**Global Journal of Agrotechnology**
Vol. 1 No.1 2026 Page 15-24
E-ISSN: XXXX-XXXX, DOI: 10.XXXXX/XXXX

# Socio-Technical Analysis of Smart Farming Adoption in Sustainable Agricultural Systems in Indonesia

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**Article Info**

Received : 8 February 2026
Revised : 11 March 2026
Accepted : 29 March 2026

**Keyword:**

Smart Farming;
Socio-Technical Analysis;
Sustainable Agriculture;
Digital Agriculture;
Smallholder Farmers.

**ABSTRACT**

This study aims to analyze smart farming adoption in sustainable agricultural systems in Indonesia through a socio-technical perspective. The study responds to the growing need to understand why digital agricultural technologies are not always adopted evenly by farmers, despite their potential to improve efficiency, productivity, and environmental sustainability. This research used a qualitative multi-site case study design in three agricultural contexts that represent different stages of smart farming adoption. Data were collected through semi-structured interviews, field observation, and documentation involving 20 to 25 participants, including farmers, farmer group leaders, agricultural extension workers, village officers, technology facilitators, and local program managers. Data were analyzed using thematic analysis supported by data condensation, data display, and conclusion drawing. The findings reveal five main themes: technological readiness, farmer learning and digital literacy, trust in digital recommendations, institutional support, and adaptation to local farming practices. The study shows that smart farming adoption is not only a technical matter, but also a social process shaped by trust, collective learning, infrastructure, and institutional mediation. Farmers adopt smart farming when they see clear benefits, understand the tool, receive continuous support, and can adjust the technology to local farming needs. The study contributes to socio-technical theory by explaining how digital agriculture operates in smallholder farming contexts. It also offers practical and policy implications for designing inclusive, affordable, and locally relevant smart farming programs in Indonesia.



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## 1. Introduction

Smart farming has become a strategic issue in sustainable agricultural transformation because it connects agricultural production with digital data, automated monitoring, and more precise resource management. In global agricultural systems, smart farming uses technologies such as sensors, Internet of Things devices, drones, artificial intelligence, mobile applications, and data-based decision support systems to improve input efficiency and reduce environmental pressure. Basso and Antle (2020) argue that digital agriculture can support the design of more sustainable agricultural systems when farmers use data to manage soil, water, nutrients, and climate risks. This development shows that smart farming is not only a technical innovation. It also changes how farmers produce knowledge, make decisions, and interact with institutions that support agricultural sustainability.

In Indonesia, smart farming has gained attention because agriculture still faces structural problems related to productivity, climate uncertainty, land fragmentation, aging farmers, limited rural infrastructure, and unequal access to digital technology. Rachmawati (2020) explains that smart farming 4.0 in Indonesia includes the use of drones, weather sensors, soil sensors, digital irrigation, and agricultural information systems. However, the adoption process remains uneven across regions and farmer groups. Hutapea et al. (2025) show that digitalization and technology can support millennial farmers' productivity, but success depends on infrastructure, user capacity, and business conditions. These findings indicate that smart farming in Indonesia must be studied through the real conditions of farmers, not only through the availability of technological tools.

Field-based studies show that farmers often face practical barriers when they try to adopt smart farming. These barriers include high technology costs, weak internet access, limited digital literacy, low trust in digital recommendations, and minimal technical assistance after training. Susilawati et al. (2025) found that Indonesian farmers' intention to adopt internet-based fertilization systems depends on perceived usefulness, perceived ease of use, social influence, and institutional trust. Santoso et al. (2023) also found that agricultural information systems in Indonesia can strengthen farmer capacity, but their implementation needs better coordination, reliable information, and user-oriented support. These empirical findings show that smart farming adoption is shaped by social trust, learning processes, farmer networks, and institutional readiness.

The socio-technical perspective provides a relevant foundation for analyzing this issue because smart farming adoption involves the interaction between technology, users, institutions, infrastructure, and agricultural practices. Rijswijk et al. (2021) describe agricultural digital transformation as a socio-cyber-physical process that connects social actors, digital systems, and physical farming environments. Fielke et al. (2020) also show that digitalization changes agricultural knowledge and advice networks because information now flows through extension workers, platforms, private technology providers, farmer communities, and digital applications. This means that smart farming cannot work effectively when technology design does not match local knowledge, farmer capacity, and daily agricultural routines.

The social and cultural dimensions of smart farming also deserve close attention. Digital tools can support young farmers, improve access to market information, and strengthen climate adaptation. However, smart farming can also widen inequality when only farmers with capital, devices, internet access, and digital skills can benefit from it. Hackfort (2021) argues that digital agriculture may reproduce inequality when access to data, platforms, and technology remains concentrated among stronger actors. Gumbi et al. (2023) found that smallholder farmers need affordable technology, digital skills, infrastructure, and supportive ecosystems to benefit from digital agriculture. This issue is important for Indonesia because many farmers still operate small-scale farms and depend on collective support from farmer groups, extension workers, cooperatives, and local government programs.

Previous studies have discussed smart farming technologies, digital agriculture, precision farming, and technology adoption models. Giua et al. (2022) show that smart farming adoption is not a single decision because farmers move through different stages of intention, trial, and actual use. Osrof et al. (2023) also identify that smart farming adoption in field operations requires further research on user behavior, organizational readiness, and long-term implementation. However, many studies still focus on adoption factors, technology readiness, or quantitative models. They have not sufficiently explored how farmers interpret smart farming, how they negotiate new technology with existing farming habits, and how local institutions shape the meaning of adoption in Indonesian agricultural communities.

Based on this gap, this study aims to analyze the adoption of smart farming in sustainable agricultural systems in Indonesia through a socio-technical perspective. The study focuses on farmers' experiences, local institutional support, digital literacy, infrastructure readiness, trust in technology, and the adaptation of smart farming in daily agricultural practice. The theoretical contribution of this study lies in strengthening socio-technical analysis in digital agriculture research, especially in smallholder farming contexts. Its practical contribution lies in providing insights for government agencies, extension workers, technology developers, farmer groups, and rural institutions to design smart farming programs that are socially inclusive, technically feasible, and aligned with sustainable agricultural goals. Wu and Zhong (2025) emphasize that sustainable agricultural technology needs a socio-technical roadmap so that artificial intelligence and digital systems support users, institutions, and ecological goals. Manzoor et al. (2025) also show that digital agriculture adoption in low and middle-income countries depends on the interaction between enabling factors and structural barriers.

## 2. Materials and Methods

This study used a qualitative approach with a multi-site case study design. This design was selected because smart farming adoption in Indonesia cannot be explained only by technology ownership or frequency of use. It also involves farmers' experiences, social relations, institutional support, infrastructure, local knowledge, and perceptions of sustainability. Priya (2021) explains that qualitative case studies are useful for understanding complex social phenomena within their real-life context. In this study, the case study design helped the researcher examine how farmers and supporting actors understand, accept, adapt, or resist smart farming in specific agricultural settings.

The study was conducted in three agricultural sites in Indonesia that represent different stages of smart farming adoption. The first site focused on rice farming communities that use digital fertilization or irrigation information. The second site focused on horticultural farmers who use mobile applications, weather information, or sensor-based monitoring. The third site focused on farmer groups that have received training or pilot support for digital agriculture. Data collection was conducted from January to April 2026. The multi-site design allowed the study to compare how smart farming adoption differs across commodities, farmer capacities, infrastructure conditions, and institutional support systems. This strategy follows the view that agricultural digitalization needs contextual analysis because technology works differently across social and physical environments (Rijswijk et al., 2021).

## 3. Results and Discussion

The analysis produced five main themes that explain how smart farming adoption operates within sustainable agricultural systems in Indonesia. These themes include technological readiness, farmer learning and digital literacy, trust in digital recommendations, institutional support, and the adjustment of smart farming to local farming practices. The findings show that adoption was not a linear process. Farmers did not simply accept technology after receiving training or seeing demonstrations. They assessed whether the technology matched their daily routines, financial capacity, local climate risks, land conditions, and trust in the actors who introduced the innovation.

### Technological Readiness and Unequal Access

The first theme concerns technological readiness. Farmers recognized the potential of smart farming to improve efficiency, but they also faced uneven access to devices, internet networks, and supporting infrastructure. In rice farming sites, several farmers used mobile applications to access weather information and fertilizer recommendations. However, sensor-based systems and automated irrigation tools were still limited to pilot plots or demonstration areas. One farmer stated, "The application helps us check information, but in the field the signal is not always stable.

Sometimes we still ask the extension worker because the data does not open quickly" (P4, farmer). This statement shows that digital access shaped the practical value of smart farming.

Observation also confirmed that technology use depended on basic infrastructure. Farmers who had smartphones and stable internet access used digital tools more often than farmers who shared devices with family members or depended on group leaders for information. In some locations, farmer group leaders acted as digital intermediaries. They received information from applications or extension workers, then explained it to other farmers during group meetings. This pattern shows that smart farming adoption was collective in practice, even when the technology was designed for individual users.

### Farmer Learning and Digital Literacy

The second theme relates to farmer learning and digital literacy. Farmers did not reject smart farming because they disliked technology. They hesitated when the technology required unfamiliar procedures, technical terms, or data interpretation skills. Older farmers often depended on younger farmers, children, or extension workers to operate applications. A senior farmer explained, "I understand the benefit, but I need someone to show me step by step. If I press the wrong menu, I become afraid to continue" (P7, farmer). This finding indicates that digital literacy influenced confidence, not only technical ability.

Young farmers showed stronger interest in digital tools because they already used smartphones in daily life. They viewed smart farming as a way to reduce uncertainty and improve farm planning. One young farmer said, "I use the application to compare weather predictions with what we see in the field. It does not replace experience, but it helps us plan better" (P11, young farmer). This response shows that digital tools worked best when farmers combined them with local knowledge. Smart farming adoption therefore required a learning process that connected digital information with practical farming experience.

### Trust in Digital Recommendations

The third theme concerns trust. Farmers did not automatically follow digital recommendations, especially when the recommendation differed from their usual practice. This issue appeared clearly in fertilizer use, irrigation decisions, and pest control. Some farmers trusted digital advice after they saw positive results in demonstration plots. Others waited for confirmation from extension workers or experienced farmers. One participant stated, "If the data says we should reduce fertilizer, I cannot directly follow it. I need proof first because harvest failure is our own risk" (P9, farmer). This quote shows that trust in smart farming depends on evidence, experience, and risk perception.

Extension workers played a key role in translating digital recommendations into practical decisions. Farmers were more willing to try smart farming when extension workers explained the logic behind the data. In several cases, farmers treated smart farming as an additional source of information rather than the main decision-making tool. They compared digital recommendations with rainfall patterns, soil condition, past harvest experience, and advice from other farmers. This pattern suggests that adoption involved negotiation between digital knowledge and local knowledge.

### Institutional Support and Collective Mediation

The fourth theme highlights institutional support. Farmer groups, extension workers, village officers, and local agricultural programs influenced whether smart farming continued after initial training. In locations where farmer groups held regular meetings, technology use became more consistent. Group leaders helped farmers register accounts, interpret information, and solve technical problems. One extension worker explained, "The challenge is not only introducing the tool. The harder part is accompanying farmers until they feel the tool is useful for their own land"

(P18, extension worker). This finding shows that institutional support must continue beyond short-term training.

Documentation from training materials and local program records showed that most smart farming initiatives began through government or partner-supported programs. However, sustainability depended on follow-up assistance, repair mechanisms, and access to affordable devices. Some farmers stopped using the technology after the project ended because they did not know who to contact when problems occurred. This condition indicates that smart farming adoption requires a support ecosystem, not only equipment distribution.

**Adaptation to Local Farming Practices and Sustainability Goals**

The fifth theme shows that farmers adapted smart farming according to local farming practices. They did not always use the technology exactly as instructed. Instead, they selected features that matched their needs. Weather information, fertilizer guidance, pest alerts, and market information were seen as more useful than complex features that required sensors or paid services. One farmer stated, “We use what is simple first. If the tool helps us save water or fertilizer, we continue. If it is complicated, we return to the old way” (P13, farmer). This statement reflects a practical logic of adoption.

Farmers connected smart farming with sustainability when they saw direct benefits such as reduced input waste, better water management, and more accurate timing of farm activities. However, they rarely used the term “sustainability” in a formal sense. They described it through practical outcomes such as saving costs, protecting soil, reducing failed planting, and maintaining harvest stability. This finding suggests that sustainability messages should be translated into terms that reflect farmers’ daily concerns. Smart farming becomes meaningful when it supports livelihood security and environmental management at the same time.

**Summary of Main Findings**

| Theme | Main Finding | Meaning for Smart Farming Adoption |
|---|---|---|
| Technological readiness | Access to smartphones, internet, electricity, and devices remains uneven | Technology adoption depends on basic infrastructure |
| Digital literacy | Farmers need practical and repeated learning support | Training must use simple language and field-based demonstration |
| Trust | Farmers compare digital recommendations with local experience | Adoption grows when digital advice proves useful in real conditions |
| Institutional support | Extension workers and farmer groups mediate technology use | Smart farming needs continuous assistance and local coordination |
| Local adaptation | Farmers select tools that match daily farming needs | Adoption succeeds when technology fits local routines and risks |

**Discussion**

The findings show that smart farming adoption in Indonesia is a socio-technical process. It does not depend only on the technical quality of sensors, applications, or digital platforms. Farmers adopt technology when they see clear benefits, understand how to use it, trust the recommendation, and receive support from local institutions. This finding supports Rijswijk et al.

(2021), who argue that digital transformation in agriculture connects social actors, cyber systems, and physical farming environments. The present study extends this view by showing that smallholder farmers in Indonesia evaluate smart farming through practical risk, social trust, and daily usability.

The findings also align with Fielke et al. (2020), who explain that digitalization changes agricultural knowledge and advice networks. In this study, knowledge did not flow only from applications to farmers. It moved through farmer group leaders, extension workers, young farmers, village officers, and technology facilitators. This pattern shows that smart farming adoption remains socially mediated. Digital tools can provide information, but local actors help farmers interpret and apply that information. This finding is important because technology programs often assume that access to a digital tool automatically leads to adoption.

The role of digital literacy in this study supports previous research on smart farming adoption. Giua et al. (2022) found that smart farming adoption involves different stages, from awareness to actual use. This study shows that farmers may move back and forth between these stages. They may try a tool, stop using it, ask for help, and later use it again after seeing proof from other farmers. This process shows that adoption is not a one-time decision. It is a gradual learning process that requires repeated support and locally relevant examples.

The findings also support Susilawati et al. (2025), who found that perceived usefulness, perceived ease of use, social influence, and institutional trust affect farmers' intention to adopt internet-based fertilization systems in Indonesia. This study adds a qualitative explanation to those factors. Farmers considered a technology useful when it helped reduce costs, manage risk, or improve timing. They considered it easy to use when the instructions matched their digital skills. They trusted it when extension workers or respected farmers could explain and validate the recommendation. These insights show how adoption factors operate in real farming contexts.

Trust emerged as one of the most important findings. Farmers were careful because wrong decisions could affect harvest outcomes and household income. This finding differs from studies that present smart farming mainly as a rational efficiency tool. Farmers did not reject efficiency, but they wanted evidence before changing long-standing practices. This finding supports Zscheischler et al. (2022), who argue that digital agriculture creates perceived risks and vulnerabilities related to data, control, and dependency. In the Indonesian context, these risks become more concrete when farmers must decide whether to follow fertilizer, irrigation, or pest recommendations from digital systems.

The findings also strengthen the argument that smart farming can create inequality when access and capacity remain uneven. Hackfort (2021) explains that digital agriculture may reproduce unequal power relations when some actors control data, platforms, and technological resources. This study found a similar pattern at the local level. Farmers with smartphones, younger family members, stable internet, or strong group support accessed more benefits than farmers without those resources. This means that smart farming programs must address inclusion from the beginning. They should not treat farmers as a uniform group with equal capacity to use digital tools.

From a sustainability perspective, the study shows that farmers accepted smart farming when it helped solve immediate farming problems. They valued technology that supported water savings, input efficiency, pest control, and harvest planning. This finding is consistent with Basso and Antle (2020), who state that digital agriculture can support sustainable systems when data improves decisions on soil, water, nutrients, and climate risk. However, this study shows that sustainability must be communicated through practical language. Farmers relate sustainability to lower production costs, stable harvests, reduced waste, and better land management.

The role of institutions also became central. Smart farming adoption improved when farmer groups, extension workers, and local government programs provided continuous support. This finding supports Gumbi et al. (2023), who emphasize that smallholder digital agriculture needs an ecosystem that includes infrastructure, skills, affordability, and support services. In this study, farmers often stopped using smart farming tools when programs ended or when technical support disappeared. This suggests that smart farming policy should move beyond pilot projects. It should build long-term assistance, maintenance systems, local trainers, and affordable access models.

The study offers a theoretical contribution by showing how socio-technical analysis can explain smart farming adoption in smallholder contexts. The findings show that technology adoption involves interaction between material tools, user capacity, social trust, institutional mediation, and environmental goals. This perspective expands technology adoption studies that focus mainly on individual intention or perceived usefulness. It also helps explain why farmers with similar access to technology may show different adoption patterns. Social position, group support, risk perception, and local farming culture shape how farmers interpret digital innovation.

The study also offers practical implications. First, smart farming programs should begin with needs assessment at the farmer group level. Second, training should use simple demonstrations, repeated mentoring, and local language. Third, extension workers need stronger digital capacity so they can act as translators between data systems and farming decisions. Fourth, technology providers should design tools that work in low-connectivity areas and match smallholder routines. Fifth, government and rural institutions should develop support systems for device maintenance, data interpretation, and affordable access. These steps can help smart farming become more inclusive and sustainable.

Further research can deepen this topic in several ways. Future studies can compare smart farming adoption across different commodities, regions, and farmer generations. Longitudinal research can examine how farmers' trust changes after several planting seasons. Mixed-method studies can also measure the relationship between digital literacy, institutional support, input efficiency, and sustainability outcomes. Future research should also examine gender dimensions in smart farming because women often contribute to farm management, record keeping, post-harvest activities, and household decision-making. This issue remains underexplored in many studies of agricultural digitalization.

Overall, the findings confirm that smart farming adoption in Indonesia requires more than technology introduction. It requires social readiness, institutional continuity, digital literacy, trust-building, and adaptation to local farming practices. Smart farming can support sustainable agriculture when farmers see it as useful, understandable, reliable, and relevant to their daily work. Therefore, the success of smart farming in Indonesia depends on how well technological innovation connects with the social realities of smallholder agriculture.

## 4. Conclusions

This study concludes that smart farming adoption in sustainable agricultural systems in Indonesia is a socio-technical process shaped by the interaction between technology, farmer capacity, institutional support, infrastructure readiness, and local farming culture. The findings show that farmers do not adopt smart farming only because digital tools are available. They adopt it when the technology is useful, easy to understand, trusted, supported by local actors, and relevant to daily farming risks. The main themes identified in this study include technological readiness, digital literacy, trust in digital recommendations, institutional mediation, and adaptation to local farming practices. These themes show that smart farming works best when digital systems strengthen farmer decision-making rather than replace local knowledge.

The study contributes to the literature by extending socio-technical analysis in the context of smallholder agriculture and digital transformation in Indonesia. Theoretically, it shows that smart farming adoption must be understood through the relationship between social actors, digital tools, and physical farming environments. Practically, the findings suggest that government agencies, extension workers, technology developers, and farmer groups need to design inclusive smart farming programs based on continuous mentoring, affordable access, simple digital interfaces, and local institutional support. From a policy perspective, smart farming initiatives should move beyond pilot projects and build long-term rural digital ecosystems. Future research should examine adoption patterns across different commodities, regions, gender groups, and planting seasons to better understand how trust, digital literacy, and sustainability outcomes develop over time.

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