**CHAPTER-11**

# CLIMATE SMART AGRICULTURE AND DIGITAL INNOVATIONS: FARM LEVEL TRANSFORMATION FOR SUSTAINABLE AGRICULTURE

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## Abstract

Climate-Smart Agriculture (CSA) combines productivity improvement, resilience building, and reduction of greenhouse gases to respond to increasing challenges posed by climate variations. This research analyzes the impact of digitalization using IoT sensors, remote sensing, artificial intelligence advisory services, and mobile advisories for operational transformation and building resilience against climate change. With a cross-sectional survey involving 176 respondents from agricultural settings of rural and semi-urban areas, the study analyzes awareness, reasons behind usage, barriers, and attitudes towards digital innovations under the concept of Climate-Smart Agriculture. The analysis shows that despite high recognition among respondents regarding the importance of implementing adaptive measures, the implementation of digital tools is rather low at farm level. Key barriers include low digital literacy, lack of adequate infrastructure for connectivity, cost, and non-localized advisory contents. In addition, younger and better-educated respondents are much more ready to embrace innovations, suggesting that adoption is associated with high human capital endowment. Based on this analysis, it appears that full-scale application of digital technologies under CSA requires creating digital ecosystems. Such an approach is necessary for incorporating all key stakeholders and establishing appropriate infrastructure and institutional arrangements.

Keywords: Climate smart agriculture, digital agriculture, farm level transformation, precision farming, climate resilience.

## 1. Introduction

Current global food systems face mounting challenges posed by climatic variation, water shortages, soil degradation, and increased demand. All the above put considerable strain on small-scale and subsistence farmers, whose existence is heavily dependent on agricultural and climatic circumstances. Climate Smart Agriculture (CSA) can help improve food productivity, increase resilience to climatic stress, and lower greenhouse gas emissions (FAO, 2019). The need for flexible technologies that can be used on farms to manage agricultural risk, and decision-making becomes particularly relevant amid climate change.

Technologies including remote sensing technologies, mobile apps for advisory services, IoT sensors, GIS applications, and AI decision support have already proven to be valuable components of CSA frameworks at the farm level (FAO Regional Conference for Europe, 2024). They allow delivering up-to-date climatic information, providing advice regarding the crops, forecasting pests, and optimizing inputs. In contexts where farmers had traditionally struggled with the problem of asymmetric information, these technologies represent an entirely different paradigm in farm advisory systems.

At the same time, while the introduction of digital solutions in agriculture appears quite promising, turning digital potential into practice at the farm level is not always easy. Research shows that digital technology adoption is affected by multiple determinants related to economic, institutional, and behavioral dimensions (Ramaprasad et al., 2023). Among them are the size of a farm, education, income level, internet and smartphone ownership, digital literacy, and extension support. A comprehensive understanding of such determinants is crucial for shaping agricultural policies.

Despite an abundance of academic studies dedicated to technological issues, relatively few researchers focus on studying how digital innovations contribute to qualitative and behavioral changes in farms in the context of CSA, especially in developing countries. One of the most relevant questions in this area concerns the ability of digital advisory solutions to induce behavioral changes at the farm level (Digital Transformation in Agriculture, 2026). In this regard, this study aims to fill the gap in research literature by using primary survey data to analyze attitudes towards digital innovations, their perceived benefits, barriers, and adoption by farming households in India.

## 2. Review of Literature

In today's contemporary agricultural sciences, climate-smart agriculture (CSA) is identified as an indispensable approach towards coping with the problems of climate change, food security, and vulnerability among farming enterprises. Indeed, there is widespread consensus that the implementation of climate-smart agricultural practices is critical for achieving sustainable production, adaptability, and environmental protection amid climate changes (Digital Agriculture Innovations CCARDESA, 2025). With the appearance of digital agriculture, this discourse has become even more complex as digital innovations have come to be regarded as tools that allow the scale-up of CSA use.

The application of remote sensing technologies, mobile advisories, and agricultural data applications are especially notable here because they provide means to monitor crops' condition, forecast weather, detect pests, and plan irrigation in order to boost farm-level efficiency. In this case, precision agriculture approaches that leverage spatiotemporal data to make the most accurate application of inputs have proved their efficiency in minimizing waste and evidence-based decision-making (Frontiers in Sustainable Food Systems, 2023).

Moreover, scholars have shown that small farmers are likely to reap significant advantages from using digital innovations due to information asymmetry and lack of extension services. Indeed, mobile alerts, SMS advisories, and sensors can help to get customized suggestions about sowing timing, fertilizers to apply, and water supply strategies, though the level of benefit will largely depend on the financial capability, connectivity of farms, and ability of their operators to interpret the recommendations received (Digital Transformation in Agriculture, 2026). For example, small farmers in South Asia may not fully utilize the power of innovations owing to inadequate institutions.

As the discussion proceeds, one may observe increasing interest in exploring determinants of digital adoption in the agricultural sector. Whereas in earlier works emphasis was put on technical factors, including access to devices and the Internet, nowadays more attention is paid to social and institutional aspects. Higher education and more financial capacity are positively correlated with adoption, whereas farmers operating in poorly supported and isolated areas still lag behind (Essential Role of Digital Transformation in Agriculture, 2026). Moreover, there are other factors determining the process of technology uptake, including trust, literacy, and extension.

According to the World Bank (2017) estimates and subsequent global analyses, the cost of inaction in terms of macroeconomics in agriculture, including the problem of antimicrobial resistance, is significantly higher than the cost of adaptation.

Similarly, the findings from the current synthesis suggest that the long-run productivity costs resulting from the postponement in the uptake of climate-resilient technologies will be greater than the initial costs incurred in establishing the enabling infrastructure and increasing farmers' digital literacy. However, most research in the existing literature has been focused on the technical and productivity benefits of adopting digital agriculture, while little focus has been paid to the behavioral aspect of adopting digital agriculture at the farm level within the CSA paradigm (FAO Regional Conference for Europe, 2024).

## 3. Methodology

The study will investigate the adoption, awareness, and attitudes towards digital innovation in CSA using a structured survey research tool among a sample of agricultural respondents. The framework is based on four categories, which include: (i) demographic and socio-economic profile of the respondent; (ii) awareness and attitude towards digital innovations and CSA practices; (iii) perceived advantages of digital tools; and (iv) constraints to the adoption of digital technologies.

### 3.1. Survey Design and Instrument

Considering the research aims, a multi-sectoral survey tool was designed to assess knowledge, attitudes, and perceptions regarding CSA and digital agricultural innovations. The tool encompasses technology acceptance constructs, diffusion of innovations, theoretical perspectives, and CSA policy. Survey items have been grouped in five modules: (a) demographics and farm profile; (b) climate and CSA knowledge; (c) usage of digital technology; (d) usefulness and ease-of-use of digital technology; and (e) adoption barriers.

All survey questions have been constructed to facilitate authenticity in answering them. Questions are also crafted with due attention to reading ability, thus making sure the items can be answered in an authentic manner regardless of respondents' background. The survey has been developed in hard copy to enable its administration in person to those lacking access to digital means. Where clarifications are needed, they are provided verbally. Respondents' identities are kept confidential; they have been made aware that their participation is optional, and responses cannot be identified individually.

### 3.2. Sampling and Data Collection

Targeted respondents include farmers and individuals involved in agriculture either directly or indirectly, disregarding factors such as age, sex, education, or farm size. In total, 176 full survey forms were collected through administering the tool in print format personally. Responses were then collated and coded.

The sampling method used in this study is purposive. The sample includes all those who, in one way or another, are involved in agricultural activities such as cultivators, agricultural laborers, agri-input dealers, and extension workers. The purpose of employing this sampling method was to gain insights beyond the perception of farmers alone as regards the adoption of digital technology under the CSA framework. An in-person survey administration method was chosen to reduce self-selection.

### 3.3. Analysis Framework

Data collection, coding, and analysis were carried out following the research objectives. Three stages marked the data analysis process. The first stage involved calculating descriptive statistics for all demographic and adoption-related variables. In the second stage, cross-tabulation and frequency distribution were used to establish trends in awareness, adoption, and barriers related to demographic subgroups. Finally, qualitative synthesis was conducted on open-ended and attitudinal questions to determine emergent themes about farm-level transformation.

The analytical dimensions in this research include: technological dimensions (mobile advisory system, remote sensing technology, IoT sensors, artificial intelligence advice); demographic dimensions (age, education, farm size, income, geographical location); psychological dimensions (risk-taking behavior, confidence, willingness to innovate); socio-cultural dimensions (peer effect, adherence to traditional practices); and institutional dimensions (government programs, extension services, infrastructure). The multidimensional framework is consistent with other theoretical frameworks used in technology adoption literature, including those that inform technology policy modeling studies (Acosta et al., 2026).

## 4. Results

### 4.1 Demographics of Respondents

There were 176 fully filled questionnaires collected. Out of those, 96 (55.6%) were male respondents and 80 (44.6%) were female respondents, making for a balanced representation regarding gender. In terms of the age of the respondents, the highest proportion belonged to the 20-45 age bracket with 84 (46.9%) respondents, followed by 18-25 age bracket with 39 (21.8%) respondents, 46-55 age bracket with 27 (15.1%) respondents, 56-65 age bracket with 18 (10.1%) respondents, and finally, the group above 65 years with 11 (6.1%) respondents. All respondents were involved in agricultural activities in one way or another (Table 1).

**Table 1: Demographic Profile of Respondents**

| Particulars | Category | Number (n) | Percentage (%) |
|---|---|---|---|
| Total responses | — | 176 | 100.0 |
| Gender | Male | 96 | 54.5 |
| Gender | Female | 80 | 45.5 |
| Age | 18-25 years | 39 | 22.2 |
| Age | 20-45 years | 84 | 47.7 |
| Age | 46-55 years | 27 | 15.3 |
| Age | 56-65 years | 18 | 10.2 |
| Age | Above 65 years | 11 | 6.3 |

The demographic data suggest that the respondents are mostly middle-aged people, who fall under the economically active working population. This is especially important for digital technology research since the age group of 20-45 years is more familiar with the use of digital technology compared to other age groups. The balanced representation of gender provides a broader range of analysis, but gender-based adoption trends are discussed in Section 5.

### 4.2. Education

The participants had varied educational backgrounds ranging from secondary education to postgraduate degrees, thus producing a heterogeneous sample as far as formal education is concerned (Table 2). The variation has implications for analysis since educational level has been recognized as one of the major determinants of adopting digital technologies and interpreting data-based suggestions (Digital Transformation in Agriculture, 2026).

**Table 2: Educational Background of Respondents**

| Educational level | Description |
|---|---|
| School level | More than 10 years of schooling |
| Diploma | Diploma holders |
| Undergraduate | Completed graduation |
| Postgraduate | Completed postgraduation |

An increased educational level was found to be correlated with greater knowledge of digital advising tools and readiness to try them out and use them. Those who had postgraduate and undergraduate degrees showed much greater involvement in using digital technology compared to those who graduated from secondary schools as argued by FAO (2019) and Ramaprasad et al. (2023).

### 4.3 Perceived Benefits of Digital Innovations in CSA

Respondents were provided with a set of digital innovations and requested to specify the most important benefits they offer. Table 3 highlights digital tools considered along with their main benefits as noted by survey participants. Mobile advisory platforms were recognized as the most readily available instruments that offered immediate advice in relation to weather reports and crops management. Remote sensing technologies, as well as IoT soil monitoring services, were found useful but complicated and too costly for poorer respondents.

**Table 3: Key Obstacles to the use of Digital Innovations**

| Obstacle | Impact on Usage |
|---|---|
| Low levels of digital literacy | Decreases self-assurance in utilizing digital tools |
| Inadequate network connections | Restricts availability to advisory platforms |
| Expensive costs | Increases costs to make them unaffordable for small-scale farmers |
| Lack of trust | Decreases likelihood of adopting the use of digital recommendations |
| Unlocalized advisories | Decreases relevance of information provided |

Overall, the perception of digital innovation benefits can be largely justified by findings described in the empirical literature. Specifically, respondents with higher levels of education and age believed AI-based advice to be reliable; however, this was not the case for respondents from the less-educated and elderly groups who did not believe in the clarity of advice provided.

### 4.4 Barriers to Digital Innovations Adoption

One of the core findings of the survey was related to the scope and nature of barriers to the adoption of digital innovations that were experienced by the participants of the study. The taxonomy of barriers is presented in Table 4. The lowest level of digital literacy was the barrier reported most often due to structural factors that hindered the ability of participants to use digital recommendations. Low-quality internet connection was one of the key problems among people living in the countryside. Moreover, some barriers were related to costs, such as the price of smartphones and their usage. Finally, distrust in automated systems and disagreement with the recommendation provided due to local knowledge were identified as another type of barrier.

The below-mentioned barriers are consistent with the literature available in the field of the adoption of digital innovations by farmers (Essential Role of Digital Transformation in Agriculture, 2026; FAO, 2019; Frontiers in Sustainable Food Systems, 2023). Specifically, the majority of them are not purely technical but represent more complex challenges related to the institutional and socio-economic contexts. Therefore, the solution should also move beyond addressing technological needs.

**Table 4: Taxonomy of barriers to Digital Innovations adoption in CSA**

| Barrier | Type of Constraint | Group Affected |
|---|---|---|
| Digital illiteracy | Impedes confidence in using technology | Older farmers with low levels of confidence |
| Poor connectivity | Impedes the access of advisory services | Rural and isolated areas |
| High access cost | Limits ability of farmers to pay for the technologies | Marginalized and small-scale farmers |
| Disbelief in advisories | Limits acceptance of technology-based recommendations | All groups, especially older farmers |
| Content not localized | Decreases relevance of advisories | All groups |
| Absence of extension advice | Lack of institutional support for using the technology | Women and small-scale farmers |

### 4.5. Adoption Readiness by Demographic Subgroups

The results from cross-tabulation show considerable differences in the level of adoption readiness among different demographic subgroups. People who are between 18 and 45 years old demonstrated greater knowledge about digital advisory applications on their smartphones, less hesitation when using AI-recommended information, and more adoption readiness as compared to people 55 years old and above, whose attitude remained skeptical towards new technologies, preferring more traditional modes of agricultural extension.

Educational level positively impacted on the level of adoption readiness. Postgraduates and undergraduates claimed they were more aware of the digital platform for advisory purposes and felt that such recommendations had some utility value. Although female participants displayed similar levels of awareness to men, they faced barriers related to device accessibility and the ability to work with digital tools.

## 5. Discussion

The results of this study demonstrate a promising, albeit cautiously optimistic, path towards digital technology adoption under the context of CSA practices. Most survey respondents expressed an understanding of the importance of climate-adaptive farming techniques and also recognized the potential of digital solutions in improving their farms' performance. However, despite their understanding, the adoption rates were not as high, which can be attributed to a similar pattern of technological adoption found in literature studies on this issue (Ramaprasad at al., 2023; FAO, 2019).

A critical observation made in the process of analyzing the collected data was related to the timing of the advantages and disadvantages of adopting digital technologies in the practice of CSA. The initial period when an innovative solution was adopted included financial expenditure on hardware and internet connection, as well as mental cost of mastering the new tool. The benefits, such as enhanced decision making and resource conservation on the one hand, and greater protection against weather risks on the other hand were only realized after some time had passed. The temporally asymmetric pattern observed is likely to resemble another economically-based model of action versus non-action costs (Acosta et al., 2026).

As it turned out, the trustworthiness factor played an important role in encouraging adoption of innovations. Specifically, respondents reported being more willing to follow the recommendation generated automatically by artificial intelligence if the same recommendations came from their personal contact at the local extension office. These insights have implications for designing hybrid digital advisories where the delivery of advice is facilitated by a human rather than automated software. The use of mobile advisory services was perceived most positively, in accordance with existing literature on the topic (FAO, Climate Smart Agriculture, 2022).

The findings on adoption-readiness demographics in the paper coincide with research from other parts of the world. Younger and better-educated respondents show disproportionately high openness toward digital technologies, which is a result of their higher baseline knowledge about digital technologies and greater willingness to accept new sources of information. Older people with relatively lower technological literacy display skepticism regarding innovations, as found in similar studies from South Asia and sub-Saharan Africa (Digital Agriculture Innovations CCARDESA, 2025).

The limitations revealed in this study, such as digital illiteracy, poor infrastructure, and lack of culturally appropriate content, have been noted in international evaluations of the adoption rates of digital agriculture (Essential Role of Digital Transformation in Agriculture, 2026; Frontiers in Sustainable Food Systems, 2023). It is important to note that none of these factors can be addressed solely through technology distribution. Rather, investment in infrastructure, capacity building, and culturally sensitive content become as important to enable digital CSA.

## 6. Limitations

A few limitations of the analysis must be noted while interpreting its results. The scope of the survey was limited since only 176 participants were selected from agricultural communities that live in rural areas and in semi-urban settlements. Although the sample included variations based on age, gender, and level of education, it lacked global or even national representativeness. Therefore, the presented results can be regarded as preliminary exploratory findings.

Second, the use of the cross-sectional research design hinders drawing causation conclusions. It means that correlations can be demonstrated, yet any associations cannot be used to make predictions about how changes in certain variables lead to other processes or vice versa. For instance, longitudinal studies would help establish the impact of various educational efforts and investments in the field of digital infrastructure on farmers' decisions about using new technologies.

Third, even though the in-person survey approach helped to reach people who did not have access to modern technologies, it may still involve social desirability biases since people tend to provide socially acceptable answers to certain questions when interviewed. To minimize such bias, anonymous surveys and guarantees of anonymity were utilized; however, some bias remained.

Fourth, the lack of consideration of environmental externalities related to digital technologies applied to agriculture can be named another limitation. The impact of these factors on the sustainable use of technology should be analyzed; however, the current work is aimed at another set of issues related to digital CSA.

Finally, the analysis did not calculate the cost of non-adoption in monetary terms since no information on the economic consequences of such a decision was obtained during the interview. To obtain such data, additional calculations should be conducted with the assistance of models like those developed for livestock and food systems (Acosta et al., 2026).

**7. Research Areas for the Future**

The limitations discussed above imply various avenues for further research. First, it is important to devise a research design involving longitudinal studies aimed at examining the effects of changes in farmers' awareness, adoption, and behavior resulting from policy intervention such as digital literacy training, device subsidies, and improved rural connectivity.

Second, future research could attempt to quantify the benefits arising from adopting a digital CSA at the farm level. Rather than relying on attitudes alone, researchers should focus on collecting data regarding crop yields, costs of inputs, revenue, and vulnerability to climatic events to conduct a cost-benefit analysis and guide investments by policymakers, development partners, and private sector stakeholders.

Third, it would be useful to conduct a comparative cross-case study to examine whether the findings of this study can be generalized to a broader context and if the barriers to and enablers of digital adoption discussed above exist across diverse agronomic and socioeconomic environments. Comparative cross-country studies using a standardized survey instrument can enhance our understanding of the topic.

Fourth, future research should consider the implications of adopting digital technologies for agricultural production by different genders. This paper has established that women encounter unique barriers pertaining to access to devices and their usage; however, the processes underlying unequal adoption patterns have not been considered in depth. Research informed by gender-sensitive theory would help design digital extension services that account for these dynamics.

Lastly, it would be interesting to conduct a study to explore the possible integration of farm-level behavior models used in this study with larger-scale simulations as done in research related to agricultural system modeling (Acosta et al., 2026). Such an integrative approach will allow for tracing changes in farmers' behavior resulting from policy action through agricultural markets.

**8. Conclusion and Policy Implications**

This paper provides a survey methodology to assess the awareness, adoption, and attitudes towards digital innovation in climate-smart agriculture (CSA). The main contribution of the study is its multidimensional framework that considers the various determinants of digital adoption in a CSA context, including demographics, technology, psychology, sociology, culture, and institutions.

Findings show that digital technologies, ranging from mobile advisory services, IoT sensors, remote sensing technologies, and AI recommendations, hold great promise for improving the efficiency of farms, minimizing waste, and boosting climate resilience. However, the potential of digital innovation is far from being realized due to barriers such as lack of digital literacy, connectivity, cost constraints, and the lack of credible localized advisory content. Digital adoption readiness was positively associated with age and education, showing human capital as an important enabler of technology adoption.

One of the key issues related to technology adoption is the time gap between the cost of adoption and its productivity and resilience payoffs, which creates a natural barrier to adoption, especially in cases when costs occur immediately while the payoff occurs later. Unless there is some institutional intervention, this asymmetry would result in low investments and delayed technology adoption, particularly among the small farmers most exposed to climate risks.

Based on these findings, the following policy recommendations have been formulated. First, agricultural authorities and extension providers need to focus their attention on the development of locally tailored, vernacular digital advisory services using easily accessible modes of delivery, such as text messages and voice calls. Second, training programs incorporating elements of field demonstrations, community seminars, and online learning courses need to be expanded to promote digital literacy among various groups of farmers, with a particular emphasis on empowering female, elderly, and uneducated farmers.

Structurally speaking, investments in rural digital infrastructure, including broadband access, device availability, and energy supply, are crucial for the effective uptake of digital innovations. Public-private cooperation, subsidies for technology provision, and collaborative approaches to extension can help reduce both economic and institutional obstacles to the adoption process. Finally, awareness programs implemented through farmer cooperatives and community networks can boost farmers' confidence in the reliability of digital advisory services.

Like all survey-based studies relying on primary data, this research provides only scenario-consistent predictions rather than generalized forecasts. The model, however, is readily extendable and can serve as a transparent foundation for future investigations. To increase its explanatory power and applicability, the method could be applied to more complex designs, including longitudinal surveys, analysis of economic variables, and coupling with macroeconomic modeling tools.

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