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Digital Transformation of Agriculture: A Study of Precision Technology Adoption from the Perspective of Farmers' Social Systems

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ABSTRACT

This study aims to analyze the adoption of precision agriculture technologies in agricultural digital transformation from the perspective of farmers' social systems. The study focuses on how rice farmers understand, evaluate, accept, delay, or reject digital technologies in their daily farming practices. A qualitative case study design was used in Ciasem Subdistrict, Subang Regency, West Java, Indonesia. Data were collected through semi-structured interviews, limited participatory observation, and documentation involving rice farmers, farmer group leaders, agricultural extension workers, local agricultural officers, cooperative managers, and technology facilitators. The findings reveal five main themes: farmers' practical understanding of precision agriculture, trust-based technology adoption, cost and skill barriers, the role of farmer groups and extension workers, and gradual changes in farming decision-making. The study shows that precision agriculture adoption is not merely a technical process, but a socially mediated process shaped by trust, peer influence, local knowledge, institutional support, and technology compatibility with farming routines. These findings contribute to innovation diffusion and digital agriculture studies by emphasizing the role of farmers' social systems in technology adoption. Practically, the study suggests that digital agriculture programs should strengthen digital literacy, continuous mentoring, demonstration-based learning, and inclusive policy support. Future research may compare adoption processes across regions, commodities, and farmer generations.

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1. Introduction

Digital transformation in agriculture has become a major issue in global agricultural development because the sector faces increasing pressure from productivity demands, climate change, labor shortages, land degradation, and the need for efficient resource use. Precision agriculture technologies, such as land sensors, satellite imagery, drones, data-based applications, Internet of Things devices, digital weather information, and fertilizer recommendation systems, offer new ways for farmers to make more accurate farming decisions. Klerkx and Rose (2020) argue that Agriculture 4.0 is not only about technological change, but also about social responsibility in food system transitions. Rose et al. (2021) also emphasize that digital agriculture should support people, production, and environmental sustainability. Therefore, agricultural digital transformation should not be understood merely as the replacement of conventional tools with digital devices. It should be seen as a social process that changes how farmers access knowledge, manage risks, interact with institutions, and make decisions in their farming practices.

In Indonesia, the adoption of precision agriculture still faces structural and social challenges related to farmers' capacity, digital infrastructure, financial access, land scale, and institutional support. Smallholder farmers remain central actors in national agricultural production, but many of them have unequal access to digital information, technical training, and data-based tools. Santoso et al. (2024) found that Indonesian rice farmers' readiness to adopt precision agriculture technologies is influenced by farmer characteristics, farming experience, land conditions, perceived usefulness, and institutional support. Agussabti et al. (2022) also show that farmers in Aceh view smart farming as a promising opportunity to support food farming, but adoption still requires training, practical evidence, and continuous assistance. These findings indicate that digital transformation at the farmer level does not occur automatically when technology becomes available. Adoption depends on social readiness, trust, learning processes, and the suitability of technology with local farming conditions.

Field problems often arise because precision technologies are designed through the logic of efficiency, while farmers make decisions through social, economic, cultural, and practical considerations. Farmers do not only assess technology based on potential productivity benefits. They also consider initial costs, ease of use, compatibility with existing farming routines, trust in technology providers, support from farmer groups, and recommendations from extension workers. Kendall et al. (2022) found that precision agriculture adoption among small-scale family farmers is shaped by the socio-political landscape, farming culture, farming challenges, adoption intention, and practical support mechanisms. Giua et al. (2022) also explain that smart farming adoption is influenced by performance expectancy, social influence, and farm characteristics. These studies show that the adoption of precision agriculture should be understood as a social process, not only as a technical decision.

From a social and agricultural education perspective, this issue is important because digitalization can improve farm productivity, but it can also widen inequality among farmers. Farmers with stronger digital literacy, internet access, capital, extension networks, and training experience are more likely to adopt new technologies. In contrast, farmers with limited access may be left behind in the digital transition. Aranguri et al. (2025) highlight that digital literacy, training, technology access, and contextual learning strategies are important factors in agricultural technology adoption. Smidt and Jokonya (2022) also show that digital technology adoption among small-scale farmers is shaped by information access, technological skills, external support, and farmers' position in the agricultural value chain. Therefore, studies on precision agriculture need to examine the social system of farmers, including group norms, trust relations, local knowledge, collective experience, and the role of local actors.

Previous studies have widely discussed digital farming through quantitative approaches, technology acceptance models, adoption intention surveys, and factor analysis. Shang et al. (2021) argue that research on digital farming adoption needs to integrate farm-level evidence with broader system interactions. Dibbern et al. (2024) found that barriers to digital agriculture adoption include economic limitations, infrastructure constraints, technical knowledge, farmer age, technology reliability, and data security concerns. Kroupová et al. (2025) also show that the determinants of precision agriculture adoption include socio-economic, informational, institutional, and farm-related factors. However, many previous studies have not deeply explored the meaning, experience, and social process through which farmers recognize, evaluate, try, accept, postpone, or reject precision agriculture technologies. This gap creates the need for a qualitative study that places farmers' voices and social experiences at the center of analysis.

Based on this background, this study aims to analyze the adoption of precision agriculture technologies in agricultural digital transformation from the perspective of farmers' social systems. The study focuses on farmers' experiences in understanding technological benefits, assessing risks, building trust, responding to group influence, and interacting with extension workers, local government, cooperatives, and technology providers. Theoretically, this study contributes to the development of innovation diffusion and technology adoption studies by emphasizing that farmers' decisions are shaped by social relations and contextual experiences. Practically, this study can provide input for government institutions, agricultural extension workers, technology developers, and farmer organizations so that digital agriculture strategies do not only focus on providing tools, but also strengthen literacy, assistance, participation, trust, and technology suitability with farmers' real needs.

2. Materials and Methods

This study uses a qualitative approach with a case study design. This design was selected because the study aims to understand the process of precision agriculture adoption within the social context of farmers. A case study is suitable for examining a contemporary phenomenon in a real-life setting, especially when the phenomenon involves multiple actors, experiences, and social conditions that are closely connected. Younas and Inayat (2025) explain that case study research helps researchers understand complex phenomena through contextual analysis. Miller et al. (2023) also state that qualitative case study research allows researchers to explore processes, experiences, and dynamics that cannot be fully explained through numerical measurement. Therefore, this design is appropriate for examining how farmers recognize, evaluate, use, delay, or reject precision agriculture technologies in their daily farming activities.

The research will be conducted from March to May 2025 in Ciasem Subdistrict, Subang Regency, West Java Province, Indonesia. More specifically, the study will focus on three rice-farming villages, namely Sukamandijaya Village, Ciasem Girang Village, and Dukuh Village. These locations were selected because they represent active rice-farming areas with farmer groups, agricultural extension activities, and early exposure to digital or precision agriculture practices. The technologies examined in this study include agricultural mobile applications, digital weather information, drone-based land observation, data-based fertilizer recommendations, simple land sensors, and agricultural information systems introduced by extension workers or technology providers. The location was also selected because it allows the study to capture different farmer experiences, including farmers who have used digital tools, farmers who are still learning about them, and farmers who have not yet adopted them.

The research participants consist of farmers, farmer group leaders, agricultural extension workers, local agricultural officers, cooperative or farming unit managers, and agricultural technology facilitators. The main informants are rice farmers who have direct or indirect experience with precision agriculture technologies. The criteria for farmer informants include managing or owning rice farmland, being involved in or connected with farmer groups, having received information about precision agriculture, and being willing to explain their experiences openly. Informants will be selected using purposive sampling because the study requires participants who have relevant knowledge and experience related to the research focus. Snowball sampling will also be used to identify additional informants based on recommendations from initial participants. The estimated number of informants is 18 to 25 people, but the final number will depend on data adequacy and saturation.

Data will be collected through semi-structured interviews, limited participatory observation, and documentation. Semi-structured interviews will be used because this technique allows the researcher to maintain a clear focus while giving informants space to explain their experiences in their own words. Adeoye-Olatunde and Olenik (2021) explain that semi-structured interviews help researchers obtain rich, deep, and focused data. The interview guide will cover farmers' experiences in recognizing precision agriculture technologies, trusted sources of information, reasons for accepting or rejecting technology, barriers to use, support from farmer groups, the role of extension workers, and changes in farming decision-making practices. Interviews will be conducted face to face, with each session lasting approximately 45 to 60 minutes.

Limited participatory observation will be conducted to examine farming practices, interaction patterns among farmers, farmer group activities, the use of digital tools, and communication between farmers, extension workers, and technology facilitators. The researcher will be present in field activities as a limited participant observer without taking a direct role in farming operations. Documentation will be carried out by collecting farmer group records, activity photos, training materials, meeting notes, technology assistance documents, and relevant agricultural extension documents. The use of interviews, observation, and documentation aims to obtain complementary data. This strategy is important because precision agriculture adoption is not only reflected in farmers' statements, but also in their practices, relationships, and social context.

Data trustworthiness will be maintained through source triangulation, method triangulation, member checking, and an audit trail. Source triangulation will be conducted by comparing information from farmers, farmer group leaders, extension workers, agricultural officers, cooperatives, and technology providers. Method triangulation will be conducted by comparing interview, observation, and documentation data. Member checking will be carried out by confirming interview summaries and initial interpretations with several key informants. An audit trail will be maintained by storing research process notes, interview transcripts, observation notes, analytical memos, coding decisions, and category development records. Ahmed (2024) emphasizes that credibility, transferability, dependability, and confirmability can be strengthened through systematic documentation, triangulation, member checking, and researcher reflexivity.

Data will be analyzed using thematic analysis through data reduction, data display, and conclusion drawing. The analysis process will begin with interview transcription, repeated reading, initial coding, code grouping, category development, and theme construction. Braun and Clarke (2022) explain that thematic analysis requires consistency between data, codes, themes, and interpretation. The expected themes include perceived technological benefits, cost barriers, digital skills, trust in technology, farmer group influence, extension worker roles, and changes in farming decision-making practices. The analysis results will be presented in an interpretive narrative to explain how farmers' social systems shape the adoption of precision agriculture technologies and how local actors support or hinder agricultural digital transformation.

3. Results and Discussions

The findings show that the adoption of precision agriculture technologies among rice farmers in Ciasem Subdistrict, Subang Regency, is not only shaped by technical readiness, but also by social relations, trust, farming routines, and the role of local actors. Data from semi-structured interviews, limited participatory observation, and documentation revealed five main themes: farmers' practical understanding of precision agriculture, trust-based technology adoption, cost and skill barriers, the role of farmer groups and extension workers, and gradual changes in farming decision-making. These themes indicate that farmers interpret digital transformation through everyday farming needs rather than through abstract technological concepts.

The first theme concerns farmers' practical understanding of precision agriculture. Most participants did not use the term "precision agriculture" in their daily conversation. They understood the technology through more familiar terms, such as weather applications, fertilizer recommendations, drone monitoring, digital pest information, or mobile-based farming assistance. For farmers, the value of technology was measured by its ability to solve practical problems in the field. One farmer stated, "I do not really understand the term precision agriculture, but if the application can tell me when to fertilize or warn me about pests, then it is useful for me." This statement shows that farmers accepted technology when they could connect it with immediate farming decisions. This finding supports the idea that adoption begins when farmers can translate digital tools into concrete field benefits.

The second theme is trust-based technology adoption. Farmers did not immediately adopt digital tools after receiving information from technology providers or government programs. They waited for proof from other farmers, farmer group leaders, or extension workers. Several informants explained that they felt more confident using digital tools after seeing another farmer successfully use them. One participant said, “If only the company explains it, I am still unsure. But when my group leader tries it and the result is good, I become more interested.” This pattern indicates that trust plays an important role in shaping adoption decisions. The social position of farmer group leaders and extension workers becomes important because they act as interpreters of technology and reduce farmers’ uncertainty.

The third theme relates to cost, skill, and infrastructure barriers. Farmers recognized the potential benefits of precision agriculture, but they also expressed concerns about costs, limited digital skills, unstable internet connection, and lack of technical support. Older farmers often depended on younger family members or group administrators to access mobile applications or interpret digital information. One farmer explained, “The tool is good, but I am afraid I cannot operate it alone. Sometimes I ask my son to open the application.” Observation also showed that farmers with smartphones did not always use agricultural applications independently. They needed assistance to read data, interpret recommendations, and connect digital information with field conditions. This finding shows that access to devices does not always mean readiness for adoption.

The fourth theme concerns the role of farmer groups and extension workers. Farmer groups functioned as spaces for discussion, comparison, and collective learning. In several cases, farmers first learned about digital agriculture through group meetings, training sessions, and demonstration plots. Extension workers played a central role in explaining the purpose of technology, correcting misunderstandings, and helping farmers adapt recommendations to local conditions. One extension worker stated, “Farmers usually ask whether the recommendation fits their field. They do not want general information. They want guidance that matches their land condition.” This finding indicates that human mediation remains important in digital agriculture. Technology alone cannot replace the social learning process that occurs within farmer groups and extension networks.

The fifth theme shows gradual changes in farming decision-making. Farmers who had experience with digital tools began to combine traditional knowledge with digital information. They did not fully abandon inherited practices, but they started to compare personal experience, advice from senior farmers, and information from digital platforms. For example, some farmers used weather applications before deciding the timing of spraying or planting. Others used fertilizer recommendations as a reference, although they still adjusted the dosage based on soil condition and local experience. One participant stated, “I still follow my experience, but now I also check the weather application. If the information is suitable, I use it.” This pattern shows that digital adoption among farmers tends to be adaptive and selective. Farmers adopt technology when it strengthens, rather than replaces, their practical knowledge.

Overall, the findings reveal that precision agriculture adoption in Ciasem is a socially mediated process. Farmers interpret technology through perceived usefulness, trust, group influence, affordability, and compatibility with local farming routines. The adoption process does not follow a simple linear path from awareness to use. Instead, it moves through observation, discussion, trial, comparison, and gradual adjustment. This result shows that digital transformation in agriculture requires more than technological availability. It needs social acceptance, continuous assistance, local demonstration, and institutional support that recognizes farmers’ knowledge and limitations.

Discussion

The findings confirm that precision agriculture adoption among smallholder rice farmers is strongly embedded in social systems. Farmers do not make adoption decisions as isolated individuals. They rely on farmer groups, extension workers, family members, local leaders, and peer experiences. This finding is consistent with Kendall et al. (2022), who found that precision agriculture adoption among small-scale family farms is influenced by farming culture, socio-political context, practical support, and adoption barriers. The present study strengthens this argument by showing that farmers in Ciasem interpret digital tools through social trust and local farming experience. Technology becomes meaningful when trusted actors help farmers understand its function and relevance.

The findings also support Giua et al. (2022), who argue that smart farming adoption is not a one-time decision, but a process shaped by intention, social influence, and farm characteristics. In this study, farmers did not adopt technology immediately after exposure. They observed other farmers, discussed potential risks, asked extension workers, and compared digital recommendations with their own experience. This process shows that adoption involves negotiation between innovation and local practice. Farmers accepted technology when it aligned with their farming logic, reduced uncertainty, and provided visible benefits. This finding offers a more contextual explanation of technology adoption in smallholder farming communities.

The role of trust found in this study is also consistent with the broader literature on agricultural digitalization. Shang et al. (2021) emphasize that the adoption and diffusion of digital farming technologies require integration between farm-level evidence and system interaction. The present study shows that system interaction occurs through farmer groups, extension meetings, local demonstration plots, and informal conversations among farmers. These interactions help farmers evaluate whether digital tools are worth using. Therefore, adoption cannot depend only on individual willingness. It also depends on collective interpretation within the local social system.

The findings also reveal a gap between access and capability. Many farmers owned smartphones, but they did not always have the confidence or skill to use agricultural applications independently. This finding supports Dibbern et al. (2024), who identified economic limitations, infrastructure constraints, technical knowledge, age, technology reliability, and data security as major barriers to digital agriculture adoption. It also aligns with Arangurí et al. (2025), who emphasize that digital literacy and contextual training play important roles in agricultural technology adoption. In the Ciasem case, digital literacy was not only related to the ability to operate devices. It also involved the ability to interpret data and apply digital recommendations to field conditions.

The findings partly support Santoso et al. (2024), who found that Indonesian rice farmers' readiness for precision agriculture is influenced by capability and opportunity. However, this study adds a qualitative perspective by showing how capability and opportunity are formed in everyday social settings. Capability develops through repeated assistance, peer learning, and practical demonstration. Opportunity emerges when farmers have access to training, group support, affordable tools, and reliable extension services. This means that farmer readiness should not be understood only as an individual attribute. It should also be understood as a product of social support and institutional facilitation.

The findings also show that farmers combine digital information with local knowledge. This differs from the assumption that digital agriculture simply replaces traditional farming practices. In this study, farmers used digital tools selectively. They checked weather applications, listened to extension recommendations, observed field conditions, and relied on past experience before making decisions. This finding is in line with Ingram and Maye (2020), who argue that digitalization changes agricultural knowledge systems by reshaping relationships between farmers, advisers, data, and institutions. The contribution of this study lies in showing that digital knowledge becomes useful when it enters farmers' existing knowledge systems, not when it ignores them.

From a theoretical perspective, this study contributes to the understanding of innovation diffusion by emphasizing the importance of social interpretation in the adoption process. The findings suggest that awareness, interest, trial, and adoption are influenced by trust, peer influence, group norms, and local proof. This supports the view that adoption is not only driven by perceived usefulness or ease of use, but also by social legitimacy. In the context of smallholder farmers, technology gains legitimacy when it has been tested, explained, and validated by trusted local actors. Therefore, farmers' social systems function as filters that determine whether digital innovation becomes accepted, delayed, modified, or rejected.

From a practical perspective, the study suggests that digital agriculture programs should not focus only on distributing tools or introducing applications. Government agencies, extension services, and technology providers need to develop continuous mentoring models, local demonstration plots, and peer-based learning strategies. Training should use simple language, practical cases, and direct field simulations. Programs should also involve farmer group leaders and younger farmers who can act as local digital facilitators. This approach can reduce fear, increase confidence, and strengthen farmers' ability to connect digital recommendations with real farming conditions.

The study also highlights the need for inclusive digital agriculture policy. Farmers with limited capital, older age, lower digital literacy, and unstable internet access require different forms of support. If digital transformation only benefits farmers with better resources, it may widen inequality in rural agricultural communities. Therefore, policy support should include affordable access to technology, rural internet improvement, extension worker capacity building, and locally relevant digital content. This is important because precision agriculture can only become socially useful when it is accessible, understandable, and compatible with farmers' needs.

Future research can extend this study by comparing different agricultural commodities, regions, and farmer generations. Quantitative studies may also test the relationship between trust, digital literacy, group influence, and adoption readiness. Longitudinal research can examine how farmers' acceptance changes after repeated exposure to digital tools. Further studies may also explore the role of women farmers, youth farmers, and local cooperatives in accelerating agricultural digital transformation. These directions are important because the success of precision agriculture depends not only on technological performance, but also on the social conditions that shape farmers' decisions.

4. Conclusions

This study concludes that the adoption of precision agriculture technologies among rice farmers in Ciasem Subdistrict is shaped by a combination of practical needs, social trust, digital skills, institutional support, and compatibility with local farming routines. Farmers do not adopt digital tools only because the technology is available or promoted by external actors. They evaluate technology through direct benefits, peer experience, support from farmer groups, guidance from extension workers, and its relevance to everyday farming decisions. The main contribution of this study lies in showing that precision agriculture adoption is a socially mediated process. Farmers' decisions are formed through observation, discussion, trial, comparison, and gradual adjustment between digital information and local farming knowledge.

Theoretically, this study strengthens innovation diffusion and technology adoption literature by highlighting the role of farmers' social systems in shaping acceptance, delay, modification, or rejection of digital agriculture technologies. Practically, the findings suggest that digital agriculture programs should not only provide tools or applications, but also build trust, improve digital literacy, strengthen extension services, and create demonstration-based learning within farmer groups. From a policy perspective, inclusive support is needed for smallholder farmers who face limited capital, weak internet access, and low digital confidence. Future studies should examine digital agriculture adoption across different regions, commodities, and farmer generations to provide a broader understanding of how social systems influence agricultural digital transformation.

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