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Examining Farmers' Perceptions of Precision Agriculture Technologies and Their Interest in Conducting on-Farm Precision Experimentation

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95 Pages

Precision agriculture technologies (PATs) have revolutionized the agriculture industry. These technologies have offered many benefits for farmers, including cost savings and higher yields through improved application of inputs (i.e., fertilizers and herbicides). PATs also allow farmers to conduct experiments through a process known as on-farm precision experimentation (OFPE). By conducting these experiments and collaborating with researchers, crop consultants, and extension agents, farmers can learn site-specific management practices to better address challenges to their operations. Despite these benefits, adoption rates of PATs in the U.S. have barely eclipsed 50%. Furthermore, there may be some skepticism amongst farmers towards researchers who seek to conduct experiments without consulting with farmers. The literature on OFPE has yet to explore the factors that influence a farmer's decision to conduct experiments and their willingness to collaborate with researchers. If OFPE is the future of agricultural research, then farmers' views of the work done by researchers and their willingness to conduct these experiments must be explored.

This study seeks to fill the gap in the literature by conducting a needs assessment on OFPE. This needs assessment is comprised of two phases. The first phase was interviews with 11 Illinois farmers to gain initial viewpoints on farmers' perceptions of OFPE. The results from the first phase were utilized to develop a survey that was distributed to a broader, more diverse group of farmers from across multiple states. The results from the survey indicate that farmers are conducting experiments on their operations, but are not collaborating with researchers, crop consultants, or extension agents. Furthermore, farmers are willing to collaborate with researchers to conduct experiments, so long as researchers actively engage farmers throughout the research process.

KEYWORDS: precision agriculture technologies, on-farm precision experimentation, collaboration.

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- R.G.T.

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CHAPTER I: INTRODUCTION

Since their introduction nearly 40 years ago, precision agriculture technologies (PATs) have promised to revolutionize the agriculture industry. Precision agriculture can be considered more than just one technology but a whole suite of different technologies that serve a range of other purposes. From the first GPS-based guidance systems of the 1990s to self-driving tractors of the future, the goal of precision agriculture has not changed. PATs offer many benefits to farmers, including improving efficiency by decreasing inputs, improving yields, providing farmers with information to make better management decisions for their operations, and reducing the impact to local ecosystems. Another benefit of PATs is the ability of farmers to conduct research trials on their operations in a process known as on-farm precision experimentation (OFPE). OFPE benefits farmers by giving them information about the value of different input management strategies. It is not just farmers that can benefit from OFPE. Researchers, extension agents, crop consultants, and others can also benefit from OFPE by working with farmers to conduct experiments that address topics relevant to farmers. This collaborative research helps facilitate knowledge sharing that is beneficial to all in the agricultural community.

Despite these promoted benefits, the adoption rates of PATs have remained low throughout the United States with many farmers yet to recognize the benefits of these technologies on their operations. Additionally, some farmers may be skeptical of experiments conducted on trial plots by researchers who attempt to answer questions without consulting farmers and their knowledge. Several studies have addressed the low adoption rates of precision technologies and how researchers can utilize farmers' knowledge to benefit research. Analyzing farmers' perceptions of PATs and understanding the factors that affect those perceptions and adoption rates, in addition to exploring their views of working with researchers to conduct

OFPE, is an important contribution to the overall discussion of OFPE. A two-part needs assessment is the best manner to provide this information. The first part seeks to gain initial insights from a small number of farmers on their use of PATs, their perceptions of experiments, and their interest in conducting OFPE with researchers. To do this, interviews were conducted with 11 Illinois farmers during the summer of 2022. Based on the results of that pilot study, a survey was developed and distributed to a broader and more diverse group of farmers across multiple states to understand the farming community's views of these topics. The results of the survey show that respondents have overwhelmingly adopted PATs on their operations and believe that these technologies have benefited their operation in numerous ways. A majority of the respondents do conduct experiments on their operations, but do not collaborate with researchers, crop consultants, or extension agents to conduct these experiments. Nearly half of the respondents have some level of interest in conducting experiments in collaboration with researchers. If OFPE is the future of agricultural research, and if researchers intend to conduct more experiments with farmers, then there must be an understanding of the factors that influence a farmer's decision to conduct OFPE and collaborate with researchers.

Thesis Organization

This thesis is an alternate format. It includes a general introduction, a manuscript formatted to the style of the Agricultural & Environmental Letters journal, a second manuscript formatted to the style of the Precision Agriculture journal, a review of the literature, and appendices.

CHAPTER II: DISCOVERING FARMERS' VIEWS OF ON-FARM PRECISION EXPERIMENTATION

Abstract

Precision agriculture technologies (PATs) have revolutionized agriculture production and provide many benefits to farmers. Among these benefits is the ability to conduct experiments using PATs and collaborate with researchers in a process known as on-farm precision experimentation (OFPE), which is often viewed as the future of agricultural research. While the literature on precision agriculture is extensive, there is a gap in the OFPE literature, particularly concerning whether farmers are interested in conducting these experiments with researchers. This study seeks to fill this gap by interviewing 11 Illinois farmers to gain initial insights about participants' adoption of precision agriculture technologies and their views of and interest in conducting OFPE. Most participants have adopted precision agriculture technologies and identified benefits they receive from using those technologies. Participants' interest in collaborating with researchers and conducting OFPE was mixed, demonstrating the need for additional study among the larger farming community.

Keywords

precision agriculture technologies, on-farm precision experimentation.

Introduction

Precision agriculture technologies (PATs) have promised to revolutionize the agriculture industry by improving efficiency and increasing profits through higher yields and lower input costs. Another benefit of PATs is making it easier and more convenient for farmers to conduct their own on-farm research and trials. On-farm precision experimentation (OFPE) is seen by many as the future of agricultural research because it supplements the work done on university trial plots. Farmers can benefit from conducting OFPE by learning new practices and effectively employing site-specific management in their operations to help them balance economic pressures (i.e., slim profit margins and higher input costs) with environmental challenges (i.e., reducing nutrient losses). The benefits of OFPE are not just limited to farmers. For researchers, conducting OFPE can be beneficial because they engage directly with farmers to ensure that the topics being addressed are relevant to real-world production.

Despite these promoted benefits, PAT adoption rates have remained low throughout the United States. Farmers have yet to fully recognize the benefits of these technologies on their operations, including the ability to conduct their own on-farm research. Several studies have addressed the low adoption rates of PATs (e.g., Schimmelpfennig, 2016). However, one thing missing from the literature on OFPE is a discussion of whether farmers are interested in conducting OFPE. If the future of agricultural research is OFPE, this must be explored.

To contribute to the discourse about OFPE, an overall needs assessment of OFPE is needed. A needs assessment will also explore topics such as motivating factors for farmers to conduct OFPE, their perceptions of the work done by university researchers on trial plots, and their interest in working with university researchers or extension agents to conduct OFPE. The first step of the needs assessment is to gain initial insights from farmers. To accomplish this, interviews were conducted with 11 Illinois farmers, which revealed varying perspectives on precision agriculture technologies and OFPE.

Literature Review

As soon as the first PATs were available for civilian use, researchers began to analyze their effect on the agriculture industry. The literature on PAT adoption can be broken into two groups: farmers' perceptions of PATs and the factors influencing a farmer's decision to adopt these technologies.

<u>Perceptions of Precision Agriculture Technologies</u>

Farmers perceive increased convenience from precision agriculture technologies such as autosteer and guidance, while variable rate technologies are more likely to reduce inputs and save costs (Batte & Arnholt, 2002). Furthermore, farmers believe that technologies such as GPS and autosteer are important contributors to their operation's profitability, with the most significant benefits from using PATs being precise knowledge of soil nutrient and pH levels (Thompson et al., 2019). Enhanced monitoring of soil health and weather patterns can increase efficiency through the accurate application of inputs, and machinery can be managed more precisely and serviced when needed (Boehlje & Langemeier, 2022). Ofori & El-Gayar (2021) analyzed 45,000 posts on social media platforms such as Twitter, Reddit, and LinkedIn over a ten-year span, which showed that users were discussing topics such as data privacy and smart farming, yield gains/losses, and reducing climate change. However, an analysis of USDA data showed that only 30-50% of corn and soybean acres were farmed using PATs, revealing the slow adoption rate of these technologies (Schimmelpfennig, 2016). Despite these low levels, there has been an increase in the adoption rates of some technologies (Boehlje & Langemeier, 2022; McFadden et al., 2023).

Factors Affecting Decisions to Adopt

Ofori et al. (2020) conducted a duration analysis of embodied-knowledge and information-intensive technologies to evaluate the time lapse between a technology becoming available and a farmer's adoption of that technology. Embodied-knowledge technologies are those that do not require a farmer to have specialized skills to use the technology (e.g., automated guidance), while information-intensive technologies generate substantial amounts of data that requires interpretation (e.g., yield monitors or variable rate technology) (Miller et al., 2019). In general, the embodied-knowledge technologies were adopted more quickly than information-intensive technologies, and younger farmers adopted technologies sooner than older farmers (Ofori et al., 2020). Kolady et al. (2021) revealed that embodied-knowledge technologies had adoption rates above 50% whereas the only information-intensive technology with an adoption rate above 50% was a yield monitor. The least-adopted technologies (aerial satellite imagery, crop tissue sampling, and grid soil sampling) were information intensive (Kolady et al., 2021). This study also supports the belief that farm size has a positive effect on the adoption of PATs.

Tey and Brindal's (2022) meta-analysis found that a farmer's education, farm income, cropped farm size, access to consultants, use of computers, and perceived profitability from using these technologies all influence a farmer's decision to adopt precision agriculture technologies. Pierpaoli et al. (2013) analyzed drivers of adoption from an ex-post (after adoption) and ex-ante (before adoption) perspective. Ex-post, some of the most influential factors include farm size, desire to reduce costs/increase profits, a farmer's education level, and their familiarity with computers. Ex-ante, factors that affect farmers' decision to adopt include the presence of experts to help them learn the technology, a technology's ease of use, and a farmer's overall views of precision agriculture technologies (Pierpaoli et al., 2013).

Schimmelpfennig (2016) found that large operations in the United States are more likely to adopt precision agriculture technologies, with corn and soybean farms adopting them at higher rates than wheat, cotton, and rice operations. A survey of Midwestern corn farmers found that concerns regarding flooding can increase the likelihood of adoption by 13%, while concerns about soil erosion can negatively affect the likelihood of adoption (Gardezi & Bronson, 2020). Owner-operators are less likely to use (PATs), while farmers are more likely to use them if they rent the land they operate. Higher operational diversity (i.e., growing more than two crop enterprises a year, or raising livestock and growing crops) is also positively correlated with precision agriculture use (Gardezi & Bronson, 2020). A study of U.S. cotton farmers' adoption of autosteer technology found that farmers who indicated that PATs would be more important in the next five years were approximately 10% more likely to have adopted autosteer (D'Antoni et al., 2012).

A farmer's decision to adopt precision agriculture technologies may also be affected by data privacy concerns. Ellixson et al. (2019) argued that the vast amounts of money being invested into big data in agriculture demonstrates the value of farm-level data, and further noted that very few legal protections exist for farmers and data collected on farms. In a survey of Australian farmers, Wiseman et al. (2019) found that nearly 75% of the respondents did not know much about the terms and conditions associated with using these technologies, with half feeling uncomfortable about a technology provider having direct access to collected data. More than half of their respondents did not trust a technology provider to protect their privacy and not share data with a third party (Wiseman et al., 2019).

Literature on OFPE

On-farm precision experimentation (OFPE) is a collaborative, demand-driven process that brings farmers and researchers together “around mutually beneficial experimentation” (Lacoste et al., 2022. p. 2). Farmers have long expressed their desire to be involved in the research process and contribute their knowledge and experience to experiments (Gerber, 1992). Many farmer-researcher organizations prioritize this collaboration. One of the earliest organizations, the Practical Farmers of Iowa (PFI), was founded in 1985 and helps guide research on farming practices that are profitable and environmentally sound by conducting experiments in on-farm research plots controlled by the farmers (Thompson & Thompson, 1990). Additional groups, such as the Nebraska On-Farm Research Network, the Ohio eFields program, and the Washington State University Farmers Network, bridge the gap between farmers and researchers to ensure research is interesting and beneficial for farmers.

Longchamps (2022) interviewed ten farmers across New York State and found that all the farmers interviewed stated they are conducting some kind of OFPE. This shows that OFPE is important for these farmers to run their operations. Further results indicate that farmers’ data collection can be rudimentary, the experiments require considerable time investments by a farmer, and farmers put much thought and consideration into these experiments (Longchamps, 2022). This study provides unique insights into the dynamic landscape of OFPE, but the literature addressing farmers’ views of and willingness to engage in OFPE remains sparse.

Procedures

Interviews were conducted with a small group of Illinois farmers in the summer of 2022 to explore their perceptions of OFPE (Illinois State University IRB 2022-130). The basis for these interviews is the customer discovery model (Blank, 2013). Startups use this model to identify demand and potential customers for a new product. With OFPE being a relatively new concept, this model can help understand farmers' perceptions of OFPE by exploring whether farmers are conducting experiments, or if they have any interest to begin conducting these experiments. A total of 11 farmers were interviewed. Three farmers were participants in the Data-Intensive Farm Management (DIFM) project, which is a network of farmers and university researchers that collaborate to implement on-farm field trials ("Data-Intensive Farm Management Project," 2023). The other eight participants are farmers in Logan County, IL. Participants were asked a series of questions addressing demographics, their use of precision agriculture technologies, the benefits from using those technologies, any concerns regarding internet access and data privacy, and their views on collaborating with researchers to conduct OFPE.

Findings and Discussion

Findings

All participants produce corn and soybeans, with some also raising livestock or growing hay. Participants' operations ranged in size from as few as 300 acres to as many as 7,500 acres. Nearly all of the participants use precision agriculture technologies and have varying levels of use. For example, one participant only uses a yield monitor, while another stated they were on the "cutting edge" of PAT use. Those that use PATs indicated several benefits of using these technologies, including the availability of data to make better decisions or to negotiate cash rent agreements, and saving money on input costs. One participant went as far to say PATs "changed [their] farm." Other than occasional setbacks, such as the time needed to learn how to use these technologies, all participants stated that the benefits outweighed those challenges.

Participants expressed many different views on how they define OFPE and their level of interest in conducting experiments. One believed OFPE is a process of conducting experiments that is simplified by using PATs. Many participants had done some kind of experiment on their operations, with seed variety trials being the most frequently mentioned. Some participants reported using portions of their fields for other types of experiments such as variable nutrient application rates, with one setting aside an entire field for experimentation. Those that conduct experiments do not often work with crop consultants, and aside from the DIFM participants, these farmers almost never work with university research personnel. Participants expressed varying opinions on the significance of university trial plot experiments, with some participants paying no attention to these experiments, while others pay close attention to their results. Most participants would be willing to consider collaborating with researchers to conduct OFPE while others were not interested due to factors such as not having the right equipment, not being comfortable with setting aside acres for an experiment, or simply not having a desire to conduct experiments.

Participants also expressed varying views on internet access and data privacy. Many of the participants that use precision agriculture technologies indicated they had sufficient internet access to use those technologies. Despite this, many participants said that having faster, more reliable internet in some parts of their operation would be necessary in improving the reliability and accuracy of these technologies. Regarding data privacy, the majority of participants were not aware of the terms and conditions associated with using their technologies but had little concern about the privacy of their data. However, some participants were extremely worried about who has access to data collected on their operations and what is done with their data.

Discussion

Farmers' adoption of precision agriculture technologies, and the benefits farmers perceive from those technologies, is well established in the literature. On-farm precision experimentation (OFPE) can benefit both farmers and researchers; however, farmers' willingness to engage in OFPE has not been widely studied. OFPE enables researchers to expand their studies from trial plots to farmers' fields. The resulting collaborations between farmers and researchers can contribute to the wider conversation about management practices that can help farmers balance economic and environmental pressures. The interviews discussed in this study are an important first step in analyzing farmers' willingness to engage in OFPE and will serve as a pilot study for a survey to be designed and distributed to a larger and more diverse group of farmers. This survey will give a more generalized view of the perspectives of the broader agriculture community, with the ultimate goal of helping fill the knowledge gap about OFPE. The results from the pilot study and survey will provide researchers with the tools to help them effectively collaborate with farmers to produce research findings that are of benefit to the wider agricultural community.

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Figures

1) How long have you been farming? Do you own or rent the ground? What types of crops do you grow?
2) How long have you used these technologies? What technologies do you use?
3) What benefits do you get from using precision agriculture technologies? Are there any negatives to using these technologies?
4) What comes to mind when you hear the term "on-farm precision experimentation?"
5) Have you done any "informal" experiments using precision technologies?
    a. If YES
        i. What was the goal of your experiment(s)?
        ii. How many acres did you dedicate to the experiment(s)?
        iii. How did you determine if the experiment(s) were effective?
        iv. Did you work with any researchers or crop consultants on the experiment(s)?
        v. What technology/technologies did you use to conduct the experiment(s)? Which technology/technologies were most effective and why?
    b. If NO
        i. Have you ever tried on-farm experimentation? If so, why did you not continue to conduct experiments?
        ii. What would encourage or motivate you to conduct on-farm experiments?
            1. Would the availability of a PA technology affect your decision to conduct experiments?
6) Do the precision technologies that you use require internet connection? Do you have a reliable internet connection to use these technologies?
7) Does access to internet affect your decision to use a precision technology? What about your decision to conduct OFPE?
8) In using a precision technology, would you be comfortable or willing to share data with a technology provider? If a provider had direct access to the data, would that cause any concerns on data privacy?
9) When you work with a university researcher/extension agent, how involved are you in the process? Do they keep you involved throughout the process?
10) What is your perception of university research trials on trial plots? Do you believe they have any relevance to your operations?
11) When the trials are completed, how do you get the results?
12) Would you be willing to work more closely with university researchers/extension agents to conduct OFPE?

Figure 1: Farmer interview script.

CHAPTER III: FARMERS' PERCEPTIONS OF AND INTEREST IN CONDUCTING ON-FARM PRECISION EXPERIMENTATION

Abstract

Precision agriculture technologies have revolutionized the agriculture industry and provide many benefits to farmers. Among these benefits is the ability to conduct experiments in a process known as on-farm precision experimentation. By conducting these experiments and through collaboration with researchers, crop consultants, and extension agents, farmers can learn site-specific management practices to better address challenges in their operations. However, adoption rates of these technologies have remained below 50% in the U.S. Furthermore, very few studies have explored the factors that influence a farmer's decision to conduct experiments and collaborate with researchers, crop consultants, and extension agents. If these experiments are the future of agricultural research, farmers' views and willingness to conduct these experiments must be explored and understood. This study seeks to fill this literature gap by exploring farmers' perceptions of the work done by researchers, and their willingness to collaborate and conduct experiments. The results from this study indicate that farmers are already conducting experiments on their operations, but very few are collaborating with researchers, crop consultants, or extension agents to do them. If there is to be collective action to solve the challenges facing agriculture, collaboration between farmers and researchers is important. Additionally, there is a willingness amongst farmers to begin working with researchers, crop consultants, and extension agents to conduct these experiments, so long as researchers keep farmers engaged and informed throughout the research process.

Introduction

The agriculture industry relies on technological advancements to produce food, fuel, and fiber needed for a growing global population. Advancements in technology have revolutionized the agriculture industry in recent decades. One such advancement has been the introduction of precision agriculture technologies (PATs). From the first GPS-based guidance systems of the 1990s to the self-driving tractors and remote sensors of the future, the goal and promise of PATs has not changed: improve efficiency and increase profits through higher yields and lower input costs. PATs offer many additional benefits to farmers, the environment, and the agricultural community, one of which is the ability of farmers to conduct experiments on their own operations. In a process known as on-farm precision experimentation (OFPE), researchers and farmers collaborate together to conduct research experiments on farms. This is beneficial for both farmers and researchers because it fosters relationships and knowledge-sharing to address economic and environmental challenges facing farmers (Krmenec & Stelford, 2022). Furthermore, farmers can benefit from conducting OFPE by learning new production techniques and site-specific management practices to help balance economic pressures and environmental challenges.

Despite the benefits of PATs, adoption rates of these technologies in the United States have remained relatively low (Schimmelpfennig, 2016; McFadden et al., 2023). Many farmers have yet to realize the benefits of these technologies, including the ability to conduct OFPE. Furthermore, there is skepticism amongst some in the agriculture industry towards researchers, particularly towards researchers that attempt to conduct experiments and answer questions without consulting farmers and their knowledge. Some studies have sought to understand why adoption rates of PATs are low and the factors that influence their adoption (Pierpaoli et al., 2023; Tey & Brindal, 2022). Additional studies have also looked at how collaboration with farmers is necessary if more researchers are going to be conducting OFPE in the future (Tao et al., 2019). One thing missing from the discourse on OFPE is a discussion of whether farmers are interested in conducting OFPE and the factors that influence a farmer's willingness to collaborate with researchers.

An overall needs assessment that explores topics such as motivating factors for farmers to conduct OFPE, and farmer perceptions of the work done by researchers on trial plots is a logical and necessary step to fill this literature gap. After interviews of 11 Illinois farmers revealed initial insights on PATs and OFPE, a survey was developed and distributed to a larger, more diverse group of farmers from several states. The survey asked respondents questions regarding their adoption of PATs, the benefits from using these technologies, potential concerns regarding data privacy, and their willingness to conduct OFPE with researchers. The responses to these questions, in addition to statistical analysis, provide a perspective into farmers' views on OFPE and collaboration with researchers. The results from this study will help researchers further understand how to collaborate with farmers and conduct OFPE.

Literature Review

For as long as precision agriculture technologies (PATs) have been utilized by farmers, researchers have explored the impact of these technologies on the agriculture industry. The literature on the adoption of PATs can be divided into two groups: farmer perceptions of PATs, and the characteristics/factors that influence a farmer's decision to adopt a new PAT on their operation.

Perceptions of Precision Agriculture Technologies

Batte & Arnholt (2002) surveyed farmers in central Ohio to determine the types of technologies adopted, and how respondents viewed these technologies. The study found that 84.6% of respondents had adopted soil sampling, 73% had adopted variable rate technology (VRT) to apply fertilizers or lime, 27.5% had adopted a combine yield monitor, and only 12% had adopted a GPS receiver to utilize autosteer. Nearly 84% of respondents believed that having precise knowledge of soil nutrient and pH levels was very important, in addition to a reduction in lime usage, increases in crop yields, and a reduction in fertilizer application. All of these benefits were made possible because respondents had adopted PATs on their operations.

Thompson et al. (2019) conducted a survey that explored farmers' views on various PATs. The results from the survey showed high rates of adoption for various technologies, with 93% of respondents using yield monitors, 91% using autosteer, and 73% using variable rate technology (VRT) fertilizer application. Cost savings and yield improvements were two of the most compelling reasons for respondents adopting PATs. VRT for fertilizer application was seen as most likely to increase yield and reduce production costs (29%), while 30% of respondents believed guidance and autosteer technologies were most likely to increase convenience. Furthermore, yield monitors were least likely to increase yields and reduce production costs, while VRT fertilizer application was least likely to increase convenience.

Ofori & El-Gayar (2021) collected nearly 45,000 posts and content from various social media websites to further analyze farmer perceptions of PATs. Some of the factors that drove users to adopt PATs include government policies, trade opportunities, and the potential for new jobs and employment opportunities while some of the challenges identified including data ownership/privacy, cost and complexity, and educational resources. These results show that adopters of PATs have positive views of these technologies but have identified some potential challenges and drawbacks to using and/or adopting new technologies in the future.

Boehlje & Langemeier (2022) analyzed the benefits that PATs offer to farmers, the environment, and the agricultural community as a whole, and found that one of the most "direct and obvious payoffs" of PATs is the improved ability to monitor soil characteristics and weather (p. 46). Using PATs such as drones/unmanned aerial vehicles and satellite imagery, farmers can better identify areas in fields where fertilizer could be used more efficiently, or where pest infestation is present. Additionally, using PATs provides valuable information that can help farmers negotiate rent agreements with a landowner (Boehlje & Langemeier, 2022). For the environment, PATs such as variable rate technologies can provide a direct benefit by helping reduce over-application of fertilizer.

Factors Influencing the Adoption of Precision Agriculture Technologies

Schimmelpfennig (2016) analyzed PAT adoption trends and how farm profits affect a farmer's decision to adopt PATs. The report notes that adoption rates of PATs are usually slow in the beginning and eventually increase later, due to the time needed to learn a new technology. While PATs can help farmers reduce the over-application of inputs (i.e., seeds, fertilizers, fungicides), these technologies can also help increase yield and profits. Approximately half of all corn farms (49%) and soybean farms (51%) in the U.S. adopted yield monitors, while guidance systems, yield maps, and variable rate technology (VRT) were adopted on between 20-30% of those same farms. These adoption rates for corn and soybean-planted acres are significantly higher than the adoption rates for wheat, cotton, rice, and peanut acres. GPS mapping and guidance systems (i.e., autosteer) are often adopted by themselves, while VRT is often adopted with other technologies. The report also found that larger operations are more likely to adopt

PATs, with farms over 3,800 acres in size having the highest adoption rates of GPS soil/yield mapping, guidance systems, and VRT, while farms below 1,300 acres have adoption rates less than 40%.

McFadden et al. (2023) discussed how digital agriculture (DA) has changed the way farmers adopt and utilize PATs, and the data collected by these technologies. DA technologies and tools (i.e., automated robots and data analysis tools) can be used with site-specific technologies (i.e., yield maps) to help improve the effectiveness of conventional PATs (e.g., VRT, yield monitors, and guidance maps) utilized across the U.S. Corn and soybean acres planted using yield maps have the highest adoption rates (~45%) than other crops such as wheat, cotton, and rice. Corn and winter wheat acres utilize yield monitors to track moisture content during harvest, while soybean, cotton, and sorghum acres utilize yield monitors to determine chemical input usage. The report noted that adoption of variable rate technologies (VRT) tends to follow a common trend: larger farms adopt VRT at higher rates than smaller farms. Data showed that approximately 37% of corn acres and 26% of soybean acres utilized VRT, while 22.7% of cotton acres were planted using VRT. Guidance systems remain the most adopted PATs across all crop acres, with nearly 60% of corn acres and 55% of soybean acres utilizing guidance systems, while sorghum acres had the highest rate of adoption at 72.9%. McFadden et al. (2023) also explored factors that influence adoption, giving special attention to factors that have been under-examined, such as technology costs, which can present a potential barrier to adopting a new technology. The report showed that the average annual fee for soybean acres to utilize a yield monitor is $1,041, the average annual fee for a guidance system is $1,154, and the average premium for utilizing VRT is $5,630. These costs could be prohibitive for some farmers, especially those with smaller operations. Corn and soybean farmers that have adopted yield maps, soil maps, variable rate seed application, variable rate fertilizer application, guidance systems, and drones/UAVs all have higher expected yields than non-adopters.

Pierpaoli et al. (2013) conducted a literature review to examine the factors that are often cited by farmers to increase the probability of adoption. Among ex-post (after PAT adoption) studies, the most relevant factors identified were farm size, costs reduction, total income, land tenure, farmer education, familiarity with computers, access to information, and a farmer's location. The typical adopter of PATs is an educated farmer, who owns a farm with good soil quality, and is striving to implement production practices that improve productivity. Furthermore, the adopter is already comfortable with using computers, but hires consultants and views PATs in terms of improving profitability for their operation. The ex-ante (before PAT adoption) studies found that the main motivation among potential adopters is increasing profitability for an operation, while the desire to integrate new technologies also influences a farmer's decision to adopt. The presence of PAT experts also emerged as a factor, which allows farmers to have access to resources to learn technologies and use them to the fullest potential.

Tey and Brindal (2022) conducted a meta-analysis to uncover several of the underlying factors influencing PAT adoption. The analysis found that socio-economic factors (education and farm income), farm and agro-ecological factors (cropped farm size and yield), an informational factor (access to consultants), and technological factors (whether a farmer uses a computer and perceived profitability of PATs) influence a farmer's decision to adopt PATs on their operation.

D'Antoni et al. (2012) analyzed the adoption of autosteer technology among cotton farmers across 12 southern U.S. states. The results show that farmers who indicated a high importance of PATs over the next five years were 10.3% more likely to have adopted autosteer, while finding that a positive perception of PATs and perception of cost savings from utilizing

PATs also increase the likelihood of adoption. The study also found that the size of a cotton picker and the age of a cotton farmer significantly affect adoption of autosteer technologies. As the size of a cotton picker increases from four rows to five rows, the likelihood of adoption increases by 7.5%. In contrast, as a cotton farmer gets older, their likelihood to adopt autosteer decreases 0.1%. Furthermore, cotton farmers that prefer cost savings over other benefits of PATs, and who believe PATs will be important in the future, are more likely to adopt autosteer.

Watcharaanantapong et al. (2014) also studied the adoption of PATs by cotton farmers to understand the factors that influenced early adopters of grid soil sampling, yield monitors, and remote sensing. The results from this study demonstrated that older farmers adopted grid soil sampling and yield monitors later than younger farmers, while farmers that used computers for farm management adopted these technologies sooner than those who did not use computers. Farmers who also believed that PATs are important and improve profitability adopted yield monitors earlier. However, farmers that believed PATs help improve environmental quality adopted all three technologies earlier. The only farm characteristic that had any effect on adoption was land tenure, with results showing that farmers who rented all the land they operate adopted the technologies later than the farmers that owned their farmland.

Gardezi and Bronson (2020) analyzed the effect of social factors and farmer identity on PAT adoption. Farmers that were concerned about flooding were 13% more likely to utilize PATs on their operations, but farmers more concerned with soil erosion were 8% less likely to adopt PATs. In addition, farmers were less likely to utilize PATs if they own all the land they operate, while farmers that rented all of the land they operate were more inclined to adopt and utilize PATs. Farmers that had higher levels of education, and who had more diverse operations (i.e., livestock and crops, or more than two crop enterprises per year) were more likely to adopt

PATs. Furthermore, larger farms and higher farm sales also increased the likelihood of a farmer utilizing PATs. The study found that higher levels of daily and seasonal precipitation, and drought conditions also increase the likelihood of PAT use by 10%, 23%, and 16%, respectively.

Kolady et al. (2021) conducted a survey of South Dakota farmers to determine how different technologies are adopted by farmers. The study divided PATs into two groups: embodied-knowledge technologies (those that do not require specific skills to fully utilize them) and information-intensive technologies (those that require interpretation by a farmer) (Miller et al., 2019). The study found that the average age of the respondents was 59.5 years old, with 45.6% having a college education, and the average farm size was 771.1 acres. The results show that embodied-knowledge technologies were adopted more than information-intensive technologies. In total, 73.7% of respondents adopted autosteer and 75.8% adopted GPS guidance systems (both embodied knowledge). In contrast, 68.7% of respondents adopted yield monitors, 50% adopted variable rate technologies, and 30.8% adopted aerial/satellite imagery (all information-intensive). The study further found that larger farms are more likely to adopt both types of PATs Additionally, farmers who perceive that PATs will increase profitability are more likely to adopt both types, while farmers who are familiar with computers are more likely to adopt information-intensive technologies.

Data Privacy Concerns

PATs collect many different types of data, including geospatial (i.e., site-specific yield data), metadata (i.e., application dates and planting depths), and telematics (i.e., machinery diagnostics). Data privacy and the potential misappropriation of data present issues that farmers must consider when deciding to adopt a new PAT for their operations. Miller et al. (2018) analyzed the potential value of on-farm data collected by PATs in the context of misappropriation by a technology/service provider. The general consensus among many in the agricultural community is that on-farm collected data is completely controlled by the farmer. While farmers benefit from the data collected on their operations, technology/service providers have access to and collect substantial amounts of data from countless users of their technologies. For these providers, the value of accumulated data can come from data analytics services to individual farmers, or from selling raw data to interested third parties.

Ellixson et al. (2019) analyzed the legal implications that arise from on-farm collected data. The authors noted that farm data is not covered by intellectual property laws, potentially leaving farmers with few options for legal protection. The study further noted that the value of aggregated farm data is significant because of billions of dollars in investments from agribusiness and technology firms over recent years in data aggregation and analytics tools. The study also described three different types of farm data: data collected on a farm by a farmer, data collected by someone other than a farmer (i.e., a crop advisor), and data collected by an outside third party. The authors further noted a lack of clarity on who has the right to access and use farm data. However, there may be some protections for farmers and their data under trade secret laws, but this has yet to be clarified.

Wiseman et al. (2019) surveyed Australian farmers to understand their views on data access and privacy. Nearly 75% of respondents did not know much about the terms and conditions of the technologies they utilized on their operations. Approximately half of the respondents would be uncomfortable with a technology/service provider having direct access to the data collected by their technology. Two-thirds (67%) of respondents did not feel comfortable with a technology/service provider selling on-farm collected data for a profit, and 56% of respondents have little to no trust in a technology/service provider to maintain the privacy of on-farm collected data and not share it with a third party.

Wachenheim et al. (2023) surveyed North Dakota farmers and ranchers to explore their perspectives on data privacy. Approximately 75% of respondents were comfortable sharing on-farm collected data with crop insurance agents, and 73% of respondents were comfortable sharing on-farm collected data with a service provider (i.e., a crop consultant). If a respondent receives an incentive from the sale of on-farm collected data (i.e., receiving a share of the profits), 48% of respondents would be uncomfortable sharing their data with a third party. If a respondent does not receive some kind of incentive from the sale of on-farm collected data, then nearly 82% of respondents were uncomfortable sharing their data with a third-party. Forty-eight percent of respondents stated that data security had a strong level of influence on their decision to adopt a new PAT. These results demonstrate that there are concerns among farmers when it comes to data privacy, and that farmers do not trust technology/service providers to adequately protect on-farm collected data.

On-Farm Precision Experimentation

The literature exploring on-farm precision experimentation (OFPE) and the characteristics that influence farmers to collaborate with researchers is limited, with only a handful of studies exploring OFPE. Even fewer studies have defined what OFPE is and the benefits it provides to farmers, researchers, and the agricultural community as a whole. Lacoste et al. (2022) defined OFPE as “an innovati[ve] process that brings agricultural stakeholders together around mutually beneficial experimentation to support farmers’ own management decisions” (p. 2). The authors outline three pillars based on the long-standing history of farmer engagement in research: the experiments occur on a farmers’ own fields, the interest of farmers is acknowledged to build a relationship with researchers, and researchers work jointly with farmers to conduct the experiments. The authors also noted the benefits to farmers, including the value created by learning new production techniques to improve their operations. In addition, OFPE is driven by the demand and motivation of farmers to gain information that is directly relevant to their operations and the production practices they employ.

Thompson and Thompson (1990) explored the collaborative approach to research employed by the Practical Farmers of Iowa (PFI). Established in 1985, the PFI conducts experiments using on-farm research plots that provides farmers with information on environmentally sound and profitable farming practices and connects farmers with researchers to further explore various aspects of sustainable agricultural practices. Rosmann (1994) noted that farmers have long worked with researchers at land-grant universities (LGUs) across the United States since their establishment in 1862. Farmer input into research design was a crucial part of the work done by researchers, but many farmers became skeptical of research done at LGU research farms. Despite these challenges, farmers play a significant role in LGU research experiments, and farmers across the United States still engage in collaborative research.

It is important to understand how farmer participation in research can help inform farmers of new production practices and techniques. Gerber (1992) defined and explained an adaptive model that incorporates farmers into the research process at nearly every level to produce relevant information for farmers. This participatory model shows how farmers can be involved in the various steps of the research design and experimentation process. For example, all relevant partners (farmers, researchers, community leaders, etc.) must be included in the process to determine issues that are facing the agricultural community and how an experiment can provide information to deal with these issues. Gerber warned researchers to not change or alter the research question, so that the ideas and input by farmers are not altered in any significant way. In addition to this, the proposed model stresses the importance of sharing the results with the relevant parties at the end of the experiment. This is the most essential element because it is where farmers can learn, provide their perspectives, and share their views with others through a farmer-researcher network.

Tao et al. (2019) described the benefits of farmer-researcher networks and how the structure of these networks can be tailored to meet the needs of a particular group. A farmer-researcher network provides a structured platform for learning, information exchange, and communication between farmers and researchers to develop, design, conduct, and discuss the results of on-farm experiments and share new ideas and perspectives. The proposed model includes many different groups and elements that can all contribute to successful on-farm experimentation, such as a scientific committee, a farmer advisory committee, and a support committee. A well-organized farmer-researcher network can be a powerful tool to help farmers learn about new production practices and foster new relationships between farmers and researchers.

Longchamps (2022) conducted interviews with ten crop farmers in New York state to determine if farmers were conducting experiments on their operations and how to inform more farmers about the benefits of conducting OFPE. All of the participants were conducting experiments on their operation, demonstrating that farmers are always looking to try new methods and production practices on their operation. The author found that respondents do not keep extensive data records that would aid farmers in determining the results from their experiments. The interviews also revealed that farmers must dedicate a significant amount of time to design, implement, and interpret the results of an experiment. However, the interviews also show that the respondents are methodical about the research design and implementation, indicating that farmers are serious about conducting these experiments These interviews of New York State farmers demonstrate that farmers are interested in conducting experiments on their operations, and many of them are already doing experiments by themselves.

Methodology

Following the completion of a pilot study, an online survey was designed and distributed (Illinois State University IRB-2022-365) utilizing the Qualtrics survey platform, which was open for 94 days. To reach a diverse group of farmers, different agricultural organizations were contacted and agreed to distribute the survey. These organizations were the Logan County and McLean County IL Farm Bureaus, the Missouri Farm Bureau, the U.S. Rice Producers Association, and the Ohio State University Extension's eFields Program. Members of these organizations were primarily invited to participate through either an email or a newsletter sent to them by the organization, which contained a link to the survey. The Logan County Farm Bureau does not communicate with its members by email, so its members received a mailed postcard from the organization's office, which contained the survey link and a QR code to the survey. The questions in the survey addressed respondents' demographics, their adoption of precision agriculture technologies, the perceived benefits from using these technologies, internet reliability and data privacy concerns, status of conducting experiments on their operations, views of the work done by researchers, and level of interest in conducting OFPE. The survey contained a total of 36 questions. It is important to note that not every respondent was presented with every question. For example, respondents that have not adopted PATs on their operations were not shown any questions regarding PAT adoption and the benefits of using these technologies. This was done using skip logic in Qualtrics. One-hundred and two (102) responses to the survey were received. Excluded from this analysis were respondents that operate livestock-only farms or who were non-farm operators, and responses that were incomplete. Once these responses were excluded, a total of 78 valid responses remained. Analysis was conducted using SPSS version 29.0.0.0.

To understand the relationship between a respondent conducting experiments on their operation with several explanatory variables, two types of statistical tests were conducted. The dependent variable used for these tests was whether a respondent conducts experiments on their operations, while the independent variables used were land tenure (rent/own), farm size (less than 1,000 acres/more than 1,000 acres), age (younger than 55/55 or older), years of farming experience (less than 30/30 or more), education (less than a Bachelor's degree/Bachelor's degree or higher), years of experience using PATs (15 or fewer/more than 15), whether a respondent is on the "leading edge" of PAT adoption (yes/no), whether a respondent believes that PATs have significantly contributed to their operation's profitability (agree/disagree), whether a respondent believes PATs have helped them make better decisions for their operation (agree/disagree), and whether a respondent believes PATs have made their role as a farm manager easier (agree/disagree). These dependent variables were modified from the raw data to binary categories. A Chi-square test of independence was conducted to determine if a statistically significant relationship exists between whether a respondent conducts experiments and the independent variables (Zibran, 2007).

To further understand the nature of a statistically significant relationship, a binary logistic regression test was conducted. A binary logistic regression is highly effective at allowing a researcher to estimate the probability that an event will occur (Sweet & Grace-Martin, 1999). A binary logistic regression reports a regression coefficient (log odds) for each independent variable, in addition to an odds ratio. The odds ratio indicates “how many more times higher the odds of occurrence are for each one-unit increase in the independent variable” (Sweet & Grace-Martin, p. 161). For example, an odds ratio for the farm size variable of 1.210 indicates that as a respondent’s farm size increases, the odds of the respondent conducting experiments on their operation increases by a factor of 1.210. In order to interpret the log odds, the figure must be converted to probability. Sweet & Grace-Martin (1999) used the equation below to calculate probability from the odds ratio.

$$Probability = \frac{Exp\ (A + B(X))}{1 + Exp(A + B(X))} \tag{1}$$

In the equation, *A* represents the regression coefficient for the model’s constant, *B* is the regression coefficient for an independent variable, and *X* is the coding used for a particular variable. Using the example of the farm size variable, a calculated probability of .49 indicates that the probability of a respondent with a farm size 1,000 acres or larger conducting experiments is .49.

Results and Discussion

Demographic Results

At the beginning of the survey, all respondents were asked in which sector of agriculture they were involved, the crops they grow on their operations, and what state the largest portion of their operation is located in. Of the 78 respondents, 61 (60.4%) farm only row crops/vegetables and 17 (16.8%) raise livestock and grow row crops/vegetables. Respondents were asked to select all of the crops they grow on their operation, with 76 respondents growing soybeans, 75 growing corn, and ten growing wheat. A large majority of the respondents (61) are in Illinois, with nine respondents from Missouri, five from Ohio, one from Indiana, and one from Iowa.

At the end of the survey, respondents were presented with a final set of demographic questions. The results from these questions are shown in Table 1. Nearly 57% of respondents are between the ages of 55 and 74, which is somewhat similar to the national average age of 57.5, and the Illinois state average of 58.0 from the 2017 Census of Agriculture (USDA NASS, 2019). Approximately 30% of the respondents are in the 65-74 age range, indicating these respondents are older than the national average. When asked about their highest level of education, 52% of the respondents have a bachelor's degree, with 23% having either an associate degree or some college education. Approximately 58% of the respondents have 30 or more years of farming experience, which is significantly more than the U.S. Census of Agriculture average of 23 years, and the Illinois state average of 26.1 years (USDA NASS, 2019). Another area where the respondents differ from the Census of Agriculture is in farm size. According to the Census of Agriculture, the average farm size in the U.S. is 441 acres, with the Illinois state average being 372 acres. However, only 8% of survey respondents have farms between 250-499 acres. In stark contrast to the national average, 47% of the respondents have farms in the 1,500-1,999 acres range, with 27% of respondents having farms with 2,000 or more acres. The Census of Agriculture data showed that only 2.72% of U.S. farms have 2,000 or more acres of harvested cropland with only 4.29% of Illinois farms having 2,000 or more acres. Respondents were further asked about the tenure of the land they operate. Forty-two percent of respondents indicated they are full owners of the land they operate, and nearly 55% either share rent or cash rent a majority of the land they operate. This result also differs from the Census of Agriculture, which reported that 60.53% of U.S. harvested cropland acres and 49.43% of Illinois harvested cropland acres are operated by full owners. Furthermore, 39.46% of U.S. harvested cropland acres and 50.57% of Illinois harvested cropland acres are operated by part owners or tenants (USDA NASS, 2019).

Table 1: Respondents' Demographic Characteristics

Age (n=64)	*Number*	*%*
25 or younger	0	0
25-34	4	6.3
35-44	11	17.2
45-54	11	17.2
55-64	17	26.6
65-74	19	29.7
75 or older	2	3.1
Level of education (n=64)	*Number*	*%*
Some high school	0	0
High school diploma/GED	7	10.9
Associate degree/some college	15	23.4
Bachelor's degree	33	51.6
Master's degree or higher	9	14.1
Years of farming experience (n=64)	*Number*	*%*
5 or fewer	4	6.3
6-10	2	3.1
11-15	6	5.9
16-20	4	3.9
21-25	6	9.4
26-30	5	7.8
30 or more	37	57.8
Land tenure (n=64)	*Number*	*%*
Owned	27	42.2
Cash rent	17	26.6
Shared rent	18	28.1
Other	2	3.1
Farm Size (n=64)	*Number*	*%*
Less than 250	6	9.4
250-499	5	7.8
500-749	7	10.9
750-999	10	15.6
1,000-1,499	5	7.8
1,500-1,999	13	20.3
2,000 or more	18	28.1

Precision Agriculture Technologies

Respondents were asked a series of questions about their adoption of precision agriculture technologies. Table 2 illustrates survey respondents' adoption of specific precision agriculture technologies. Respondents have overwhelmingly adopted yield monitors (93%), autosteer/GPS technologies (88%), variable rate seeding/fertilizer application technologies (80%) (VRT), and precision soil sampling (71%). Only 3% of the respondents do not utilize any precision agriculture technologies. These results are similar to the findings of Thompson et al. (2019), whose respondents reported adoption rates of 93% for yield monitors, 91% for autosteer, 73% for VRT seed, 60% for VRT fertilizer, and 66% for soil sampling. Other studies of precision agriculture technology adoption show lower levels of adoption, but they are older than Thompson et al. (2019) and this study. For example, Batte and Arnholt (2002) found that 28% of their respondents adopted yield monitors, and 73% adopted VRT. Schimmelpfennig' s (2016) USDA report found that 48% of corn farms and 51% of soybean farms had adopted precision agriculture technologies, while 45% of all corn and soybean acres adopted guidance systems, and 23% of the same acres used VRT. A more recent study also presented different results from this survey. McFadden et al.'s (2023) USDA report found that GPS technologies were used on 40% of all cropland acres in the U.S., while ~45% of all corn and soybean acres adopted yield maps, and only 20% and 15% of corn and soybean acres adopted soil mapping. McFadden et al. (2023) additionally found that only 25.3% of soybean and 37.4% of corn acres adopted VRT.

In addition to what technologies they have adopted, survey respondents were asked how long they have utilized precision agriculture technologies (PATs) and the barriers to adopting these technologies. Sixty-three percent of the respondents have been using PATs between 5 and 15 years, with 37% using these technologies for 5-10 years. This shows that while these respondents are older and more experienced, they have been using PATs for a relatively short period of time. When asked what barriers would prevent them from adopting a new PAT, 89% of the respondents selected cost as the most significant barrier, with the time needed to learn a new technology in second with 45%. Respondents were presented with three statements and were asked to rate their level of agreement with these statements, with the results shown in Table 3. Nearly all of the respondents (83%) either somewhat or strongly agree that PATs have significantly contributed to their operation's profitability, while 85% agreed that they have made better decisions because of PATs, and 76% agreed that their role as a farm manager has been made easier because of PATs. These results are somewhat similar to Thompson et al. (2019), who found that 88% of their respondents agreed that PATs are important contributors to their operation's profitability, 80% stated they were better farm managers because of PATs, and 77% of respondents agreed that PATs have made their role as a farm manager easier.

The section on precision agriculture technologies concludes by asking respondents to rank the benefits of using PATs that they have adopted, as shown in Table 4. The technologies a respondent chose at the beginning of the survey were displayed for this question. This means that some technologies may have more cumulative rankings than others depending on how many respondents utilize those technologies. *Cost savings* (21) and *access to data for better decision making* (19) received the most #1 rankings, while *yield improvements* received the most #2 rankings with 34. Respondents were further asked to rank which PAT would be the most important over the next decade. Autosteer/GPS technologies were ranked as the most important, with 26 respondents ranking it #1, while yield monitors and variable rate fertilizer/seeding technology received 12 #1 rankings.

Table 2: Respondents' Adoption of Precision Agriculture Technologies

Precision agriculture technologies adopted by respondents (n=73)	*Number*	*%*[1]
Yield monitor	68	93.15
Autosteer/GPS	64	87.67
Variable rate seeding/fertilizer application technology	58	79.45
Precision soil sampling	52	71.23
Satellite imagery	40	54.79
Drones/unmanned aerial vehicles	20	27.40
Other	4	5.48
Do Not Use PATs	2	2.74

Respondents' years of experience using precision agriculture technologies (n=71)	*Number*	*%*
Less than 5	3	4.2
5-10	26	36.6
11-15	19	26.8
16-20	12	16.9
More than 20	11	15.5

Barriers to respondents' adoption precision agriculture technologies (n=65)	*Number*	*%*[2]
Cost	58	89.23
The time needed to learn the technology	29	44.62
A lack of reliable internet connection	22	33.85
Concerns regarding data privacy	19	29.23
Other	2	3.08

[1] Percentages may add up to more than 100% because respondents were able to select more than one technology.

[2] Percentages may add up to more than 100% because respondents were able to identify more than one barrier.

Table 3: Respondents' Agreement with Statements Regarding PATs

	Strongly Disagree	*Somewhat Disagree*	*Somewhat Agree*	*Strongly Agree*
Precision agriculture technologies have significantly contributed to my operation's current profitability. (n=70)	11.43%	5.71%	51.43%	31.43%
I have made better decisions for my operation because of precision agriculture technologies. (n=71)	5.63%	9.86%	42.25%	42.25%
My role as a farm manager has been made easier because of precision agriculture technologies. (n=69)	5.80%	15.94%	28.99%	49.28%

Table 4: Rankings of the Benefits of Using PATS[1]

Benefit (n=64)	*1*	*2*	*3*	*4*	*5*
Cost savings	32.81%	23.44%	25%	18.75%	0%
Access to data for better decision making	26.69%	14.06%	15.63%	37.5%	3.13%
Yield improvements	18.75%	53.13%	21.88%	4.69%	1.56%
Convenience	17.19%	46.88%	35.94%	35.94%	6.25%
Other	1.56%	4.69%	1.56%	3.13%	89.06%

[1]Ranking Scale: 1-Most Important, 5-Least Important

Internet Reliability and Data Privacy Concerns

Respondents were additionally presented questions regarding internet reliability and concerns on data privacy. One aspect of precision agriculture technologies that is often not explored or discussed is the amount of data that is being collected and stored. This data has significant value not only for farmers, but also for technology/service providers, researchers, and others (Ellixson et al., 2019). The value of this data, combined with a general lack of legal and regulatory protections, can put farmers in a precarious situation with data privacy and security. Survey questions addressing data privacy concerns were adapted from Wiseman et al. (2018). As illustrated in Table 5, nearly 75% of respondents have a reliable internet connection to use with their PATs. This result differs from a U.S. Federal Communications Commission report from 2020 that found 81.7% of rural Americans lack reliable internet (FCC, 2020). Respondents were also presented questions regarding their familiarity with the terms and conditions of using PATs. A majority of respondents (nearly 60%) were either somewhat or very familiar with the terms and conditions to use their PATs. Wiseman et al. (2019) found that 74% of their respondents in Australia did not know much about the terms and conditions of the technologies they utilize. Roughly 47% of respondents were either somewhat or very uncomfortable with a technology/service provider accessing on-farm collected data. This is similar to Wiseman et al.'s results of roughly half of their respondents feeling uncomfortable if a technology/service provider had direct access to on-farm collected data. In contrast to these results, a survey conducted by Wachenheim et al. (2023) found that 73.3% of North Dakota farmers would be comfortable sharing on-farm collected data with a service provider. Respondents were almost evenly split on their level of trust in a technology/service provider not accessing on-farm collected data, with approximately 49% having very little or no trust and approximately 51%

having somewhat or total trust. Approximately 55% of respondents have either no or very little trust in a technology/service provider not to share on-farm collected data with a third party. These findings are fairly consistent with Wiseman et al. (2019) and Wachenheim et al. (2023). Finally, respondents were asked about their willingness to share input or output data with a technology/service provider. As shown in Table 6, approximately 54% somewhat or very willing to share input data and 50% somewhat or very willing to share output data.

Table 5: Respondents' Internet Reliability and Data Privacy Concerns

Reliability of respondents' internet/cellular connection (n=67)	*Number*	*%*
No Connection	2	3.0
Connection not reliable enough to use PATS	15	22.4
Connection reliable enough to use PATs	50	74.6

Respondents' familiarity with the terms and conditions of using their PATs (n=67)	*Number*	*%*
Very Unfamiliar	14	20.9
Somewhat Unfamiliar	13	19.4
Somewhat Familiar	32	47.8
Very Familiar	8	11.9

Respondents' level of comfort with a technology/service provider accessing on-farm collected data (n=67)	*Number*	*%*
Very Uncomfortable	11	16.4
Somewhat uncomfortable	21	31.3
Neutral	16	23.9
Somewhat Comfortable	13	19.4
Very Comfortable	6	9.0

Respondents' level of trust in a technology/service provider not accessing on-farm collected data (n=67)	*Number*	*%*
No Trust	5	7.5
Very Little Trust	28	41.8
Somewhat Trust	30	44.8
Total Trust	4	6.0

Respondents' level of trust in a technology/service provider to not share on-farm collected data with a third party (n=67)	*Number*	*%*
No Trust	9	13.4
Very Little Trust	28	41.8
Somewhat Trust	25	37.3
Total Trust	5	7.5

Table 6: Respondents' Level of Willingness to Share Input or Output Data with a Technology/Service Provider

Input Data (n=67)	*Number*	*%*
Totally Unwilling	9	13.4
Somewhat Unwilling	22	32.8
Somewhat Willing	30	44.8
Very Willing	6	9.0

Output Data (n=67)	*Number*	*%*
Totally Unwilling	12	17.9
Somewhat Unwilling	21	31.3
Somewhat Willing	27	40.3
Very Willing	7	10.4

On-Farm Precision Experimentation

Finally, respondents were asked questions regarding their views of on-farm precision experimentation (OFPE) and their level of interest in collaborating with researchers to conduct these experiments. With a general lack of studies regarding farmers' views of OFPE and their willingness to engage in experimentation, the results from these questions are important for researchers looking to start or to expand OFPE networks with farmers. As shown in Table 7, a large majority of the respondents (78%) conduct experiments either every year or on occasion, demonstrating the potential for researchers to expand or start OFPE networks. Respondents that conduct experiments on their operations explore many different topics, including fertilizer rates, variable seeding/fertilizer application, and fungicide application. Nearly all (98%) of the respondents that conduct experiments find PATs beneficial in conducting these experiments. Over half of respondents that conduct experiments have never worked with a researcher, crop consultant, or extension agent to conduct these experiments. Respondents listed many benefits of conducting OFPE on their operations, including better management of inputs, cost savings, first-hand experience with new technologies and practices, and refining current production practices. Cost, time, and not seeing the benefits of conducting OFPE were most common reasons for respondents to stop or never conduct experiments. Additionally, 50% of respondents pay very close attention to research experiments conducted on trial plots. Nearly 50% of respondents were either somewhat or very interested working with researchers to conduct OFPE. If there is a desire to address the economic and environmental challenges farmers are facing on their operations, then collaboration and knowledge sharing between farmers and researchers is important. These results show that farmers are actively trying to address these challenges, but without collaboration, then little collective action can be taken by the agriculture industry.

To further understand potential ways to motivate more farmers to conduct OFPE, respondents that answered either uninterested, somewhat uninterested, or unsure were asked if a software tool that would help them create experiments would change their level of interest. As part of the USDA NRCS grant project entitled “Improving the Economic and Ecological Sustainability of U.S. Crop Production Through On-Farm Experimentation,” members of the project are creating a software tool that would help farmers and crop consultants create experiments on their operations. Roughly 63% of the respondents stated such a software tool would have either little or no effect on their willingness to engage in OFPE with researchers. To further understand whether certain features of a software would influence a respondent’s decision to adopt the software, respondents were given several point-counterpoint statements and asked to rate the impact of that statement on their decision to adopt. The results from this question are shown in Table 8. Overall, these results indicate that respondents are more likely to adopt and utilize a trial design software that is free to use and allows the prescription to be directly uploaded to their equipment. Respondents had mixed views on whether collaboration with a university researcher, extension agent, or certified crop advisor is required to utilize the software.

Table 7: Respondents' Views of On-Farm Precision Experimentation (OFPE)

Respondents' status of conducting experiments on their operations (n=69)	*Number*	*%*
Yes, every year	24	34.8
Yes, on occasion	30	43.5
No longer conduct experiments	9	13.0
Never have conducted experiments	6	8.7

Respondents that utilize PATs to conduct experiments. (n=53).	*Number*	*%*
Yes, always	34	64.2
Yes, sometimes	17	32.1
No	2	3.8

Are PATs beneficial in conducting the experiments? (n=50)	*Number*	*%*
Yes	49	98.0
No	1	2.0

Have you ever worked with a university researcher/certified crop advisor to conduct experiments on your operation? (n=52)	*Number*	*%*
Yes, always	4	7.7
Yes, sometimes	18	34.6
No	30	57.7

Respondents' views of research experiments conducted on trial plots (n=64)	*Number*	*%*
Respondent pays little to no attention to the findings	7	10.9
Respondent looks at the results but does not implement their findings	25	39.1
Respondent pays serious attention to the findings.	32	50.0

Table 7, continued

Respondents' level of interest in conducting OFPE with researchers (n=65)	*Number*	*%*
Uninterested	8	12.3
Somewhat uninterested	9	13.8
Unsure	16	24.6
Somewhat interested	21	32.3
Very interested	11	16.9

Level of effect a software tool has on a respondent's level of interest to conduct OFPE with researchers (n=33)	*Number*	*%*
No effect	7	21.2
Little effect	14	42.4
Some effect	11	33.3
Significant effect	1	3.0

Table 8: Characteristics of a Software Tool.

Characteristic (n=63)	*I would be less likely to adopt a software with this feature.*	*No effect on my decision to adopt.*	*I would be more likely to adopt a software with this feature.*
The software is free to use.	4	15	44
There is a fee/cost to utilize the software.	26	34	3
The prescription developed by the software can be uploaded directly to my current equipment.	2	13	48
The prescription cannot be directly uploaded to my current equipment.	45	16	2
The software does not require collaboration with a researcher/extension agent/certified crop advisor.	6	29	28
Collaboration with a researcher/extension agent/certified crop advisor is required to use the software.	27	30	6

Relationship Between Farmer Characteristics, Conducting Experiments, and Being on the Leading Edge

Chi-Square Test of Independence

The results shown in Tables 1-8 provide an overview of the demographic characteristics of the respondents, their adoption of precision agriculture technologies, their level of interest in conducting OFPE, and any potential concerns relating to data privacy. Further investigation is needed to determine which characteristics would make a farmer more willing to conduct OFPE on their operation. To do so, a Chi-Square test of independence was conducted to determine if a relationship exists between a respondent conducting experiments on their operation and various independent variables. The null hypothesis for the Chi-Square test was that conducting experiments is independent of the variables listed and, therefore, no relationship exists. The results from the test can be found in Table 9. Among the variables tested, a statistically significant relationship exists between a respondent being on the leading edge of PAT adoption, farm size, and land tenure with a respondent conducting experiments on their operation. Respondents who believe they are on the leading edge of PAT adoption are more likely to be conducting experiments on their operations (100%) than those who do not believe they are on the leading edge (69.8%. Respondents who have farms 1,000 acres or larger are more likely to conduct experiments (88.9%) than respondents who have farms less than 1,000 acres in size (67.9%). Respondents who rent a majority of the land they operate are more likely to conduct experiments (88.6%) than respondents who own a majority of the land they operate (67.9%). The remaining variables show a numerical tendency but are not statistically significant.

Table 9: Relationship Between Respondents Conducting Experiments on Their Operations with Other Variables

	Conducting Experiments on Their Operation	
Leading Edge of PAT Adoption[1]	Yes	No
Yes	100%	0%
No	69.8%	30.2%
Years of Experience Using PATs	Yes	No
15 or Fewer	79.5%	20.5%
16 or More	82.6%	17.4%
PATs have Significantly Contributed to Profitability	Yes	No
Agree	79.6%	20.4%
Disagree	83.3%	16.7%
PATs have Helped Make Better Decisions	Yes	No
Agree	82.5%	17.5%
Disagree	70%	30%
PATs have Made the Role as Farm Manager Easier	Yes	No
Agree	82%	18%
Disagree	80%	20%
Farm Size[2]	Yes	No
Less than 1,000 acres	67.9%	32.1%
1,000 acres or more	88.9%	11.1%
Land Tenure[3]	Yes	No
Own	67.9%	32.1%
Rent	88.6%	11.4%
Years of Farming Experience	Yes	No
Less than 30	77.8%	22.2%
30 or More	81.1%	18.9%
Age	Yes	No
Younger than 55	80.8%	19.2%
55 or Older	78.9%	21.1%
Education	Yes	No
Less than a Bachelor's Degree	90.9%	9.1%
Bachelor's Degree or Higher	73.8%	20.3%

[1] $(\chi^2(1) = 9.003, p < .05)$
[2] $(\chi^2(1) = 4.304, p < .05)$
[3] $(\chi^2(1) = 4.076, p < .05)$

Binary Logistic Regression

Following the Chi-Square test of independence, a binary logistic regression was conducted to understand the nature of the relationship between a respondent conducting experiments on their operation and the various independent variables. The results from this test are found in Table 10. The overall model was found to be statistically significant (χ^2 (10) = 23.496, $p < .01$), with a Nagelkerke R Square value of .532. Two variables in the model were found to be statistically significant ($p < .10$): land tenure and a respondent believing that PATs have helped make better decisions for their operation. To determine the possibility of a respondent conducting experiment based on the two significant independent variables, odds ratios and probability are utilized. Land tenure has an odds ratio of 9.045, indicating that a respondent who rents a majority of the land they operate is 9.045 times as likely to conduct experiments than a respondent who owns a majority of the land they operate. The calculated probability of a respondent who rents a majority of the land they operate to conduct experiments is .982. These results demonstrate that respondents who rent a majority of the land they operate are highly likely to conduct experiments on their operations.

For respondents who believe that PATs have helped them make better decisions for their operations, the odds ratio is 17.671, indicating that a respondent who agrees that PATs have helped them make better decisions for their operation is 17.671 times as likely to conduct experiments than a respondent who disagrees. For a respondent who believes that PATs have helped them make better decisions for their operation, the calculated probability of the same respondent conducting experiments on their operation is .991. These results show that respondents who believe that PATs have helped them make better decisions for their operation are very likely to conduct experiments on their operations. It is important to note that several independent variables were found to not be statistically significant, showing these variables are independent of a respondent conducting experiments on their operations. The high coefficient, standard error, and odds ratio for the leading edge of PAT adoption variable are also of interest. One possible explanation of these high figures is the difference between respondents who are on the leading edge and who conduct experiments. The number of respondents that do conduct experiments on their operation (54) is higher than the number of respondents who are on the leading edge of PAT adoption (29). Furthermore, there are more respondents that are on the leading edge and do not conduct experiments (6) or who are not on the leading edge and do conduct experiments (31) than respondents that answered yes (23) or no (7) to both questions. While this does not fully explain these high numbers, it does provide some idea as to why the numbers for this variable are higher than any other variable.

Table 10: Results From Binary Logistic Regression Test

Variable	Coefficient	Std. Error	Odds Ratio
Leading edge of PAT adoption[1]			
Yes	20.768	7492.966	1045788737
Years using PATs[2]			
More than 15	-1.814	1.277	.163
PATs have significantly contributed to profitability[3]			
Agree	-1.859	1.723	.156
PATs have helped make better decisions[4]			
Agree	2.872*	1.710	17.671
PATs have made role as farm manager easier[5]			
Agree	-1.304	1.514	.271
Farm size[6]			
1,000 acres or larger	.785	1.002	2.192
Land tenure[7]			
Rent	2.202*	1.250	9.045
Years of farming experience[8]			
30 or more	-.315	1.401	.730
Age[9]			
Younger than 55	-.408	1.419	.665
Education[10]			
Bachelor's degree or higher	-1.716	1.182	.180
Constant	1.818	1.977	6.161

**10% Significance Level, ** 5% Significance Level, ***1% Significance Level*

[1]*Leading Edge (base: No)*
[2]*Years Using PATs (base: 15 or fewer)*
[3]*PAT Profitability (base: Disagree)*
[4]*PAT Better Decisions (base: Disagree)*
[5]*PAT Easier Role (base: Disagree)*
[6]*Farm Size (base: less than 1,000 acres)*
[7]*Land Tenure (base: Own)*
[8]*Years of Farming Experience (base: Less than 30)*
[9]*Age (base: Younger than 55)*
[10]*Education (base: Less than a Bachelor's degree*

Conclusion

On-farm precision experimentation (OFPE) has been viewed as the future of agricultural research. By utilizing precision agriculture technologies (PATs) and through collaboration with university researchers, crop consultants, and extension agents, farmers can conduct experiments on their operations to learn new site-specific management practices that can help balance economic pressures and environmental challenges. There is a lack of literature that explores farmers' perceptions of OFPE, particularly their interest in conducting experiments on their operations and their views of the work done by researchers on university trial plots. This study seeks to fill this gap in the literature by surveying a diverse group of farmers to understand their views on OFPE, in addition to their perceptions of PATs, potential concerns regarding data privacy from utilizing PATs, and what factors influence their willingness to conduct experiments on their operation.

Respondents have overwhelmingly adopted PATs and believe that these technologies have provided many benefits to their operations. While most of the respondents were familiar with the terms and conditions of the PATs they utilize on their operation, they were still uncomfortable with a technology/service provider accessing on-farm collected data and had little to no trust in a technology/service provider to neither access on-farm collected data nor share the data with a third-party. Over 75% of the respondents conduct experiments on their operations every year or on occasion, but 58% have never worked with a university researcher, crop consultant, or extension agent to conduct these experiments. Further statistical analysis demonstrated that a respondent who rents a majority of the land they operate is more likely to conduct experiments on their operation. This result is interesting in that it appears to be counter intuitive. Conducting experiments on an operation can be time consuming and may also be risky for a farmer to implement. Due to this, one might believe that farmers who own a majority of the land they operate would be more likely to conduct experiments on their operations. A farmer who owns the land they operate does not have to worry about the continuation of a rent agreement or the relationship with the landowner, and thus might be more willing to take the risk of conducting an experiment. However, the results from this survey indicate the opposite. What motivations exist for farmers that rent a majority of the land they operate to conduct experiments? How does the relationship between a farmer and a landowner influence a decision to conduct an experiment? Is a competitive agricultural land market driving tenant farmers to try new practices to keep renting the land? These questions, and others, would need to be investigated further to understand why farmers who rent a majority of the land they operate are more likely to conduct experiments. Furthermore, a respondent who agrees that PATs have helped them make better decisions for their operation is more likely to conduct experiments. This result seems to align with the general perceptions of the benefits of PATs. For a respondent that is looking to make better decisions for their operations, and who utilizes information to help them make these decisions, conducting experiments would align with these goals. The PATs utilized by a respondent would be able to help implement the experiment but would also provide valuable information to a farmer. This information would help a farmer understand what they learned from the experiment, and how that information could influence their production practices moving forward.

The results from the survey show that farmers are already conducting experiments on their operations, and many are willing to collaborate with researchers and others to conduct these experiments. This demonstrates the ability of researchers to begin developing relationships with farmers to start conducting these experiments. Whether on a small scale with a smaller number of farmers, or on a large scale with many farmers and many experiments, researchers have the opportunity to begin conducting more experiments and building new farmer-researcher networks to expand these relationships and experiments. If researchers wish to do more of these experiments with farmers and build new farmer-researcher networks, then it is imperative for researchers to constantly involve farmers in the research process and develop experiments that are of interest to farmers. These results further demonstrate the importance of collaboration between farmers and researchers to conduct OFPE. Farmers are facing many different challenges and pressures on their operations, and in response, some are conducting experiments to understand how site-specific management practices can help them better address these challenges. By collaborating with researchers, farmers can share their experiences and knowledge gained from these experiments and help the agriculture industry collectively tackle these challenges and pressures in a way that benefits all.

While the information in this study is important to understand the factors that influence a farmer's decision to conduct experiments, there are limitations to the findings. The first limitation is the small number of respondents. Due to only 78 valid responses the survey, this does prevent assumptions from being reliably made for the overall farming population. However, this study does provide an insight of the perceptions that some farmers may have toward researchers and their willingness to conduct experiments on their operations. In addition, despite the majority of respondents being in Illinois, their demographics are different from the overall Illinois farming population. As noted in the Results section, the respondents to this study are older, operate larger operations, and have higher levels of education than the average Illinois farmer. This study also present opportunities for further investigation. One potential area for further investigation is how farm financial characteristics (i.e., annual receipts, business structure) influence whether a farmer conducts experiments on their operation. Geographic location and characteristics (i.e., soil type/quality, annual rainfall, drought concerns) can also be investigated to determine if they influence a farmer's decision to conduct experiments.

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CHAPTER IV: LITERATURE REVIEW

Precision agriculture technologies (PATs) have revolutionized the agriculture industry. Like other advancements over time, PATs have offered several benefits to farmers. The literature surrounding precision agriculture technologies is as old as the technologies themselves. As soon as the first precision agriculture technologies were made available for civilian use in the 1990s, researchers began investigating these innovative technologies and their effect on the agriculture industry, specifically analyzing how farmers viewed these technologies and the factors that influenced their adoption. A large amount of precision agriculture technology adoption literature can be divided into two groups: farmers' perceptions of precision agriculture technologies and the factors influencing a farmer's decision to adopt these technologies. In addition to the benefits explored in these numerous studies, farmers can conduct on-farm precision experimentation (OFPE) with researchers, crop consultants, and extension agents. These experiments can help farmers learn new management practices and bridge the gap between researchers and farmers. Researchers can further refine their experiments to be more adapted for farmers and improve their practices for future experiments. While the literature on PATs is extensive, the literature on OFPE is scarce with few studies analyzing the benefits of conducting OFPE and farmers' views on collaborating with researchers, crop consultants, and extension agents. This lack of literature demonstrates the need to further explore OFPE and farmers' views. To do this, interviews and surveys can all be employed as methods of discovering farmers' viewpoints and guide both farmers and researchers in conducting successful experiments in the future.

Perceptions of Precision Agriculture Technologies

Soon after the first precision agriculture technologies were introduced, researchers began exploring farmers' perceptions of these technologies and the benefits they receive from using them. Battle & Arnholt (2002) surveyed Ohio farmers to understand their adoption of PATs, and their views on the benefits of using PATs on their operations. A mail survey was distributed to 156 farmer-members of a central Ohio cooperative that sold PATs, with 62 farmers completing the survey. Nearly 85% of the respondents adopted georeferenced grid soil sampling, 73% adopted variable rate technology (VRT) to apply fertilizers or lime, 28% adopted a combine yield monitor, with other technologies (i.e., satellite GPS receivers, aerial satellite imagery, etc.) having very low rates or were not adopted by these respondents. When asked what benefits they received from using these technologies, respondents indicated that precise knowledge of soil pH levels and soil nutrient levels and increased average farm yield with decreased yield variability were the main benefits that they received (Battle & Arnholt, 2002).

Similar to the survey conducted by Batte & Arnholt, Thompson et al. (2019) surveyed crop producers across the United States by phone interviews, with 837 respondents participating. The results of this survey show high adoption levels of yield monitors (93%), autosteer (91%), and variable rate fertilizer application (73%), with drones/UAVs only being used by 25% of respondents. A significant portion of the respondents (88%) stated they believed PATs had positively contributed to their farm's financial profitability, with 80% stating PATs made them a better farm manager, and 77% indicating that PATs made their job as a farm manager easier when asked to decide the most compelling reason to adopt PATs in a pairwise decision. This meant that participants were given the options of cost savings vs. yield improvement, yield improvement vs. convenience, and convenience vs. cost savings. Fifty-one percent of respondents chose cost savings over yield improvement, 65% selected yield improvement over convenience, and 69% preferred cost savings over convenience. Participants were then split into two groups, with one group asked to determine which technologies were more likely to increase yields and reduce production costs, and the other group asked to determine which technologies were most likely to increase convenience. In the first group, 29% believed variable rate fertilizer application technology was likely to increase yields and reduce input costs, while 30% of the second group believed that guidance and autosteer increased convenience (Thompson et al., 2019). Overall, this study revealed that farmers are heterogenous in their perceptions of PATs, with their perceptions affected by the technologies they use.

Another way that researchers can understand farmers' views and perceptions of PATs is through social media. Ofori & El Gayar (2021) recognized that social media platforms have been used as tools for farmers and others in the agricultural industry to express their views, concerns, and issues. Using analytics software that looks at posts on platforms like Twitter, Reddit, and online forums, the authors found 45,000 posts and that address PATs between 2010 and 2019. Of these posts, 10,862 came from the United States, with only the United Kingdom, Kenya, Nigeria, India, Canada, and Australia, having more than 1,000 posts (Ofori & El Gayar, 2021). Overall, roughly 73% of the posts were positive. For posts that discussed the drivers of PATs, the most common topics were government regulations and policies, and automation. Posts that discussed the challenges were mainly focused on data ownership and privacy.

One additional study analyzed potential payoffs that producers, the value chain, and the environment can all receive from the use of PATs. Boehlje & Langemeier (2022) looked at these payoffs in a larger context, rather than the traditional view of cost savings and more efficient production. For producers, more precise knowledge and measurement of soil health and characteristics are the most logical benefits, but other long-term payoffs (i.e., enhanced documentation) can help producers make more money and increase the value of their operations. Better data and information regarding inputs and production practices can also benefit the value chain, which can help reduce supply chain shortages and disruptions thus strengthening the resiliency of the supply chain. More precise and efficient application of pesticides, fertilizers, and other inputs is one of the most cited environmental payoffs of using precision agriculture technologies. Additional payoffs can be found in areas where water supplies are at a premium, with PATs allowing for more precise irrigation at the right locations. While these payoffs have long gone unnoticed and the adoption rates of PATs have been low in the United States, the authors noted that adoption rates have been increasing in the last decade. These technologies offer a competitive advantage for the producers that use them, and farmers that have yet to adopt these technologies should evaluate whether it benefits their operation to adopt PATs (Boehlje & Langemeier, 2022).

Factors Affecting Decisions to Adopt

In the other group of literature, studies have uncovered many factors can affect a farmer's decision to adopt. Pierpaoli et al. (2013) noted the several studies that have analyzed the benefits that farmers receive from using these technologies and focus their study on the drivers that affect a farmer's decision to adopt PATs. To do this, the authors combined and compared ex-ante and ex-post analyses to have a more holistic view of these drivers. An ex-ante analysis looks through studies and literature that discuss the decisions of potential adopters of PATs, while an ex-post analysis focuses on studies that look at farmers that have already adopted a PAT to see what factors affected their decision. For their ex-ante analysis, the authors found that three features are positively correlated with a farmer's decision to adopt a PAT: usefulness, ease of use, and farm size. The authors noted that previous studies have shown that if either of the first two features are lacking (i.e., the technology is not useful or is difficult to use), then the likelihood of adoption is significantly decreased. Furthermore, the authors noted previous studies that have shown larger and more profitable farms are more likely to adopt PATs, and their findings align with these previous studies. In the ex-post analysis, the authors found that the factors having the most influence on adopting PATs are farm size, a desire to reduce costs/raise revenues, total income, the farmer's education, their familiarity with computers, and their access to resources to help them learn the technology. Overall, this analysis found that the typical adopter is an educated farmer that owns a large farm with good soil quality, is looking to implement more productive practices to face growing pressures, is comfortable using computers, and views PATs in terms of profitability (Pierpaoli et al., 2013).

Similar to Pierpaoli et al., Tey & Brindal (2022) conducted a meta-analysis that looked at many of the same factors. For this meta-analysis, the authors divided the factors into five groups: socio-economic, farm and agroecological, institutional, informational, and technological. The results from this analysis show that a farmer's education, a farm's income, the size of the farm, access to consultants, a farmer's prior use of computers, and perceived profitability of PATs have a significant impact on a farmer's decision to adopt PATs, with changes in yield having a slightly lesser impact (Tey & Brindal, 2022).

Other studies that analyze the factors that affect a farmer's decision to adopt PATs look to specific groups of farmers to see if these groups differ from the findings of the larger analyses like Pierpaoli et al. (2013) and Tey & Brindal (2022). Schimmelpfennig (2016) investigated recent trends in the adoption of PATs, particularly three types: GPS-based mapping systems, guidance/autosteer systems, and variable-rate technology (VRT). The results from their investigation showed that adoption rates vary significantly across the three groups of technologies, with yield monitors being the most commonly adopted (used on about half of all corn and soybean farms), with guidance being adopted on about 1/3 of the same farms, and VRT on roughly 25%. Furthermore, the largest corn farms (those over 2,900 acres) have double the adoption rates of all other farms, once again demonstrating that larger farms are more likely to adopt PATs (Schimmelpfennig, 2016).

In 2023, McFadden et al. published a report that builds on Schimmelpfennig (2016) and explores new data on PAT adoption. Though these authors did not discuss the economic benefits of PATs and their impact on farm profitability like Schimmelpfennig (2016), they did look how these technologies have impacted farms that have adopted them. The report uses data from the Agricultural Resource Management Survey (ARMS), which is administered jointly by the USDA Economic Research Service (ERS) and National Agricultural Statistics Service (NASS). The report begins with a detailed analysis and explanation of the different components of digital agriculture (DA) that have been introduced since 1996, including yield monitors, variable rate technologies, and guidance controls. The report goes on to break down adoption data for each of those components of DA. The adoption rates of yield maps on row crop acres in the United States is varied by crop, with corn and soybean acres having the highest rates of adoption (~45%), winter wheat acres at approximately 20%, and cotton acres having the lowest rate of adoption at 15%. The trend of wide variation of adoption depending on the crop grown continues when looking at the adoption of yield monitors. The report looks at how adopters of yield monitors utilize this technology on their operations. Adopters use yield monitors to monitor crop moisture content, negotiate new crop leases, help determine chemical input usage, add/improve tile drainage, or for another purpose. The report found that a majority of corn acres (61.6%) and winter wheat acres (80.5%) use yield monitors to monitor moisture content, while soybean acres (68.8%), cotton acres (94.4%), and sorghum acres (95.6%) use yield monitors to help determine chemical input use. The report does not mention why there is such a wide gap between the uses between corn/winter wheat acres and soybean/cotton/sorghum acres, nor does it mention why each group depends on yield monitors for these purposes. The benefits of variable rate technologies (VRT) have long been touted, but the adoption rate of these technologies indicates that farmers have yet to fully realize these benefits. Data from the report shows that VRT are more commonly used on corn acres (~38%) than every other crop. VRT has only been adopted on roughly 25% of soybean and cotton acres, with adoption further lagging for rice, sorghum, and winter wheat acres. By far one of the most commonly adopted technologies discussed in the report is guidance/autosteer, with data showing that nearly 70% of sorghum acres utilize autosteer technologies, while 50-60% of corn and soybean acres have adopted them. The report goes on to mention the fact that these technologies are more often adopted together, rather than separately. Nearly 23% of corn acres are managed using precision soil maps, VRT, and guidance systems, while 15% of soybean acres are managed using soil maps and guidance. The only exception to this trend is winter wheat acres, where approximately 39% of acres are managed using only guidance systems (McFadden et al., 2023). The reasons behind the varied joint adoption of these technologies are not explored, but there are several factors that affect a farmer's decision to adopt one technology.

One study of corn farmers in the Midwest U.S. analyzed factors that drive adoption but also look at how a farmer views their role in the food production chain. Gardezi & Bronson (2020) recognized previous studies, but also noted the gap left by previous studies by not looking deeper into the personal characteristics and social identities of farmers. They theorized that a farmer would adopt a technology if they believe the technology can provide them with a sense of meaning among the group they identify with. This study collected data from surveys and secondary data from farmers in twenty-two hydrological watersheds in the Upper Midwest, with

5,000 farmers responding to the survey. Fifty-six percent of the respondents indicated they were currently using precision agriculture technologies and were then asked a series of questions about what makes a good farmer (Gardezi & Bronson, 2020). The results from this part of the survey found four identity types that respondents believed make a good farmer, labeled as productivist, conservationist, expert, and listener. The results from the survey showed that a single standard deviation increase in any of these characteristics corresponded to an increase in the odds of adopting PATs. In addition to these four identities, participants were asked questions regarding their risk perceptions and environmental concerns to see if these had any effect on a decision to adopt. Farmers that were concerned about soil erosion and flooding were more likely to adopt PATs, with flooding concerns having more of an effect than soil erosion concerns (Gardezi & Bronson, 2020). The results go on to show that if a farmer only owns the land they operate, they were less likely to adopt PATs than if they rented the land they operate. Higher farm diversity (i.e., growing more than two crops per year or raising livestock and growing crops) also showed a positive correlation with a farmer's use of PATs.

A study of South Dakota farmers looked to see whether embodied knowledge technologies are adopted at different rates than information intensive technologies. Embodied knowledge technologies are those that do not require a user (a farmer) to have any specialized skills to benefit from or use the technology (i.e., lightbar, genetically modified crops), while information intensive technologies produce large amounts of data that can benefit a user, but require a user to have skills and knowledge on how to interpret and use the data (i.e., precision soil sampling) (Miller et al., 2019). In their study, Kolady et al. (2021) surveyed South Dakota farmers regarding their perceptions of the cost and benefits of PATs, adoption levels of PATs, and collected other demographic data. The demographics revealed an average age of 59.5 years, 45.6% had a college education, and the average farm size was 771.1 hectares (roughly 1,905 acres). Further results from the survey show that the embodied knowledge technologies listed in the survey (autosteer, GPS guidance, and automatic section control) all had adoption levels above 50%, while only three of the six information intensive technologies (yield monitor, VRT, and prescription field maps) had adoption levels above 50%. VRT was adopted on exactly 50% of farms, and prescription field maps on 50.5% (Kolady et al., 2021). This study's results also aligned with other studies that showed farm size, farmers' familiarity with computers, and perceived profitability all are positively correlated with PAT adoption.

Looking specifically at the adoption of autosteer technology, D'Antoni et al. (2012) analyzed the perceived benefits to cotton farmers that adopted this type of PAT. The main objective was to determine if the likelihood of a farmer adopting autosteer would increase if their value placed on cost savings also increased. A survey of cotton farmers across 12 southern states in the U.S. yielded 1,692 respondents with an average age of 56 and roughly 31 years of farming experience. If a farmer indicated that PATs would be more important over the next five years, then the likelihood they would adopt autosteer would increase by 10%. Furthermore, an increase in the number of rows of cotton-picking from four to five also resulted in an increase in the likelihood of adoption. Each year a farmer and cotton-picking equipment get older, the results showed that the likelihood of adoption would decrease (D'Antoni et al., 2012).

Just as D'Antoni et al. (2012) analyzed cotton farmers to understand their views of autosteer and other PATs, Watcharaantanpong et al. (2014) looked at the adoption trends of grid soil sampling (GSS), yield monitoring (YMR), and remote sensing (RSS) among cotton farmers in the same geographic region. The results of this survey showed that only land tenure had an effect on the adoption of GSS, with the data indicating that farmers who rented all of the land they farmed adopted this technology roughly one year later than farmers who owned the land they operated. Further results indicated that older farmers adopted GSS and YMR later than younger farmers (.07 and .04 years), and farmers who used computers adopted GSS and YMR .91 and .70 years earlier than those farmers that did not use computers. Additionally, farmers that thought PATs would be profitable or important in the future adopted YMR nearly a year earlier than those that did not, with no correlation found with GSS or RMS adoption (Watcharaantapong et al., 2014).

As PATs are developed, marketed, and introduced into the marketplace, some farmers adopt these technologies faster or slower than others. The goal of Ofori et al. (2020) was to examine the time-to-adoption decisions of farmers. Time-to-adoption simply refers to the difference in time between a technology becoming available and when it is adopted by a farmer. Like in other studies, the authors analyze PATs as either embodied knowledge or information intensive to see if these differences affect the time-to-adopt for a particular technology. Embodied knowledge technologies (such as guidance and section control) were adopted in a shorter timeframe than information intensive technologies (such as yield monitors and VRT) (Ofori et al., 2020). Within these categories, there was variability in the time-to-adoption for many of the technologies, with farm location playing a role in this variability. The main drivers of time-to-adoption of these technologies are a farm's location, a farmer's age, their years of farming experience, and their total acres in crop production.

Data Privacy Issues and Concerns

Another area of literature that can further contribute to the discussion of factors that influence a farmer's decision to adopt PATs is the subject of data privacy in agriculture. The vast amount of data collected by PATs has become a relevant topic in the agriculture industry as the use of PATs has increased over the past decade, and while many believe that farmers are in control of their data, the reality is that other forces within and outside the agriculture industry view data collected on farms as public goods rather than private (Miller et al., 2018). The value of data collected on farms can vary depending on who is using and accessing the data. Farmers using data to make production and management decisions can receive many different benefits from that data, including educational experiences to improve their operations and making better decisions that enhance the efficiency of the operation. The value of this data to farmers also increases as more data is collected on their operations. As farmers have collected more data, many service providers have pushed farmers to share their data so it can be aggregated and analyzed at a larger level. This aggregation and analysis of raw data caught the attention of entities outside the agriculture industry causing the data to become more valuable. Data service providers benefit from aggregated data because it can be sold for a profit to third parties, demonstrating how the value of farm data can differ depending on the person/entity (Miller et al., 2018).

Ellixson et al. (2019) analyzed the legal protections that exist for farmers and the data they collect through the PATs they use on their operations. Much of the protection for farmers and their data stems from property law and trade secret laws, with intellectual property laws not covering agricultural data. The authors noted that agribusiness and technology firms have invested significant amounts of money in acquiring and storing farm data, thus demonstrating the importance and significant value of farm data. As of 2018, there were no existing laws that specifically address farm data ownership or the penalties for the misuse of this data, with case law and federal/state legislation likely being the deciding factor in determining the rights and protections of farm data. Three types of farm data exist: data collected on the farm by the farmer (i.e., agronomic, and economic data regarding production practices), data collected by a second party at the request of the farmer, and data collected about a farm by an outside party (Ellixson et al., 2019). Significant details need to be defined regarding the protections that exist for farmers and the different types of farm data, but it is clear that as the adoption of PATs grows, so too will the importance of farm data.

In the context of the absence of legal protections for farmers and the data collected on their farms, a farmer's views of data privacy can have an impact on their decision to adopt a PAT. Wiseman et al. (2019) set out to explore Australian farmers' views of these subjects through a survey that asked respondents their knowledge of the terms and conditions for using PATs, the direct access to data collected on their farm, attitudes towards profit-making from their data, and trust in technology providers to protect their data. A large majority (74%) indicated they knew very little about the terms and conditions relating to data collection and privacy of the technologies they used, with half of the respondents feeling uncomfortable with technology providers having direct access to the data collected on their farms. Furthermore, 67% of the respondents stated they were not comfortable with a technology provider selling data collected on their farms for a profit and 56% stated they had no trust in a technology provider to protect their data and not share it with a third party (Wiseman et al., 2019). These results show that there are genuine concerns among farmers with respects to the data collected on their operations, and their desire to protect it and restrict who has access to their data.

In a similar study to Wiseman et al., Wachenheim et al. (2023) surveyed North Dakota farmers and ranchers to understand their perspectives on data generated from using precision agriculture technologies (PATs) and data privacy issues. Respondents were asked their level of comfort with sharing data generated by PATs with different entities or groups. A large majority of the respondents were comfortable sharing data with their crop insurance agent/banker (75%) or with a service provider such as a crop consultant (73.3%), while respondents had mixed views on sharing data with a representative from a government organization such as the Farm Service Agency (FSA). Overall, a third (33.3%) of respondents were comfortable sharing data with a government representative, while 23.3% were neutral, and 43.3% uncomfortable. The authors also asked respondents their views on sharing data with third-party entities. If a third-party entity made a profit from data generated by PATs and provided some kind of incentive to the farmer, 35% of respondents felt neutral and 48.3% of respondents felt uncomfortable. In contrast, nearly 82% of respondents felt uncomfortable with a third-party entity making a profit and not providing any incentive to the farmer. Respondents were asked to what extent certain data privacy factors influence their decision to adopt PATs. Nearly half of the respondents stated that the level of security to protect data from malicious activities (i.e., identity theft) had the highest level of influence (Wachenheim et al., 2023). This study shows that farmers are concerned with who has access to the data generated by PATs and want to ensure their data is secure and protected.

Literature on OFPE

While the literature on the adoption of precision agriculture technologies is comprehensive, it does leave out one key element that has become relevant in the context of agricultural research: on-farm precision experimentation (OFPE). Lacoste et al. (2022) defined OFPE as a collaborative process that brings farmers and researchers together, which supports a farmer's management decisions. There are three mechanisms that define the deep history and ties between experimentation and farm management. The first is that OFPE occurs on a producer's operation (rather than on small plots), which makes the results more meaningful. Second, the interests of the producer and others are clearly stated and required to move forward with the experimentation process. The third mechanism is that OFPE is a joint, collaborative process that helps farmers learn from researchers (Lacoste et al., 2022). Farmers are always interested to learn new things about their operations, and OFPE provides them with an observable activity that is of interest to them. OFPE embraces the knowledge and experience of farmers and combines it with the research design expertise of researchers and others to ensure that experiments are sound and provide meaningful information.

Though OFPE is seen as a recent advancement in agricultural research, there has long been a push to move experiments away from small university trial plots and involve farmers in the research process. Gerber (1992) provided a model that combines the knowledge of both farmers and researchers to explore new production practices or products. This model of participatory research values the knowledge of farmers and researchers and provides a way to bridge the gap that has long existed between these two groups (Gerber, 1992). For too long, Gerber notes, scientists have long believed they are in touch with farmers' needs, therefore believing they do not need to consult farmers to see what interests them. Building on the participatory model described by Gerber (1992), Tao et al. (2019) described the framework of a farmer-research network to promote collaboration and research. A farmer-researcher network is a platform that can allow farmers, researchers, and various other stakeholders to exchange information and ideas, collect and analyze data, and engage in a process of co-innovation to enhance the research process. It is through a farmer-researcher network that scientific knowledge can be exchanged, and mentorships can be facilitated. The structure of a successful farmer-researcher network, according to the authors, is based on several groups that serve a specific role in the network. The advisory council is one of the most important elements, as it is comprised of farmers, researchers, extension personnel, and others that are tasked with selecting research priorities, finding funding sources, and other duties. A farmers' advisory committee is also a key element, as the committee provides key insights from farmers on the research process. A support committee is also necessary to a farmer-researcher network. This committee has several responsibilities, including selecting farms for research projects, organizing local and regional-level workshops and field days to share information, and soliciting ideas for future research projects (Tao et al., 2019). Other committees outlined by the authors include a data analysis committee, a database management committee, and a website/social media committee. All of these committees, and the people that serve on them, play a key role in ensuring the success of a farmer-researcher network.

Indeed, there are groups that have sought to bridge the gap between researchers and farmers in conducting on-farm experimentation. Established in the late 1980s, the Practical Farmers of Iowa (PFI) has guided research on environmentally sound and profitable farming practices where farmers are the primary researchers. The experiments conducted by these researchers consist of a side-by-side comparison of a farmer's usual practice next to an alternative practice (Thompson & Thompson, 1990). The trials conducted by PFI farmer-researchers have several benefits, including farmers finding the results more believable, new techniques are tested in real-world conditions, and more rigorous research by farmers can be conducted in the future by researchers (Rossman, 1994). Since the inception of the PFI, many other farmer-researcher networks have been established. Networks run through Montana State University, the University of Nebraska-Lincoln, the Ohio State University, and others around the world are working to bridge the divide between farmers and researchers to conduct OFPE (Lacoste et al., 2022).

If the future of agricultural research is OFPE, it is important to understand farmers' views of OFPE and their interest in conducting it, especially with researchers. Nevertheless, very little research addresses farmers' views of OFPE, their interest in conducting experiments, and how farmer knowledge can be useful for OFPE. Longchamps (2022) sought to gain insights on this topic by conducting interviews with farmers across New York State. This study consisted of interviews with ten farmers that operated diverse types of farms, representative of the diversity of New York agriculture. A major finding from these interviews is that all of the farmers interviewed stated they are conducting some kind of OFPE, confirming that OFPE is important for New York State farmers to run their operations (Longchamps, 2022). Further results indicate that farmers' data collection can be rudimentary, the experiments can be slow and require considerable time investments by a farmer, and farmers put much thought and consideration into these experiments (Longchamps, 2022). This study from New York State provides unique insights into the dynamic landscape of OFPE.

Customer Discovery

If OFPE is the future of agricultural research, then it is important to understand how farmers view the work done by university researchers, crop consultants, extension agents, and others, and whether farmers are interested in conducting these experiments on their operations. The customer discovery philosophy provides a blueprint to analyze these topics. Blank (2013) described a customer development model that is often used by startups and other businesses to determine if there are customers for a product/service, and whether a product/service is solution to a problem facing potential customers. Customer discovery can help identify farmers that are already conducting experiments on their operation, or who may be interested in doing so. For researchers that are seeking to conduct experiments with farmers on their operations, then customer discovery can be helpful in not only identifying farmers that may be interested, but the topics that these experiments can explore and help farmers understand.

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APPENDIX A: EMAIL TO POTENTIAL INTERVIEW PARTICIPANTS

Tibbs, Reagen

From:	Boerngen, Maria
Sent:	Friday, July 15, 2022 10:44 AM
To:	Boerngen, Maria
Cc:	Tibbs, Reagen
Subject:	DIFM Focus Group

Dear DIFM Field Trial Participant:

I am a member of the DIFM research team, and I received your contact information from Bob Dunker, who serves as the field trial coordinator here in Illinois.

As a participant in DIFM field trials, you are invited to take part in a focus group conversation conducted by Reagen Tibbs, a graduate student in the Department of Agriculture at Illinois State University, who is also part of the DIFM team. This is an important component of Reagen's master's thesis research, and the conversation will revolve farmers' adoption of precision agriculture technologies and on-farm precision experimentation.

The focus group will be conducted as a Zoom meeting on Monday, July 25, at 10:00 a.m., and should last approximately 30 minutes. You may join the meeting by clicking on the following link: https://illinoisstate.zoom.us/j/98373070339

If you are unable to participate in that meeting, but are willing to speak with Reagen about his research, we will make every effort to set something up that accommodates your schedule.

Thank you for considering this invitation, and for your participation in DIFM activities. If you have any questions, would like additional information, or would prefer to meet with Reagen at a different time, please do not hesitate to let me know. I may be reached by email at maboern@ilstu.edu, or by phone at 309-438-8097. I will touch base with you again as the Zoom meeting approaches. Reagen and I hope to see you on July 25.

Sincerely,
Maria Boerngen

Maria Boerngen, Ph.D.
Associate Professor of Agribusiness
Illinois State University
Campus Box 5020
Normal, IL 61790-5020
309-438-8097

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APPENDIX B: SCRIPT FOR FARMER INTERVIEWS

1) *Introduction*
   a. Hello everyone and thank you for your willingness to participate in this focus group. My name is Reagen Tibbs, I am a GA at Illinois State University, and along with Dr. Maria Boerngen we are conducting this focus group to understand the perceptions of precision agriculture technologies and on-farm precision experimentations as a part of my thesis research. Before we begin, Dr. Boerngen will put a full informed consent form in the chat window for you to view at any time. So you are aware, we are going to record this session so we can make a transcription. Any identifying information from the session will be redacted from the transcription. The recording will only be accessed and listened to by Dr. Boerngen and myself, and the recording will be destroyed once the transcription is made. If you have any questions please feel free to ask at any time. If at any time you do not wish to participate in the focus group you may leave the Zoom session at any time.

2) *Opening Questions*
   a. Brief introduction
      i. Briefly describe your operation.
         1. How long have you been farming? Do you own or rent the ground? What types of crops do you grow?
      ii. Describe your use of precision agriculture technologies.
         1. How long have you used these technologies? What technologies do you use?

3) *General Questions*
   a. Benefits of PA technologies
      i. What benefits do you get from using these technologies? Are there any negatives to using these technologies?

   b. OFPE
      i. What comes to mind when you hear the term "on-farm precision experimentation?"
      ii. Have you done any "informal" experiments using precision technologies?
         1. If YES
            a. What was the goal of your experiment(s)?
            b. How many acres did you dedicate to the experiment(s)?
            c. How did you determine if the experiment(s) were effective?
            d. Did you work with any researchers or crop consultants on the experiment(s)?
            e. What technology/technologies did you use to conduct the experiment(s)? Which technology/technologies were most effective and why?
         2. If NO
            a. Have you ever tried on-farm experimentation? If so, why did you not continue to conduct experiments?

b. What would encourage or motivate you to conduct on-farm experiments?
    i. Would the availability of a PA technology affect your decision to conduct experiments?

c. Data Privacy and Internet Access
    i. Do the precision technologies that you use require internet connection? Do you have a reliable internet connection to use these technologies?
    ii. Does access to internet affect your decision to use a precision technology? What about your decision to conduct OFPE?
    iii. In using a precision technology, would you be comfortable or willing to share data with a technology provider? If a provider had direct access to the data, would that cause any concerns on data privacy?

d. Researcher-farmer relationship
    i. When you work with a university researcher/extension agent, how involved are you in the process? Do they keep you involved throughout the process?
    ii. What is your perception of university research trials on trial plots? Do you believe they have any relevance to your operations?
    iii. When the trials are completed, how do you get the results?
    iv. Would you be willing to work more closely with university researchers/extension agents to conduct OFPE?

APPENDIX C: SURVEY QUESTIONS

Demographic Questions

1) What sector of agriculture are you involved in?
    a. Row crops or vegetables
    b. Livestock
    c. Both livestock and row crops or vegetables
    d. I am not a farm operator.
        i. If (b) or (d), skip to end.

2) Which crops do you typically grow on your operation? (Please select all that apply.)
    a. Corn
    b. Soybeans
    c. Wheat
    d. Cotton
    e. Rice
    f. Other (please list): open text.

3) In what state and county is the largest portion of your operation located?
    a. Open text for state and county

Precision Agriculture Questions

1) Would you consider your operation on the "leading edge" of adopting and using the latest precision agriculture technologies (i.e., yield monitor, autosteer, etc.)?
    a. Yes
    b. No

2) What precision agriculture technologies do you utilize? (Please select all that apply.) (Thompson et al., 150, 2019)
    a. Variable rate fertilizer and/or seed application
    b. Yield monitor
    c. Autosteer/GPS
    d. Precision soil sampling
    e. Drones/unmanned aerial vehicles
    f. Satellite/aerial imagery
    g. Other (please list): open text.
    h. I do not use any precision agriculture technologies.
        i. If (h), then skip to OFPE questions.

3) How many years have you used precision agriculture technologies?
    a. Less than 5
    b. 5-10
    c. 11-15
    d. 16-20
    e. More than 20

4) In the table below, please select your level of agreement with the following statements.

Scale					
Statement		Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
	Precision agriculture technologies have significantly contributed to my operation's current profitability.				
	I have made better decisions for my operation because of precision agriculture technologies.				
	My role as a farm manager has been made easier because of precision agriculture technologies.				

5) Of the benefits of precision agriculture technologies listed below, rank them based on their level of importance to your operation with 1 being most important (Thompson et al., 152, 2019)
   a. Cost savings
   b. Yield improvements
   c. Convenience
   d. Access to data for better decision making.
   e. Other (please list): open text.

6) Of the precision agriculture technologies you use on your operation, which will be most important to your operation over the next decade? (Thompson et al., 2019)
   a. Selections made in #5 appear here, rank in order (1,2, 3…)

7) Which of the following barriers could prevent you from adopting a new precision agriculture technology? (Please select all that apply.)
   a. Cost
   b. Time needed to learn the technology.
   c. Lack of reliable internet/cellular connectivity
   d. Concerns about data privacy
   e. Other (please list): open text.
   f. None of the above

8) How reliable is the internet connection/cellular signal on your farm?
    a. I do not have an internet connection/cellular signal on my operation.
    b. There is an internet connection/cellular signal, but it is too unreliable to use with my precision agriculture technologies.
    c. There is a reliable internet connection/cellular signal on my operation that I can use with my precision agriculture technologies.

Data Privacy Questions (Wiseman et al., 2019)

The term "technology/service provider" will be used frequently in the following questions. That term is defined as any company/organization that provides a precision agriculture technology that you utilize on your operation. Examples include John Deere, FieldView, etc.

9) How familiar are you with the terms and conditions regarding the collection of on-farm data by the precision agriculture technologies you use?
    a. Very unfamiliar
    b. Somewhat unfamiliar
    c. Somewhat familiar
    d. Very familiar

10) How comfortable are you with a technology/service provider accessing on-farm data collected by their technology/service?
    a. Very uncomfortable
    b. Somewhat uncomfortable
    c. Neutral
    d. Somewhat comfortable
    e. Very comfortable

11) How much do you trust a technology/service provider not to access data collected by their technology/service on your operation?
    a. No trust
    b. Very little trust
    c. Somewhat trust
    d. Total trust

12) If a technology/service provider has access to data collected on your operation, how much do you trust that technology/service provider not to share data with third parties?
    a. No trust
    b. Very little trust
    c. Somewhat trust
    d. Total trust

13) How willing are you to share input data (i.e., seeding/fertilizer rate) with a technology/service provider?
    a. Totally unwilling
    b. Somewhat unwilling
    c. Somewhat willing

d. Very willing

14) How willing are you to share output (i.e., yield) data with a technology/service provider?
    a. Totally unwilling
    b. Somewhat unwilling
    c. Somewhat willing
    d. Very willing

OFPE Questions

In this section, you will be asked a series of questions regarding on-farm precision experimentation and experiments in general. In referring to experiments, we do not include seed trials but rather variable fertilizer application, variable seeding rate, etc.

15) Do you conduct experiments on your operation?
    a. Yes, I conduct experiments every year.
    b. Yes, I conduct experiments on occasion.
    c. No, I conducted experiments in the past but no longer conduct experiments.
    d. No, I have never conducted experiments.
        i. If (a) or (b)
            1. What is/are the topic(s) of your on-farm experiment(s)?
                a. Open text

            2. Do you utilize precision agriculture technologies to conduct the experiment(s)?
                a. Yes, always.
                b. Yes, sometimes.
                c. No
                    i. If YES, are precision agriculture technologies beneficial in conducting the experiment(s)?
                        1. Yes
                        2. No

            3. Have you ever worked with a university researcher/extension agent/certified crop advisor to conduct experiments on your operation?
                a. Yes, always.
                b. Yes, sometimes.
                c. No

            4. What benefits have on-farm experiments brought to your operation?
                a. Open text

        ii. If ("c"), why did you stop conducting experiments on your operation? (Please select all that apply.)
                a. Cost

b. Time
c. No available resources (i.e., equipment, acreage)
d. Concerns of data privacy
e. Did not see the benefit of conducting experiments.
f. Other (please list): open text.

iii. If (d), why have you never conducted experiments on your operation? (Please select all that apply.)
a. Cost
b. Time
c. No available resources (i.e., equipment, acreage)
d. Concerns of data privacy
e. Do not see the benefit of conducting experiments.
f. Other (please list): open text.

16) How would you define the term "on-farm precision experimentation?"
a. Open text

17) Which statement best describes your views of research experiments conducted on university or other research plots?
a. I pay little to no attention to their results, as they are not representative of the conditions on my operation.
b. I look at some of the results from these trials but usually do not implement those practices on my operation.
c. I give serious attention and interest to these trials and consider implementing their practices on my operation.

18) Overall, what is your level of interest in conducting on-farm precision experimentation with the collaboration of a university researcher/extension agent/certified crop advisor?
a. Uninterested
b. Somewhat uninterested
c. Unsure
d. Somewhat interested.
e. Very interested
i. If (a), (b), or ("c"), If a software tool was available that designed trials and experiments was available, how would that affect your decision to conduct on-farm precision experimentation?
1. No effect
2. Little effect
3. Some effect
4. Significantly effect

19) In the table below, please select the impact that the features listed would have on your decision to adopt a software tool to conduct on-farm experiments.

	Scale		
Features	I would be less likely to adopt a software with this feature.	No effect on my decision to adopt.	I would be more likely to adopt a software with this feature.
The software is free to use.			
There is a fee/cost to utilize the software.			
The prescription developed by the software can be uploaded directly to my current equipment.			
The prescription cannot be directly uploaded to my current equipment.			
The software does not require collaboration with a researcher/extension agent/certified crop advisor.			
Collaboration with a researcher/extension agent/certified crop advisor is required to use the software.			

Demographic Questions continued

20) Approximately how many acres is your operation?
   a. Less than 250
   b. 250-499
   c. 500-749
   d. 750-999
   e. 1,000-1,499
   f. 1,500-1,999
   g. More than 2,000

21) Which of the following best describes the majority of your farm acreage?
   a. Owned
   b. Cash rent
   c. Share rent.
   d. Other

22) How many years of farming experience do you have?
   a. 5 or fewer
   b. 6-10
   c. 11-15
   d. 16-20
   e. 21-25
   f. 26-30
   g. 30 or more

23) What is your age?
   a. 25 or younger
   b. 25-34
   c. 35-44
   d. 45-54
   e. 55-64
   f. 65-74
   g. Over 75

24) What is your highest level of education?
   a. Some high school
   b. High school diploma/GED
   c. Associate degree/some college
   d. Bachelor's degree
   e. Master's degree or higher

APPENDIX D: POSTCARD MAILED TO MEMBERS OF THE LOGAN COUNTY FARM BUREAU

Dear Logan County Farm Bureau member,

On behalf of fellow Logan County Farm Bureau member Reagen Tibbs, we seek your opinion on precision agriculture technologies and on-farm precision experimentation through an anonymous online survey. This survey is part of Reagen's Master's thesis project at Illinois State University. To access the survey, you can either type in this link (https://illinoisstate.az1.qualtrics.com/jfe/form/SV_87FYjKG73qpQPmC) or use a smartphone camera to scan the QR Code below. If you have any questions or concerns, please contact Reagen by email at rgtibb1@ilstu.edu. Thank you for your time and participation.

Scan this QR code to take the survey

APPENDIX E: EMAIL TO MCLEAN COUNTY FARM BUREAU MEMBERS

McLean County Farm Bureau
Advocating for Agriculture

Reagen Tibbs, a graduate student in the Department of Agriculture at Illinois State University, is asking for your help with his master's thesis research by inviting you to participate in an anonymous online survey. This survey includes questions about precision agriculture technologies and on-farm precision experimentation (OFPE), along with other related topics. To access the survey, please go to this link.

Survey can also be found at:
https://illinoisstate.az1.qualtrics.com/jfe/form/SV_87FYjKG73qpQPmC

Take Survey

APPENDIX F: EMAIL TO MISSOURI FARM BUREAU MEMBERS

State Issues

Precision Agriculture Technology Survey

Reagen Tibbs is asking for your help with his master's thesis research by inviting you to participate in an anonymous online survey. Tibbs is a graduate student in Illinois State University's agriculture department and a graduate of Southeast Missouri State University's agricultural communications program. His important survey includes questions about precision agriculture technologies and on-farm precision experimentation (OFPE), along with other related topics.

APPENDIX G: EMAIL TO U.S. RICE PRODUCERS ASSOCIATION MEMBERS

In This Issue:

- A Message from President and CEO of USRPA, Marcela Garcia
- USRPA Welcomes FECARROZ to Houston, Texas
- Market Update: Farmers Undecided on 2023 Rice Planting Decisions
- Washington, D.C. Update
- 2023 Rice Market and Technology Convention
- Survey: Precision Agriculture Technologies and On-Farm Precision Experimentation (OFPE)
- Photo from Rice Country

- **Survey: Precision Agriculture Technologies and On-Farm Precision Experimentation (OFPE)**

Reagen Tibbs, a graduate student in the Department of Agriculture at Illinois State University, is asking for your help with his master's thesis research by inviting you to participate in an anonymous online survey. This survey includes questions about precision agriculture technologies and on-farm precision experimentation (OFPE), along with other related topics.

Take the Survey

APPENDIX H: EMAIL TO OHIO STATE UNIVERSITY EFIELDS PROGRAM PARTICIPANTS

Reagen Tibbs, a graduate student in the Department of Agriculture at Illinois State University, is asking for your help with his master's thesis research by inviting you to participate in an anonymous online survey. This survey includes questions about precision agriculture technologies, on-farm precision experimentation (OFPE), and other related topics. To access the survey, please go to this link: https://illinoisstate.az1.qualtrics.com/jfe/form/SV_87FYjKG73qpQPmC.