying yield sensing technologies, Longchamps et al. [29]. In the discussion section, we will consider what yield maps could mean for the future of digitalization.

4.2.3 Shared benefits. Although our codes might have suggested a delineation between cooperative and competitive behaviors, we find that farmers tend not to draw such clear boundaries. Instead, interactions between locally proximate farmers were often marked by an informal curiosity around new or different practices to their own. For example, P10 states that:

[A] lot of farms are...fairly open with their neighbors...[They will say,] "Boy, it seems like you did a pretty good job on growing that corn. Did you make any changes?" ... It's not like, "I'm not going to tell you my secret to how I grew that corn

On some occasions, farmers sought to benchmark their performance to others through the evaluation of a shared third party, though, in these instances, competitive knowledge seeking is directed at establishing farm performance against a broader average, as opposed to against immediate neighbors. For instance, P6 finds this information through the companies that he purchases seed from:

They do the yield trials, you know, throughout the state, and I do pay attention to those, just to compare what we're doing with other people, and, you know, just out of curiosity, what the yields were throughout the state.

This information comes with its limitations, of course, as P6 further states:

[If] somebody on the other side of my county is getting those yields, you know, other than I know what variety they're growing, I don't know how they're managing it [...] Is it management? Is it weather? Is it variety, you know, that, too?

The only clear instance of outright competition among neighboring farmers centered around purchasing land for farm expansion. But even in this case, the situation is expressed more as a matter-of-fact, rather than heated competition: "Everybody's trying to get the land, but it's not animosity there, it's just business." In addition, spatial proximity to other parties impacted the type of shared benefit that farmers could obtain through cooperation. Within the farmers' immediate vicinity, i.e., in interactions with neighboring farms, we find that informal knowledge sharing and reciprocal, ad-hoc arrangements allow farmers to gain valuable knowledge for future decision-making alongside the efficient delegation of specialized or excess tasks. For example, P5 explains:

He'll lend me his machine to get my thing done [... interviewer: *so it's a time trade? ...] Yeah ... if he owes me something or - kind of balance it out and then work it out money - wise in the end, that type of thing.*

In effect, these farmers are able to access specialized equipment through their local community, which subsequently allows them to save on investing in expensive farm equipment that might only be occasionally used, and these arrangements could also inform future decision-making around the purchase of farm equipment.

Unlike sharing equipment across small and medium farms, data is not shared between farm sellers and buyers. In the interview with P2, he explains that he doesn't get Excel sheets from a new farm he purchases:

Interviewer: *When you buy a new farm, do you say, "Let me see your Excel sheets?"*
P2: *Usually, you don't get that kind of information. [...] If I go back, we got some new fields, [and we] see their taxes on that one.*

From this quote, it becomes unclear if data-rich land improves the value of the land itself, compared to data-poor land.

4.3 Barriers to adoption of digital data collection

For farmers to be willing to adopt digital data collection methods, their trust in the technology, in their ability to use the technology, and in its improvement for their business must be well grounded. To understand the theme of barriers to digital data collection, we uncovered technology skepticism and doubts about functionality, technical hurdles, doubt about product fit, and business models.

4.3.1 Identity: Self-doubts about product fit. Many of our farmers express self-doubt about using technology. When P4 was asked if the new technology for data collection is frustrating or exciting, this farmer said, "I don't know, um I like writing it down, you know, keeping notes… I'm not em–yeah... probably, my son would be much better at that" (P4). P4 shows self-doubt in his technology literacy and a willingness to let his son, who represents a more technologically inclined generation user of digital systems for their farm.

This quote echoes some of the sentiment from P7, who mentioned being "older." Although these farmers know that products exist to address the needs they have; they feel that those systems are geared at more technologically savvy user bases. We suggest this reflects shortcomings in the design of current FMIS user interfaces. Designers should think about what kinds of interface language, style, or design pattern might help reluctant farmers with more traditional data recording practices feel more comfortable with FMIS systems.

There is some sentiment in the interviews that show that emphasizing the need for technology and modernity for its own sake can backfire. P4, for instance, is suspicious of messaging around being left behind if he doesn't adopt new systems: "Sometimes if there's a new technology coming out, they're almost meant to make you obsolete if you don't jump on the bandwagon" (P4). In a way, he faces technical obsolescence compared to others. P4 is describing, with a tone of resentment, how once others buy the newer technologies with integration, he will become obsolete.

4.3.2 Technology skepticism and doubts about functionality. We asked farmers for examples of digital or physical data records and about their sentiments about the recording process. One theme we noted was some explicit decision-making and awareness around either using digital collection methods or avoiding using such methods in favor of traditional analog record-keeping.

Many farmers wrote down their data on legal pads (P1: *"I'm old school. I use a legal pad and pen for data."*) and binders (P2, P6, P9, P10). These pads were not primarily brought out to the field or into the tractor - they were mainly used at the end of the day in the office. In fact, P10 reported that triennial chemical-use inspectors would even accept a "shoebox" with handwritten documentation, so there isn't much incentive to digitize data.

Sometimes farmers used written logs of data in addition to entering data into Microsoft Excel. One farmer (P7), when asked about this practice, told a story in which he expressed concern about the reliability of digital systems:

> *Well, to be honest with you, I do write [it] down. Because, again, I'm older. And yeah, I don't necessarily trust this stuff all the time. And I'll give you a perfect example. A lot of times with this GPS stuff, you'll leave a field and pull into a new field, and you've planted maybe a third of the field, you're out of fertilizer, or you need to go get some more seed or lunch. So you run home to refill. And when you go back up there, the color code on the portion of the field that I've planted [as displayed on the monitor of the tractor cab] is gone. I don't know what happens. It's just gone. So when I get back into the monitor, [the monitor display] reverted to the field that I planted previously.*

Farmers feel distrust in digital record-keeping systems and use analog methods as a safeguard against the perceived unreliability of such systems.

With some admission that the challenges in using the technology might be due to individual self-doubts–"I'm older"–the farmer indicates that he does not trust that the data he enters will stay in the system. As mentioned above, P2 similarly uses backup methods, like downloading the data, in case the cloud isn't reliable.

> P2: *As an agronomist, I have to know that the data is in there, but I can't just trust that it's in there. I go to make a prescription, and in a year, if there's something omitted, it*

screws everything up, yeah, which really drives me nuts.
Interviewer: *OK, so you need to go and verify every time.*
P2: *Yeah, so I like to download it from MyJohnDeere manually, just for reliability's sake.*

This indicates how important it is to preserve and reflect on the data that the agronomist inputs; any modifications or corrections made by the system must be shown in other views, lest the system be perceived to be unreliable. The immutability of hard-copy text is also useful to learn from; providing options to produce hard copies can help alleviate concerns about unexpected changes in entered data.

4.3.3 Technical hurdles and support. We see a variety of approaches to technical hurdles, including workarounds, concern about reliability, and asking for a range of support.

P7 demonstrates a workaround when he struggles with QuickBooks. He buys a new computer when QuickBooks no longer works after bringing a computer consultant in, which sheds light on the way he solves problems:

> *The only reason we bought this [computer] is to run QuickBooks. So we can do everything else on this [other computer] except QuickBooks. And we can do everything on that, including QuickBooks. But it's two separate screens with two keyboards. So now it's more clutter on the desk. But sometimes, it does work out pretty good."*

He goes on to say that he does not like computers but now has two on his desk, and he chuckles at the irony. There is an additional irony here in that the farmer is spending money on another computer for an accounting program, which is supposed to manage and optimize finances.

This sheds light on how he solves technical problems and his willingness to spend money to compensate when something breaks. One might ask, why doesn't he throw away the old computer and keep the computer that does Quickbooks and everything else? This points to his mental schema about each computer's function – the new computer is for QuickBooks, and the old computer is for everything else. Continuing to use the old computer also means he doesn't need to learn how to do his work on the new computer.

While the farmer above (P7) received technical support for his QuickBooks issue, P1 does not have the same accessible technical support. P1 describes a time when he had a technical problem with his tractor:

> *If I pull the [tractor manual] out and I read the book, I didn't get anything the first time because I'm thinking, "I am not reading a book." And then frustration sets in, and panic sets in, and then things really start to fall apart. And if I call -name-, [my wife] and I can't get an answer, or I call tech at John Deere, and I can't get an answer, yeah, it's not good. That's why I tell John Deere, "You need to be voice-activated. I'll talk nicely to it, but it needs to answer my questions."*

P7's frustrated description of his predicament demonstrates his problem-solving steps: 1) referencing the tractor manual, 2) calling someone he knows, and 3) calling the tractor company. Then he describes his desire for a machine to tell him the answers when he asks about what to do next. Knowing this process, in addition to looking into more user troubleshooting efforts, can help designers provide prioritized troubleshooting options on an FMIS.

4.3.4 Doubts about business model. P6 has experience with technology and avidly reads about the current state of farming and technology, but demonstrates a skepticism for such systems.

Interviewer: *So do you use the John Deere suite or another company?*
P6: *I stay away from all computer data collection. It's my data. I'm not gonna let them make money off me. And also, like in John Deere...It's kind of like an all-or-nothing*

Finding	Implication for design
Farmers do much of the data collection and analysis in their heads, which might be good enough, but is hard to share or check, and makes meta-analyses difficult.	Design a solution that will enable data recording where and when needed to match the practicality of memorized recordkeeping, expanding on the findings of Edalgo [15].
Farmers are willing to collect data digitally, but want to be compensated rather than feeling they are being exploited.	Make explicit the gains or compensation the farmers will get for adopting FMIS, expanding on the concerns raised by [50, 59]. Involve the farmers in this decision.
Farmers have more casual data collection practices motivated by social impulses to help other farmers or motivated by taking pride in their work.	Be sensitive to data and motivations associated with altruism and community-mindedness to encourage collection, expanding the work from Steup et al. [53]
Farmers do not have access to their data in all locations on the farm.	Make the data output portable, so farmers can print hard copies, have data output on phones, on tablets and also in the office. This would make data analysis more seamless, supporting the work of Marshall et al. [32]
Different data input tasks are done in different locations.	Streamline software to account for difference between in-field and in-office activities. This could be through the use of GPS on the farm expanding the work of Pontikakos et al. [42]

Table 3. Key findings and implications for the design of Farm Management Information Systems (FMIS)

> *thing...It's just cost prohibitive for us, we're not going to go out and dump, you know, $ 10,000 into a monitor that's gonna spit out a map that, you know, I basically can do, without, printing it out.*

P6's distrust has less to do with data reliability and more to do with fear of being taken advantage of financially. Even though he is knowledgeable about what an FMIS can do, he doesn't see it adding information use to his operation. He is concerned about the cost of John Deere's FMIS, calling it "cost prohibitive," and has an "I can do it myself" attitude around the data collection and analysis. Small and medium farms have less information to manage, meaning that the scale that FMIS can handle might not add valuable information to their business. When designing an FMIS for small and medium farms, we must pay attention to security concerns, cost, integration requirements with affordable equipment, and information value for a smaller-scale operation.

5 DISCUSSION

Our research of farm data collection practices was intended to encourage the adoption of farm management information systems for small and medium farms. We were motivated to help small-to-medium farmers be able to improve crop productivity and environmental stewardship. For this reason, the follow-on discussion is largely focused on how, based on the findings of the research, future FMIS can be better adapted to the small-to-medium farmers, how incentive structures can be better aligned to encourage adoption, and how barriers to adoption might be addressed. The points we make in the following section emerged from the discussion between the multi-disciplinary research team around design implications and CSCW literature.

5.1 Adaptations required for future FMIS systems

In the following section, we identify the findings that can help designers adapt future FMIS to the context of current small and medium farm use. This type of adaptation is in line with CSCW research which demonstrates that workplace technologies succeed or fail based on workflow fit. [43]

For FMIS to appropriately fit into current small and medium farm data collection practices, designers must understand the demographic, farming tasks involving data collection, and gauge the farmers' comfort level with interfaces and input techniques. To help designers create systems that can better fit in with current practices, we discuss the existing tasks and corresponding potential design implications. Lastly, we suggest how designers can be sensitive to the economic and political motivations of the demographic.

5.1.1 Market segmentation. One insight we have from our work, particularly in looking at Section 4.3.3, is that we should look at the issues farmers have with new data technologies, not as deficiencies in the training or capability of the farmers and more as deficiencies in the design of the technologies themselves.

When we look at our farmers' sentiment about data collection, we see three main approaches, (1) *the data indifferent*, who have a "can't be bothered" approach, primarily commit data to memory, and see no need to record their data for their own practice, (2) a middle group, *the data willing*, who believe they should be recording more data, and are interested in doing so but do not always feel that they are competent enough, and (3) *the data enthusiasts*, a group who have many systems to collect and record data. While the farmers themselves sometimes used their age as an excuse for being data indifferent, we found that the actual differences tended to be about the orientation to technology rather than some direct reflection of age. Some of our farmers fell between these groups or belonged to different groups depending on the time of the season.

Each group could be prompted to improve their data collection practices in slightly different ways, but we suggest that each of these ways could be built into the same systems. The "data indifferent," for example, could benefit from low-effort automatic capture or prompts reminding farmers to input data when the system notices a decrease in the frequency of data input. The "data willing" could benefit from familiar and simple input strategies and interfaces. Lastly, "data enthusiasts" could gain from an FMIS with the capability (potentially integratable hardware and software) to overlay data streams for data management and analysis. While these features are for independent groups, some design changes for independent groups could also be beneficial for each other's use cases.

5.1.2 Workflow. Because we wish to encourage the adoption of FMIS systems, but the adoption of such systems for small and medium farms is likely to be modular, FMIS systems need to integrate with existing practices for data collection, data analysis, and data-driven decision-making to be successful. There were practices around capturing data that were surprising and potentially rich for use in designing an FMIS. These practices included memorizing their data, using phones as social tools to share data, writing and printing out information for reliability, and formatting on open mediums, like Excel and paper.

Keeping track of, and even encouraging, farmer annotations can also help FMIS systems make better use of farmer's implicit data practices; that is, activities that the farmers are doing–like taking pictures when the crops look good–as data input that might be useful later. We see there are many moments where implicit data capture is occurring. Our sample of farmers tended to memorize information on-the-go, especially for experimentation, in cases when they could frequently drive past local farming test sites and see the status of their crops. Offering an "audio notepad" for these observations could help to make these plans more explicit. We also noticed the phone being used as an invisible tool brought into the field and a tractor cab (on the farm tour) but not often mentioned in the interviews. A more mobile FMIS system–for example, something that takes advantage of the mobile phones the farmers carry–might help the on-the-go farmer to record this data explicitly instead of relying on implicit practices like memorization. A mobile device that takes unstructured data, or data that could be classified post-facto, might appeal to the data-indifferent farmer, who often memorizes information rather than writing it down.

Another implicit data practice was described in Section 4.1.2, where a farmer and his brother exchanged email photos of "nice looking" triticale. This vignette illustrates how an FMIS could also act as a social tool. It could support the sharing of images between local farmers, future land owners, past land owners, friends, and family. This could help social ties between the farmer's community and can act as visual documentation of weather conditions, the animals of the area, and how the crops are doing at that time.

5.2 Incentive Structures

5.2.1 Awareness. One of the major motivations for data collection is to help predict crop yield; it is the critical aspect of awareness farmers care about. Yield maps can thus be a major motivator toward digitalization. With the implementation of FMIS into agricultural production, farmers are able to carry such yield maps, historically bound within large binders, on their cell phones. The ability to carry yield maps on their cell phones provisions farmers easier utility, seeing that they have less to carry and being freer to perform work they could otherwise not perform should their hands already be preoccupied. Given the apprehension amongst farmers concerning digital technologies, it was surprising that farmers did not describe cell phones as burdensome. Per contra, farmers mentioned their cell phones being a tool they carried on their person anyway, so using integrated agricultural tools on their cell phones could be relatively straightforward. For example, P5 stated, "If it was on my phone and I could just go in there and zip in there and put it in, I'd probably do that pretty quick."

Interestingly, however, farmers still printed out their yield maps, incorporating them into binders that they kept in their offices. This highlights an area of future inquiry concerning farmers' affinity for material artifacts. Why might farmers continue relying on material artifacts (e.g., paper yield maps) even when alternative, digital solutions exist? Evidence from P7 in 4.3.2 suggests that farmers' continued reliance on material artifacts is tied to trust. Farmers must trust their tools, founded upon dependability and reliability.

5.2.2 Design for annotation and export. We observed that farmers tend to make their own format on a blank spreadsheet or notepad (See Section 4.1.1). An FMIS feature that takes advantage of this interface familiarity might be a modular and customizable system, which farmers can easily manipulate flexibly.

Existing FMIS systems are often closed ecosystems, intended to bring data into, say, John Deere's database. Farmers are charged money for services to see or access that same data. For some farmers that we interviewed, such as P6 in Section 4.1.2, what is really desired is a service that helps them to collect data, but that then gives them the freedom to use their own tool to annotate, format, analyze and store data. This type of business model is counterproductive to encouraging farmers to collect data because it financially incentivizes them to work around the FMIS system rather than embracing it. People collect their own data on paper or a personal computer spreadsheet for themselves, so that they can have it in their preferred format, and *then* entering it into the FMIS doubles work; this practice also increases chances for error. The need for manual data collection also disincentives the adoption of aspects of FMIS systems that automatically collect data but only in proprietary formats.

Not only should the FMIS support the integration of affordable hardware and software for inputs, but the system itself should also make the various outputs of the data collection accessible and affordable, providing a variety of affordable data management visualization tools, so that multiple streams of data can be overlaid. Lastly, as referenced in 4.1.2, data collection tools can include social media tools, and several small and medium farms could potentially benefit from networked local condition information sharing.

Better data export in FMIS systems can also help to address farmers' concerns about reliability. We noted several farmers' use of written-out information, which later gets typed up, in case the data gets lost, as shown in 4.3.2. We see information written in places to be referenced later, like a crop plan for the year (Figure 3), which depicts a cardboard pizza box that is taped to a whiteboard and is, therefore, un-erasable. For an FMIS system, designers should consider an offline or local version of the data, which gets saved to the cloud as a backup, when connected to the internet.

One reason that existing FMIS systems are a closed ecosystem is that the agriculture companies want to ensure that the data are not contaminated or doctored. On the other hand, limiting farmers from entering explanations or annotations into the record can prevent the detection of unusual or strange data conditions. As was noted in Sections 4.3.2 and 4.1.3, it should be possible for an FMIS system to keep both the original and modified records and, over time, track the places where the FMIS system needs to be regularly corrected or annotated to improve the interpretation of sensor readings.

5.2.3 Transferrability. Sometimes, major events, like impending retirement, could drive the adoption of an FMIS system. It can be useful for FMIS designers to be aware of these types of moments. Impending retirement, for example, can provide farmers an incentive to record comprehensible data, moving farmers from data indifferent to the data willing or the data enthusiastic. This occurs because farmers are looking ahead to other farmers taking over that land and practice. As mentioned in section 4.2.3, transferability might be different for every farm, but an FMIS could potentially centralize information to smooth this transfer of equipment, data, and land across farms. Currently, this does not happen because it is of greater value to the new farmer than the original one, but on the other hand, having formalized data records in place could improve the value of the farm at the point of transition. Some information that might be challenging to comprehend or less likely to get passed on to future owners are: names of fields, acronyms for tools, and details about fields that have soil quality issues. An FMIS could prompt input for this kind of information.

Age was brought up by a few interviewees, as a reason for using analog tools, like legal pads and pens for data recording, and as a reason for not using smartphone applications (i.e., data recording apps and Facebook groups for farming). We feel it is important to reframe the traditional tools so that they are not to be seen as in opposition to new tools. By making it easier to transfer data from traditional media to FMIS systems–for example, enabling data input by taking pictures of tables on legal pads–we can take advantage of existing data enthusiast behavior that just happens not to be digital yet. In addition, we should consider transferability in terms of comfort and familiarity with interfaces. In designing an FMIS, we must incorporate familiar interface metaphors, like a notepad and pen, so that users can more easily use what they know, for example, to customize the layout of the data so that it best suits their uses.

5.3 Addressing Barriers to Adoption

5.3.1 Increasing ease for data entry. As discussed in the findings and in table 3, there are obstacles to data entry because of internet connectivity in the field, which has also been found in ICTD research [34]. We raised the possibility of using non-internet-connected voice-activated apps to input data while farmers were in the field. For P6, this possibility brought up the importance of being able to have new tools work with his existing workflow using Excel:

> *I like the idea of having an app that...talks to you. But then automating some of the collection, like the basic: the time, the date, you know, all that stuff that would save me the effort now that it's a big effort to do this. And also transferability, you know, being able to like taking an app, but being able to bring that back to an Excel sheet. And getting it in the right column at the right spot without having to do coding or, you know, it's got to be very, very simple, very easy.*

P6 gets into the details of how it could work; each piece of information could get put into the right spreadsheet column, with a low effort from him, and no coding involved. To design a system as he describes, we suggest that designers learn more about the common farmer's standard of formatting data, specifically from Excel spreadsheets and paper notes, because of the open format nature of these mediums.

5.3.2 Addressing Economic Barriers to Adoption. We note that small and medium farms are susceptible to the cost of tools and equipment and therefore need to justify using FMIS on cut-and-dried economic terms. Reducing the time cost of adoption, making modular adoption more accessible, and multiplying the benefits of FMIS use, are essential to demonstrate the economic viability of FMIS adoption for small to medium farmers.

We shouldn't assume that current FMIS systems will make small farms more profitable. As P6 points out in Section 4.3.4, the system is "cost prohibitive" and believes he can produce similar data to an FMIS anyway. At his scale, he doesn't see the opportunity in the information that another system can produce, when he can do it anyway, for much cheaper. This example demonstrates the economic motivations behind purchasing an FMIS for a small farm.

5.3.3 Modularity. Small and medium farms have specific needs because of their scale and income. As discussed in Section 5.3.2, Economic Motivations, small and medium-sized farms might have different levels of adoption of smart equipment, real-time sensing, and mapping hardware available from large agriculture companies. Therefore, an FMIS for small and medium farms should support software and hardware modularity for both the data sources and the data outputs. This is consistent with issues noted by CSCW researchers Wulf et al. [62].

Current FMIS have modular outputs and applications for data collected, but the offer of modularity is coupled with significant extra charges, which farmers are resistant to paying. From the standpoint of adoption, it would be better if modularity were considered as a tool to better adapt FMIS systems to the needs of these small and medium farm owners. It might be more attractive to present the larger FMIS system (all modules included) and subtract the costs of software and hardware modules for larger farms, so that the owners of small to medium farms feel less like they have paid a lot for a confusing suite of tools they do not need, and more like they are paying the appropriate price for what they do need. Also, designers could come up with ways to make sure data is owned collectively, as the Right to Repair movement suggests.

5.3.4 Addressing political barriers. One reason farmers sometimes will act against their economic self-interest is that they are suspicious of the political implications of technology adoption. Our most notable case is around data ownership. Two examples from P1 demonstrate the caution around the power of agriculture companies over farmers' data. Firstly, as demonstrated by the quote from P1 in Section 4.1.1, it is easier to stay within the same company's farm management tools–John Deere, in this case–because the company focuses on integrating its own equipment, software, and online services. When he tried to use another product, he explained, it just wasn't "John Deere." This integration saves time, but the farmers are conscious of how it transfers power to the company that offers that integration. This trepidation towards corporations is similar to that noted by Brown et al. [9], who discovered that as a key reason that users hack software.

Later, P1 describes how his access to his data is limited based on internet connectivity since the data is now only viewable in the cloud. This limitation especially hits small and medium farms harder because they face more network access and bandwidth limitations. Both these examples prompt us to note that small to medium farmers are sensitive to the ways that FMIS systems distribute power through data capture and access, and explicit consideration of how reliance on integration and internet connection transfers power away from these farmers. The issues of integration and data access echo concerns of the Right to Repair movement. [22] CSCW researchers Rosner and Ames investigate the causes of repair and breakdown, and from their interviews, find that repair and breakdown are emergent and often out of the designer's control because they stem from material, infrastructural, gendered, political, and socioeconomic factors [47].

From the above two examples, we see similar causes impacting small and medium farms. Firstly, breakdowns occur for *infrastructural* reasons, as internet connectivity and bandwidth are not accessible due to the remote location. Secondly, there are *political* reasons, as farmers cannot always access their own data because of cloud connection, while the owner of the software suite can access it, anytime. And thirdly, there are *socioeconomic* reasons, as high bandwidth in remote locations and a software & hardware suite are not cost-accessible.

5.4 Limitations

Our limitations include variability in the makeup of our team and farm demographic, specificity to region, and lack of saturation. We acknowledge the details of each of these limitations in this section. The make-up of the interviewing team varied based on available researchers. As mentioned above in section 3.0.1 author positionality, our different perspectives likely caused us to follow up on specific questions more than others, especially because of the open-ended nature of semi-structured interviews. Also, there was variability in the small and medium farms. Different farms had varied amounts of digitization and therefore could highlight different issues, which also created richer data. Our findings are limited to farms operating in upstate New York. Farms in different regions in the US and in other parts of the world face very different challenges. For example, farms in warm-weather regions are less bound by seasons but more constrained by water access. Therefore our findings would not apply to these farms. Small to medium farms are highly different from large farms; they tend to operate in processes in which the automation has not worked well. For researchers who are trying to design one FMIS that fits all farms' needs, reaching research saturation would be difficult. The practices employed by the farmers of small and medium farms are often self-serving and thus individualized. To that end, it's not clear that we would ever reach a point of "saturation" where we find that everything we are learning has already been reported. This paper is framed to be formative (e.g. indicating emergent issues and themes of importance) rather than summative (e.g. final findings on specific research questions).

6 CONCLUSION

In this paper, we have described farmers' data collection practices, as revealed by ten semi-structured on-farm interviews. These interviews highlight the ways that farmers currently perform agricultural data collection & management practices. We explore the challenges faced by the farmers around

FMIS–technology skepticism, technical hurdles and lack of support, and self-doubt in technical skills–as well as opportunities and incentives for better data collection and utilization. Based on this empirical work and analysis, we have developed recommendations for how FMIS systems can best address the needs of small and medium farms.

Our results will help adapt farm management information systems built for digital agronomy to the needs and constraints on small and medium farms.

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