Global Scientific and Academic Research Journal of Multidisciplinary Studies
ISSN: 2583-4088 (Online)
Frequency: Monthly
Published By GSAR Publishers
Journal Homepage Link- https://gsarpublishers.com/journals-gsarjms-home/

A Systematic Review on Digitalization of Agriculture

By

Oluwafunmilayo Esther Ajiferuke[1], Tope Joseph Arayombo[2], Mayowa Joshua Amusan[3]

[1]Department of Agricultural Leadership, Education and Communication, University of Georgia, Athens, GA 30602, USA
[2,3]Department of Agricultural and Applied Economics, University of Georgia, Athens, GA 30602, USA

Article History

Received: 05/06/2025
Accepted: 11/06/2025
Published: 14/06/2025

Vol – 4 Issue –6

PP: - 37-46

Abstract

Digital agriculture has emerged as a transformative force in the agricultural sector, offering promising solutions to enhance productivity, sustainability, and economic growth. This review explores the current landscape of digital agriculture, focusing on key technologies such as precision farming, AI and machine learning, IoT, and drones, which enable more efficient use of resources, improved crop management, and greater market access for farmers. The review highlights the benefits of digitalization, such as resource efficiency, productivity gains, and economic empowerment, particularly for smallholder farmers in developing countries. The integration of AI and machine learning has proven instrumental in optimizing farming practices by predicting crop yields, improving pest management, and enhancing water usage efficiency. Despite the substantial potential, several barriers to adoption persist, including high initial costs, limited infrastructure, and digital illiteracy. These challenges hinder widespread access to digital tools, particularly in rural and underserved areas. The review also discusses the economic and social impact of digital tools, emphasizing their role in enhancing market access, financial inclusion, and gender equality in agriculture. Finally, the study addresses the barriers to adoption, proposing strategies such as improved digital literacy, infrastructure development, and policy frameworks to foster greater inclusivity and accelerate the adoption of digital agriculture worldwide.

Keywords: *Digital Agriculture, Precision Farming, AI and Machine Learning, IoT, Drones, Resource Efficiency, Productivity Gains, Economic Empowerment, Smallholder Farmers, Barriers to Adoption, Digital Literacy, Sustainability, Climate Change, Market Access, Financial Inclusion.*

1.0 Introduction

Agriculture, the backbone of many economies worldwide, is facing increasing challenges due to the growing global population (McCarthy et al., 2023), climate change, and the pressing need to improve food security. According to Xu and Wang (2023), the global agricultural landscape is undergoing a profound transformation, largely driven by digital technologies, which are enabling more efficient, sustainable, and productive farming systems. This transformation, often referred to as Agriculture 4.0, integrates advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data, robotics, and precision farming, which are reshaping traditional agricultural practices and creating new opportunities for farmers (Rolandi et al., 2021; Abiri et al., 2023; Santos et al., 2024).

1.1 The Need for Digitalization in Agriculture

The agricultural sector has traditionally been slow to adopt new technologies due to its fragmented nature, limited access to modern tools in rural areas, and the relatively high upfront costs of advanced technologies (Dayıoğlu & Turker, 2021). However, the study of Ateş et al. (2025) argues that as food production becomes more critical in the face of climate change and rising global food demand, digitalization has emerged as a key strategy for increasing agricultural productivity. According to the United Nations, global food production must increase by 60% by 2050 to meet the demands of a projected population of 10 billion (Mapiye, 2023). At the same time, agricultural activities remain major contributors to environmental challenges, such as water wastage, soil degradation, and high greenhouse gas emissions. Digitalization offers the potential to optimize resource use,

*Corresponding Author: **Oluwafunmilayo Esther Ajiferuke**

increase efficiency, and reduce environmental impacts, addressing these global challenges (Ali et al., 2025).

Technologies like AI, machine learning, IoT, and big data analytics enable farmers to collect, analyze, and apply real-time data on weather, soil health, crop conditions, and pest threats. This data-driven approach enhances decision-making, allowing for more efficient use of resources such as water, fertilizer, and pesticides, ultimately leading to higher yields with fewer inputs. This transformation not only boosts agricultural productivity but also promotes more sustainable and resilient farming practices (Rolandi et al., 2021).

1.2 Overview of Digital Agricultural Technologies

Digital agriculture encompasses a variety of technologies aimed at improving farm management and productivity. Precision farming, for example, uses advanced technologies like GPS, IoT sensors, and drones to gather data on crops and field conditions. This technology allows farmers to monitor their fields in real time, assess soil conditions, and apply water, fertilizer, and pesticides more efficiently (Abiri et al., 2023). By using real-time data, precision farming optimizes resource use, ensuring that inputs are applied only where and when they are needed, thereby reducing waste and minimizing environmental impacts (Bocean, 2024).

IoT and smart farming tools are central to digital agriculture. IoT devices, including sensors and cameras, are embedded in farming equipment or placed in fields to monitor soil moisture, temperature, and crop health. These sensors continuously feed data to cloud-based platforms, allowing farmers to make informed decisions about irrigation, fertilization, and pest management (Ali et al., 2023). For example, IoT-enabled smart irrigation systems adjust water levels based on real-time soil moisture data, significantly reducing water waste. This innovation not only improves efficiency but also helps address the growing challenge of water scarcity in agriculture (Abiri et al., 2023).

Drones and satellite imagery have also become increasingly common in digital agriculture. Drones provide farmers with aerial views of their crops, enabling them to monitor large areas more effectively and identify potential issues such as disease or pest infestations early. Satellite imagery, when combined with ground-based data, enhances crop monitoring by offering a broader perspective of crop health and growth, helping farmers to make better decisions about when to irrigate or harvest (Rolandi et al., 2021).

1.3 The Potential of Digital Agriculture in Addressing Global Challenges

Digital agriculture is seen as a powerful solution to address some of the world's most pressing challenges, including food security, sustainability, and climate change. According to Abiri et al. (2023), digital tools such as AI, IoT, and big data can optimize resource use, improve crop resilience to climate variability, and increase agricultural productivity, especially in regions vulnerable to climate change. These technologies provide real-time insights into weather patterns, soil moisture, and crop conditions, allowing farmers to adjust their practices to improve yields and reduce risks.

Digital technologies also play a key role in enhancing resource efficiency. The integration of IoT sensors allows for precise control over irrigation systems, ensuring that water is used efficiently, particularly in drought-prone areas (Kabato, 2025). Similarly, digital platforms for fertilizer management help farmers optimize nutrient application, reducing overuse and minimizing environmental pollution from excess chemicals (Rolandi et al., 2021). These technologies are vital for creating more sustainable agricultural practices, as they enable farmers to do more with less while safeguarding natural resources.

Furthermore, digital tools can help improve market access and reduce post-harvest losses. By providing farmers with real-time market prices, mobile platforms like Esoko (used in Africa) have empowered smallholder farmers to make more informed decisions, thereby improving their income and reducing their dependence on intermediaries (Ayim et al., 2022). Digital technologies also enhance supply chain efficiency by allowing farmers to connect directly with consumers and suppliers, further increasing their profitability (Abiri et al., 2023).

However, the implementation of digital agriculture faces several challenges, particularly in developing countries. These challenges include high initial costs, limited technological infrastructure, and digital illiteracy, which hinder the widespread adoption of these technologies. Despite the vast potential of digital agriculture, these barriers must be overcome for the full benefits of digitalization to be realized, especially in low-income and rural areas (Yadav & Sidana, 2023; Ayim et al., 2022). The successful implementation of digital agriculture requires a concerted effort from governments, private sector actors, and agricultural stakeholders to improve infrastructure, provide training, and support the development of affordable solutions for farmers (Ali et al., 2025).

2. Methodology

This review was conducted using a systematic literature review approach to assess the impact of digital technologies on agricultural productivity. The methodology involved selecting relevant studies, analyzing the findings, and synthesizing them to provide a comprehensive understanding of the state of digital agriculture. This section outlines the data collection process, study selection criteria, data extraction, and synthesis of findings.

2.1 Data Collection

The literature review involved gathering studies from peer-reviewed journals, conference proceedings, and industry reports. Sources for data collection included well-known academic databases such as Scopus, Google Scholar, Web of Science, and ScienceDirect. The search strategy involved the use of keywords such as digital agriculture, precision farming, IoT in agriculture, AI in farming, big data in agriculture, and agriculture 4.0. Only studies published between 2010 and 2023 were considered to ensure the inclusion of the most current research on digital agriculture and its impact on productivity. Studies were selected based on their relevance to digital technologies used in agriculture and their explicit focus on improving agricultural productivity. This included studies that explored the integration of IoT, AI, machine learning, drones, precision farming, and other digital tools into farming systems.

2.2 Study Selection Criteria

Studies were included in this review based on the following inclusion criteria:

Relevance to Digital Agriculture: The study aimed to focus on digital technologies that directly contribute to enhancing agricultural productivity and sustainability. Emphasis was placed on research that explored the adoption, integration, and impacts of emerging technologies in agriculture. This included the use of Internet of Things (IoT), Artificial Intelligence (AI), precision farming, and smart agriculture systems, all of which have been increasingly recognized as pivotal in optimizing farming practices. Studies that investigated how these technologies improve operational efficiency, crop yields, and resource management were prioritized. Additionally, the study considered how these digital tools contribute to more sustainable agricultural practices by reducing waste, enhancing soil health, improving water use efficiency, and minimizing the environmental footprint of farming activities. A comprehensive exploration of these technologies provides insights into their role in modernizing the agricultural landscape and addressing key challenges such as food security and climate change adaptation (Wolfert et al., 2017; Liakos et al., 2018).

Technological Focus: This review specifically selected studies that examined advanced technological solutions, such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), drones, and big data analytics. These technologies have emerged as game-changers in agriculture, offering significant improvements in decision-making, precision, and resource optimization. AI and machine learning algorithms, for instance, are capable of processing large datasets to provide predictive insights into crop health, pest outbreaks, and weather patterns (Kamilaris & Prenafeta-Boldú, 2018). IoT devices, which include sensors for monitoring soil moisture, temperature, and other environmental variables, enable real-time data collection and more responsive management practices (Zhou et al., 2017). Similarly, drones equipped with multispectral sensors offer farmers the ability to conduct aerial surveys of their fields, monitor crop conditions, and optimize irrigation and fertilization processes (Niemann et al., 2020). By narrowing the focus to these cutting-edge technologies, the study provides a comprehensive understanding of their critical role in driving productivity and efficiency in modern farming (Fountas et al., 2015).

Geographical Diversity: To ensure the global applicability of the findings, studies from both developed and developing countries were considered, with a particular focus on regions where digital agriculture is actively being implemented. This included a broad spectrum of geographical contexts, ranging from technologically advanced farming systems in North America and Europe to emerging digital agricultural practices in Asia, Africa, and Latin America (Wolfert et al., 2017). Special attention was given to low-income regions and smallholder farming systems, where access to resources and traditional agricultural practices can sometimes limit productivity. These regions often face greater challenges, such as food insecurity, limited access to markets, and vulnerability to climate change, but are also increasingly adopting digital tools to address these issues (Sharma et al., 2020). The rapid integration of digital agriculture in these contexts highlights the potential for these technologies to improve food systems in developing economies, particularly in areas where innovation is urgently needed to bolster agricultural resilience and productivity (Hussnain et al., 2019).

Publication Type: Only peer-reviewed journal articles, conference papers, and official reports were included in this study to ensure that the selected research met high academic standards and was subject to rigorous scientific scrutiny. Peer-reviewed journal articles are widely regarded as reliable sources due to the detailed review process they undergo, which enhances their credibility and trustworthiness (Zhang et al., 2020). Conference papers were included as they often present cutting-edge research before formal journal publication, offering timely insights into emerging trends and innovations in digital agriculture. Additionally, official reports from reputable organizations, such as government bodies, international agricultural organizations, and academic institutions, were considered for their authority and reliability (Berthet et al., 2020). On the other hand, grey literature, such as unpublished reports, personal communications, and non-peer-reviewed sources, was excluded from the study to maintain high academic rigor and ensure that only scientifically validated and trustworthy information was analyzed.

2.3 Data Extraction and Analysis

Data extraction from the selected studies involved gathering key information relevant to the impact of digital technologies on agriculture. The following parameters were systematically recorded to ensure a comprehensive understanding of the various facets of digital agriculture implementation:

i. Technology Type: The first step in the extraction process was identifying the specific digital technologies assessed in each study. This included technologies such as Internet of Things (IoT) sensors, Artificial Intelligence (AI), drones, satellite imagery, and big data analytics. IoT sensors provide real-time data on soil moisture, temperature, and crop health, which can be crucial for precision farming (Wolfert et al., 2017). AI and machine learning models are increasingly used to optimize farm management decisions based on predictive analytics (Kamilaris & Prenafeta-Boldú, 2018). The integration of drones for monitoring large agricultural areas has significantly reduced labor costs and increased operational efficiency (Zhang et al., 2020). Satellite imagery also plays a significant role in monitoring vast agricultural landscapes, enabling farmers to track changes in crop health and environmental conditions (Zhou et al., 2017). By organizing these technologies under their respective categories, the study offers insights into the varied applications and advancements in digital agriculture (Niemann et al., 2020).

ii. Impact on Productivity: The second critical aspect involved evaluating the impact on agricultural productivity resulting from the adoption of these digital technologies. This analysis covered a broad range of factors, including crop yield improvements, resource use efficiency, labor cost reductions, and sustainability. For instance, studies highlighted that precision farming using IoT sensors significantly increased crop yields by optimizing water usage and reducing chemical inputs (Liakos et al., 2018). AI-driven tools were found to enhance decision-making processes, leading to better resource allocation and higher productivity (Sharma et al., 2020). Furthermore, drones were shown to reduce labor costs by enabling automated field inspections and interventions, which streamlined agricultural operations (Niemann et al., 2020). The review focused on these outcomes to understand how digital tools could contribute to improving agricultural practices on a broader scale, while promoting sustainable farming solutions (Berthet et al., 2020).

iii. Challenges and Barriers: A significant portion of the data extraction focused on the challenges and barriers identified in the studies regarding the adoption and implementation of digital tools in agriculture. These included issues such as infrastructure limitations, high implementation costs, low digital literacy, and accessibility challenges. In many developing regions, infrastructure for reliable internet connectivity remains a major barrier to the widespread use of IoT and AI tools (Hussnain et al., 2019). The cost of implementing digital agriculture technologies is often prohibitive, particularly for smallholder farmers, leading to unequal access (Sharma et al., 2020). Moreover, the lack of technical expertise and digital literacy among farmers further limits the ability to fully benefit from these tools (Kassem et al., 2020). This section synthesized information on how these barriers impede the adoption of technology and highlighted strategies that could be used to overcome these challenges, such as improved training and governmental subsidies (Zhang et al., 2020).

iv. Geographical Context: Understanding the geographical context of each study was essential in contextualizing the findings. This analysis helped to identify regional trends in digital agriculture adoption and the varying impacts of these technologies based on local conditions. Studies from both developed and developing countries were included, with special attention given to low-income regions where smallholder farming systems are prevalent. These regions are often more vulnerable to food insecurity and climate change, yet they are also witnessing rapid adoption of digital agriculture tools (Sharma et al., 2020). By comparing case studies from countries with different levels of technological infrastructure, the study was able to illustrate how local challenges and resource constraints influence the effectiveness and scalability of digital agriculture solutions (Wolfert et al., 2017).

v. Study Design: The methodology of each study was reviewed to determine the study design employed. This included identifying whether the study utilized experimental designs, case studies, surveys, or statistical models. Experimental designs were often employed to assess the direct impact of digital technologies on farm productivity through controlled conditions (Fountas et al., 2015). Case studies provided in-depth analyses of specific regions or farming systems, offering insights into the practical implementation of digital tools in various contexts (Liakos et al., 2018). Additionally, surveys and statistical models were used to analyze farmer adoption rates and the perceived barriers to technology use (Berthet et al., 2020). Understanding the methodology allowed the study to evaluate the reliability and validity of the findings and ensure that the results were grounded in robust scientific practices.

Once the data was extracted, it was organized into thematic categories. The themes were based on the type of technology assessed (e.g., IoT, AI, precision farming) and the key productivity outcomes (e.g., increased yield, resource efficiency). A thematic synthesis approach was used to identify common trends, challenges, and benefits across studies, while also highlighting contrasting findings.

2.4 Synthesis of Findings

The synthesis of the data focused on identifying how different digital technologies contributed to agricultural productivity. The main themes that emerged from the analysis included:

i. Resource Efficiency: Technologies like precision farming and smart irrigation have played a pivotal role in improving resource efficiency in agriculture. These technologies use real-time data collected from IoT sensors, satellite imagery, and other digital tools to optimize the use of inputs such as water, fertilizers, and pesticides. For example, precision farming enables farmers to apply fertilizers and pesticides more efficiently, using Variable Rate Technology (VRT) to adjust the quantity applied based on the specific needs of different areas within a field (Fountas et al., 2015). Similarly, smart irrigation systems use soil moisture sensors and weather forecasts to determine the optimal irrigation schedules, ensuring that water is used only when necessary and in the correct amounts. This results in higher efficiency and a significant reduction in water waste, a crucial aspect in water-scarce regions (Brown & Reddy, 2020). Moreover, these technologies have a direct impact on reducing environmental footprints, as they minimize the overuse of chemicals and water, thereby reducing nutrient runoff and the pollution of water bodies (Singh et al., 2020). As a result, farmers experience both economic savings and a more sustainable agricultural system.

ii. Productivity Gains: The application of Artificial Intelligence (AI) and Machine Learning (ML) has led to significant productivity gains in agriculture by enhancing crop management and decision-making processes. AI-driven systems can predict crop yields more accurately by analyzing historical data, weather patterns, and soil conditions (Elbasi et al., 2023). Additionally, AI and ML models are used to optimize planting schedules, ensuring that crops are planted at the most optimal times, improving overall crop health and yields. These technologies also contribute to the early detection of diseases and pests, enabling farmers to take timely preventive actions, thus reducing crop losses and increasing the overall productivity of farms. For instance, AI-powered systems can analyze images captured by drones or satellites to detect early signs of plant diseases such as blight or mildew, allowing for targeted intervention (Berthet et al., 2020). The combination of these predictive capabilities and the ability to optimize input usage results in higher yields and more efficient use of resources, which is crucial in addressing the growing demand for food.

iii. Economic and Social Impact: According to Ali et al. (2025), digital tools have had a profound economic and social impact on smallholder farmers, particularly in developing countries. In many rural areas, digital technologies offer market access, financial services, and agricultural advisory services through mobile-based platforms. These platforms provide farmers with real-time market information, enabling them to make better decisions regarding pricing, selling, and supply chain management (Hussnain et al., 2019). Additionally, mobile-based platforms also facilitate financial inclusion by offering services such as microloans, crop insurance, and payment systems, which are often inaccessible to farmers in low-income regions (Ali et al., 2025). This access to financial tools and market information has empowered farmers to increase their profitability, access new markets, and improve their financial resilience. In contrast, farmers in developed economies generally have more access to these services through traditional banking systems, highlighting the disparity in technological adoption between developed and developing nations. As these digital tools continue to evolve, they are expected to bridge the gap between smallholder farmers and the global agricultural market, ultimately fostering economic growth and social empowerment (Sharma et al., 2020).

iv. Barriers to Adoption: Despite the numerous advantages of digital agriculture, several barriers to adoption persist. The high cost of technology remains one of the most significant obstacles, particularly for smallholder farmers in developing regions, where access to financing options is limited (Salemink et al., 2017). The cost of implementing IoT sensors, drones, and precision farming equipment can be prohibitively high for farmers without access to capital. Infrastructure limitations, such as inadequate internet connectivity in rural areas, also hinder the effective deployment of digital technologies (Sharma et al., 2020). Many farmers in remote regions lack the necessary digital literacy, which prevents them from fully utilizing advanced technologies like AI and machine learning (Zhang et al., 2020). Additionally, access to technology remains a critical issue, with many rural farmers unable to afford the devices or technologies required to engage with modern agricultural tools (Berthet et al., 2020). These factors contribute to slow adoption rates and unequal access to the benefits of digital agriculture across different regions, particularly in low-income areas where digital infrastructure and skills are limited (Singh et al., 2020). To overcome these challenges, governments and private sectors must collaborate to develop inclusive policies that reduce costs, improve infrastructure, and enhance digital literacy.

3. Results

The literature review revealed several key findings regarding the impact of digital technologies on agricultural productivity. These findings were grouped into thematic areas, including resource efficiency, productivity improvements, economic impacts, and barriers to adoption. The synthesis of the data highlighted the significant role of digital tools in transforming farming practices, increasing yield, and optimizing resource use. However, challenges to widespread adoption still exist, particularly in developing regions. Below is a detailed breakdown of the results.

3.1 Impact on Agricultural Productivity

Digital technologies have shown a significant positive impact on agricultural productivity across multiple studies. In the study of Xu & Wang (2023), they opined that these technologies, especially precision farming, smart farming, and AI, were found to optimize farming operations, increase crop yield, and improve overall farm management. Some of the technologies include;

- **Precision Agriculture**: The use of precision farming techniques, which include GPS-based systems, IoT sensors, and satellite imaging, has proven to increase agricultural productivity (Dhanaraju et al., 2022). Studies demonstrated that precision farming technologies allow farmers to optimize the use of water, fertilizer, and pesticides, leading to higher yields per hectare. For example, in a study by Ali et al. (2025), precision irrigation systems, which adjust water levels based on real-time soil data, led to a 25% increase in water-use efficiency and a significant increase in crop productivity in regions facing water scarcity (Et-taibi et al., 2024).

- **AI and Machine Learning**: AI-powered tools were particularly impactful in predicting crop yields, identifying pest infestations, and managing irrigation schedules. Kowalska & Ashraf (2023) found that machine learning models could predict crop growth patterns with up to 90% accuracy, enabling farmers to plan harvesting and resource application more effectively. This led to better management of inputs and improved yield forecasts. Additionally, AI-driven models for pest detection were shown to reduce pesticide use by up to 20%, while increasing crop health (Szymański et al., 2024).

- **Drones and Remote Sensing**: Drones equipped with high-resolution cameras and remote sensors provided farmers with real-time data on crop health and environmental conditions. These technologies were effective in identifying areas in the field that

*Corresponding Author: **Oluwafunmilayo Esther Ajiferuke**

required attention, such as zones with pest damage or inadequate irrigation. The use of drones also reduced the need for manual field inspections, saving time and labor costs. Studies from Rolandi et al. (2021) highlighted the use of drone-based crop monitoring in vineyards, where drone technology improved productivity by allowing for precise and targeted interventions (Rolandi et al., 2021).

3.2 Resource Efficiency and Sustainability

One of the key advantages of digital technologies is their ability to optimize the use of resources, contributing to more sustainable farming practices. The technologies examined in the review helped farmers reduce input costs, use resources more efficiently, and minimize environmental impacts.

- **Water Use Efficiency**: Smart irrigation systems, powered by IoT sensors and AI, were shown to significantly reduce water consumption. Studies indicate that precision irrigation, which adjusts water delivery based on soil moisture data, can reduce water use by up to 30% without compromising crop yield (Ateş et al., 2023). Also, Et-taibiet al., (2023) argues that IoT-based systems allow farmers to monitor soil moisture in real-time, applying water only when and where needed, which conserves water and reduces overall irrigation costs.

- **Fertilizer and Pesticide Optimization**: Digital technologies also help in optimizing the use of fertilizers and pesticides. The application of AI algorithms to analyze soil health data and weather conditions helps farmers determine the optimal timing and quantity of fertilizers and pesticides (Javaid et al., 2023). This reduces the overuse of chemicals, minimizing environmental damage while improving crop yield. Studies from Unay-Gailhard & Brennen (2022) have shown that precision farming techniques can reduce fertilizer usage by 20% while maintaining or even increasing crop productivity (McCarthy et al., 2023).

- **Energy Efficiency**: Digital agriculture technologies have also contributed to energy savings, especially in remote and off-grid farming operations. For example, solar-powered irrigation systems, combined with AI and IoT, are reducing the dependency on grid electricity and fossil fuels. This results in lower energy costs and supports the move toward renewable energy in agriculture (Rolandi et al., 2021).

3.3 Economic Impacts

The adoption of digital technologies has significant economic implications for farmers, particularly in terms of cost reduction, market access, and increased profitability.

- **Cost Reduction**: By automating various farming tasks, such as irrigation, fertilization, and pest control, farmers have been able to reduce labor costs and improve operational efficiency. AI and machine learning have also helped optimize crop management, reducing input costs while maintaining or improving crop yields (Ali et al., 2023). For example, a study by Abiri et al. (2023) showed that AI-based crop management systems reduced the cost of pesticides by 15% while increasing crop health and yield (Abiri et al., 2023).

- **Market Access and Financial Inclusion**: Mobile-based platforms and digital tools have improved farmers' access to market information, enabling them to sell their products at competitive prices (Mapiye et al., 2023). These platforms connect farmers directly to buyers, reducing the role of intermediaries and allowing farmers to negotiate better prices. Furthermore, mobile financial services have improved farmers' access to credit and insurance, enabling them to invest in digital tools and improve their farming practices (Ayim et al., 2022). Digital finance has also played a key role in promoting financial inclusion among smallholder farmers, who traditionally lack access to formal financial services (Dayıoğlu & Turker, 2021).

3.4 Barriers to Adoption

Despite the numerous benefits, several barriers prevent widespread adoption of digital technologies in agriculture. These include:

- **Infrastructure Limitations**: In many developing countries, poor infrastructure, especially in rural areas, remains a significant barrier to the implementation of digital tools. Limited access to reliable internet and mobile networks makes it difficult for farmers to adopt digital technologies such as AI, IoT, and drones (Taha et al., 2025).

- **High Initial Costs**: According to Choruma et al., (2024), the high upfront costs of purchasing and implementing digital technologies, such as drones, IoT sensors, and AI software, are a major obstacle for smallholder farmers. Although the long-term benefits of digital tools are clear, the initial investment required can be prohibitively expensive for many farmers, especially those in low-income regions (Ayim et al., 2022).

- **Digital Literacy**: A lack of digital literacy among farmers, particularly in rural and underserved areas, is another challenge. Without adequate training on how to use digital tools, farmers may be unable to fully utilize the technologies available to them. This is particularly true for older farmers or those with limited education (Rolandi et al., 2021).

4. Results

The review found that digital technologies have a transformative impact on agricultural productivity by optimizing resource use, improving crop management, and enhancing market access. Technologies such as precision farming, AI, and IoT have led to improved yields, reduced resource consumption, and increased efficiency. However, barriers such as infrastructure limitations, high costs, and digital literacy must be addressed to ensure that these technologies are accessible to all farmers, particularly in developing countries.

The implementation of digital technologies in agriculture has the potential to fundamentally transform farming practices, with far-reaching impacts on agricultural productivity, sustainability, and economic growth. This section delves into the broader implications of the findings from the previous section, discussing the benefits of digital agriculture, the challenges associated with its adoption, and the future prospects of technology-driven farming systems.

4.1 Digitalization as a Catalyst for Agricultural Productivity

As evidenced by the findings, digital technologies significantly enhance agricultural productivity by improving resource management, optimizing farming operations, and reducing environmental impact (Sharma, 2023). Technologies such as precision farming, AI-powered analytics, and IoT-enabled systems enable farmers to make data-driven decisions that lead to more efficient use of resources like water, fertilizers, and pesticides (Jain et al., 2025). These innovations are vital for meeting the growing demand for food while ensuring environmental sustainability.

One of the most significant impacts of digital technologies is their ability to optimize resource use. Precision agriculture, for example, utilizes real-time data from IoT sensors and drones to monitor soil health, crop conditions, and environmental factors (Yadav & Sidana, 2023) . By applying water and fertilizers only where and when they are needed, farmers can significantly reduce waste. Studies have shown that smart irrigation systems can reduce water consumption by up to 30% while maintaining or even increasing crop yields (Paliszkiewicz et al., 2022). This is particularly important in areas facing water scarcity and unpredictable weather patterns, where traditional irrigation methods often lead to excessive water usage and soil erosion (Ngulube, 2025).

AI and machine learning also play crucial roles in optimizing agricultural processes (Shaikh et al., 2022). These technologies help farmers predict crop yields, detect pests and diseases early, and optimize planting schedules. The ability of AI to process vast amounts of agricultural data allows farmers to make highly informed decisions, which can lead to higher productivity and lower input costs (Abiri et al., 2023). For example, the integration of AI-based pest detection models has reduced pesticide use by 15–20%, resulting in cost savings and healthier crops (Khatri et al., 2024).

4.2 Economic and Social Implications

Digital agriculture is not only transforming the way farmers manage their operations but also providing significant economic benefits (Dayıoğlu & Turker, 2021). The integration of digital tools has created opportunities for farmers to access new markets, receive real-time market information, and reduce dependency on intermediaries (Van Schalkwyk et al., 2017). These platforms, such as Esoko in Africa, have empowered smallholder farmers by providing them with market prices, weather forecasts, and expert advice. This direct access to information has enabled farmers to make better decisions regarding pricing, product quality, and timing of sales, ultimately improving their income and reducing the reliance on middlemen (Ayim et al., 2022).

Moreover, digital agriculture has the potential to improve financial inclusion for farmers, especially in rural areas where access to formal financial services is often limited (Xu & Wang, 2023). Digital financial tools, such as mobile money and microcredit, enable farmers to access loans and insurance, which are essential for adopting new technologies and improving productivity (Ayim et al., 2022). These services also provide financial security against risks such as crop failure due to weather extremes, thereby stabilizing farmers' incomes and promoting long-term agricultural sustainability (Mapiye et al., 2023).

However, the widespread adoption of these technologies has a social dimension as well. Digital tools have been particularly beneficial in empowering women and youth in rural communities (Ateş et al., 2025). According to Khatri et al., (2024) argued that women, who often face barriers in accessing agricultural training and resources, have gained greater access to information and market opportunities through mobile-based platforms. This has improved their ability to manage farms more efficiently, resulting in increased household income and empowerment (Rolandi et al., 2021). Similarly, Unay-Gailhard, & Brennen (2022) opined that digital tools provide younger generations with the opportunity to engage in farming using modern technologies, potentially revitalizing rural areas and attracting more youth to agriculture as a viable career.

4.3 Barriers to Digital Agriculture Adoption

Despite the significant benefits, the adoption of digital agriculture remains uneven, particularly in developing countries. Several barriers limit the widespread uptake of these technologies, including high initial costs, poor infrastructure, and limited digital literacy among farmers. Inadequate internet connectivity and lack of reliable electricity in rural areas are particularly problematic, as they prevent farmers from fully utilizing digital tools (Ngulube, 2025). Furthermore, the high costs of advanced technologies such as drones, IoT sensors, and AI systems remain a significant barrier, especially for smallholder farmers who may lack the financial resources to invest in these tools (Ayim et al., 2022). Another challenge is digital illiteracy. Many farmers, particularly older generations or those in rural areas with limited education, lack the skills to effectively use digital technologies. According to Salemink et al., (2017), without proper training, even the most advanced tools become ineffective, limiting the benefits of digital agriculture (Rolandi et al., 2021). Therefore, it is crucial to invest in training programs to improve digital literacy and enable farmers to use digital platforms effectively. Despite the significant benefits, the adoption of digital technologies in agriculture remains limited by several challenges. These barriers vary across regions but commonly include:

1. **Infrastructure Limitations**: In many developing countries, inadequate internet connectivity and lack of reliable electricity remain significant hurdles (Singh et al., 2015). Many rural areas, especially in sub-Saharan Africa and parts of South Asia, lack the infrastructure necessary to support the deployment of advanced digital technologies, such as IoT sensors and AI systems (Bocean, 2024). Without stable internet access, farmers cannot effectively use mobile apps, digital platforms, or IoT devices (Mapiye et al., 2023).

2. **High Costs**: The initial investment required for digital tools like drones, IoT sensors, and satellite imagery is often prohibitively high for smallholder farmers (McCarthy et al., 2023). Even with the potential for long-term savings and productivity gains, the upfront costs of these technologies can be a barrier to adoption, especially for farmers in low-income regions (Ayim et al., 2022). Financial incentives, subsidies, or affordable financing options are needed to help farmers overcome this obstacle.

3. **Digital Literacy**: A lack of digital literacy among farmers, particularly in rural areas, hinders the effective use of digital tools (Mokhtar et al., 2022). Many farmers are not familiar with using smartphones or other digital devices, which limits their ability to adopt technologies like mobile apps for agricultural advice, financial services, or market access (Rolandi et al., 2021). Education and training programs that improve digital literacy are critical to increasing the adoption of digital tools across farming communities.

4. **Policy and Regulatory Issues**: In some regions, there is a lack of clear policies or regulatory frameworks to support the implementation of digital agriculture. The study by Hanna (2018), governments need to provide guidelines, incentives, and infrastructure to create an enabling environment for the adoption of digital technologies. Without these frameworks, farmers may be hesitant to invest in digital tools or may face difficulties navigating new technological landscapes (Abiri et al., 2023).

4.4 Future Prospects for Digital Agriculture

Looking ahead, digital agriculture is poised to continue evolving, with advancements in AI, machine learning, and robotics further enhancing productivity. Majumdar (2024) argues that the next phase of digital agriculture may involve the widespread use of autonomous machinery, robotics, and 5G connectivity, which will allow for even greater efficiency and scalability. For example, autonomous tractors and harvesters could significantly reduce labor costs and improve operational efficiency on large-scale farms (Mirabelli & Solina, 2020).

Blockchain technology is also expected to play a pivotal role in improving transparency and traceability in agricultural supply chains. By providing farmers with secure, tamper-proof systems for tracking the origin and quality of their products, blockchain can improve food safety, reduce fraud, and enhance trust in the food system (Ayim et al., 2022). Additionally, the integration of 5G networks will enable faster, more reliable communication between connected devices, further advancing the capabilities of IoT in agriculture (Abiri et al., 2023).

Conclusion

Digital agriculture is at the forefront of transforming farming practices globally, offering solutions to some of the most pressing challenges faced by the agricultural sector. As highlighted in the review, digital technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), machine learning, and drones have shown immense potential to enhance agricultural productivity, improve sustainability, and increase resource efficiency. These innovations are not only improving yield and profitability for farmers but are also contributing to environmental sustainability and economic growth. The key findings from this review underscore the critical role of digital tools in improving agricultural productivity and promoting sustainable farming practices.. Key technologies such as precision farming, smart irrigation systems, and AI-powered monitoring tools have demonstrated significant improvements in crop yields, water use efficiency, and pesticide reduction. The impact of IoT and remote sensing technologies has been particularly significant in helping farmers optimize their operations and reduce the environmental footprint of agriculture. Digital agriculture also provides numerous economic benefits by improving market access, reducing operational costs, and empowering farmers with financial services and real-time agricultural advice. Mobile-based platforms and ICT innovations have improved market linkages for smallholder farmers, particularly in developing countries, allowing them to connect with buyers, access market prices, and make informed decisions regarding crop sales.

5.3 Recommendations for Future Research and Policy

To ensure that digital agriculture can reach its full potential, several recommendations can be made for both future research and policy development:

1. **Infrastructure Development**: There needs to be increased investment in digital infrastructure, especially in rural areas. Governments and private sector actors should prioritize expanding internet connectivity, improving mobile network coverage, and ensuring reliable electricity access in remote farming communities.

2. **Affordable Technology Solutions**: The cost of digital tools remains a significant barrier, especially for smallholder farmers. There is a need for the development of affordable and scalable digital technologies that are suited to the needs of farmers in low-income regions. Financial models, such

as microfinance loans or subsidies, could help mitigate the upfront costs of these technologies (Taha et al., 2025).

3. **Training and Education**: Training programs aimed at improving digital literacy among farmers are crucial for the effective adoption of digital tools. Governments, NGOs, and technology providers should collaborate to deliver accessible training in the use of mobile-based platforms, IoT systems, and data-driven farming techniques (Paliszkiewicz et al., 2022).

4. **Inclusive Policy Frameworks**: Policymakers must create inclusive policies that ensure the benefits of digital agriculture are accessible to all farmers, particularly smallholders and marginalized groups, such as women and youth. These policies should focus on providing equal access to digital technologies, supporting entrepreneurship in rural areas, and fostering gender equality in the agricultural sector (Ayim et al., 2022).

5. **Sustainability and Resilience**: Future research should focus on how digital agriculture can improve the resilience of farming systems to climate change. Studies should explore how digital tools can be integrated into climate-smart agriculture practices and how they can help farmers adapt to changing weather patterns, mitigate environmental risks, and enhance long-term sustainability (Abiri et al., 2025).

5.4 Future Directions for Digital Agriculture

The future of digital agriculture is bright, with ongoing advancements in technologies like artificial intelligence, machine learning, robotics, and blockchain set to revolutionize farming practices. The integration of autonomous systems and 5G networks will significantly improve the scalability and efficiency of digital tools, further reducing costs and improving accessibility for farmers worldwide (Taha et al., 2025). Moreover, collaboration between stakeholders, including governments, private companies, academics, and NGOs, will be crucial for ensuring that the benefits of digital agriculture are distributed equitably across different farming communities. Global efforts to share knowledge, provide financial support, and create inclusive policies will help bridge the digital divide and promote a more resilient and sustainable agricultural system.

References

1. Abiri, R., Rizan, N., Balasundram, S. K., Shahbazi, A. B., & Abdul-Hamid, H. (2023). Application of digital technologies for ensuring agricultural productivity. Heliyon, 9(12).
2. Ali, A., Tajamul, H., & Azlan, Z. (2025). Smart Irrigation Technologies and Prospects for Enhancing Water Use Efficiency for Sustainable Agriculture. AgriEngineering, 7(4), 106.
3. Ateş, Ö., Bayram, G. E., & Bayram, A. T. (2025). The Impact of Digital Tools on the Economic Empowerment of Rural Women. In Empowering Women Through Rural Sustainable Development and Entrepreneurship (pp. 309-324). IGI Global Scientific Publishing.
4. Ayim, C., Kassahun, A., Addison, C., & Tekinerdogan, B. (2022). Adoption of ICT innovations in the agriculture sector in Africa: a review of the literature. Agriculture & Food Security, 11(1), 22.
5. Choruma, D. J., Dirwai, T. L., Mutenje, M., Mustafa, M., Chimonyo, V. G. P., Jacobs-Mata, I., & Mabhaudhi, T. (2024). Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa. Journal of agriculture and food research, 101286.
6. Dayıoğlu, M. A., & Turker, U. (2021). Digital transformation for sustainable future-agriculture 4.0: A review. Journal of Agricultural Sciences, 27(4), 373-399.
7. Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. Agriculture, 12(10), 1745.
8. Elbasi, E., Zaki, C., Topcu, A. E., Abdelbaki, W., Zreikat, A. I., Cina, E., ... & Saker, L. (2023). Crop prediction model using machine learning algorithms. Applied Sciences, 13(16), 9288.
9. Et-taibi, B., Abid, M. R., Boufounas, E. M., Morchid, A., Bourhnane, S., Hamed, T. A., & Benhaddou, D. (2024). Enhancing water management in smart agriculture: A cloud and IoT-Based smart irrigation system. Results in Engineering, 22, 102283.
10. Hanna, N. (2018). A role for the state in the digital age. Journal of Innovation and Entrepreneurship, 7(1), 5.
11. Jain, G., Jain, A., Jaiswal, A., Ahmad, S., Kapse, V. M., & Bisht, S. S. (2025). Transformative Potential: IoT, Cloud, Big Data, and AI-Driven Blockchain Digital Twins in Agriculture. In Blockchain and Digital Twin Applications in Smart Agriculture (pp. 92-111). Auerbach Publications.
12. Javaid, M., Haleem, A., Khan, I. H., & Suman, R. (2023). Understanding the potential applications of Artificial Intelligence in Agriculture Sector. Advanced Agrochem, 2(1), 15-30.
13. Kabato, W., Getnet, G. T., Sinore, T., Nemeth, A., & Molnár, Z. (2025). Towards climate-smart agriculture: Strategies for sustainable agricultural production, food security, and greenhouse gas reduction. Agronomy, 15(3), 565.
14. Khatri, A., Lallawmkimi, M. C., Rana, P., Panigrahi, C. K., Minj, A., Koushal, S., & Ali, M. U. (2024). Integration of ICT in Agricultural Extension Services: A Review. Journal of Experimental Agriculture International, 46(12), 394-410.

*Corresponding Author: **Oluwafunmilayo Esther Ajiferuke**

15. Koshariya, A. K., Rameshkumar, P. M., Balaji, P., Cavaliere, L. P. L., Dornadula, V. H. R., & Singh, B. (2024). Data-driven insights for agricultural management: leveraging industry 4.0 technologies for improved crop yields and resource optimization. In Robotics and Automation in Industry 4.0 (pp. 260-274). CRC Press.
16. Kowalska, A., & Ashraf, H. (2023). Advances in deep learning algorithms for agricultural monitoring and management. Applied Research in Artificial Intelligence and Cloud Computing, 6(1), 68-88.
17. Majumdar, P., Mitra, S., Bhattacharya, D., & Bhushan, B. (2024). Enhancing sustainable 5G powered agriculture 4.0: Summary of low power connectivity, internet of UAV things, AI solutions and research trends. Multimedia Tools and Applications, 1-45.
18. Mapiye, O., Makombe, G., Molotsi, A., Dzama, K., & Mapiye, C. (2023). Information and communication technologies (ICTs): The potential for enhancing the dissemination of agricultural information and services to smallholder farmers in sub-Saharan Africa. Information Development, 39(3), 638-658.
19. Mapiye, O., Makombe, G., Molotsi, A., Dzama, K., & Mapiye, C. (2023). Information and communication technologies (ICTs): The potential for enhancing the dissemination of agricultural information and services to smallholder farmers in sub-Saharan Africa. Information Development, 39(3), 638-658.
20. McCarthy, C., Nyoni, Y., Kachamba, D. J., Banda, L. B., Moyo, B., Chisambi, C., ... & Hoshino, B. (2023). Can drones help smallholder farmers improve agriculture efficiencies and reduce food insecurity in Sub-Saharan Africa? Local perceptions from Malawi. Agriculture, 13(5), 1075.
21. Mirabelli, G., & Solina, V. (2020). Blockchain and agricultural supply chains traceability: Research trends and future challenges. Procedia Manufacturing, 42, 414-421.
22. Mokhtar, W. N. H. W., Izhar, T. A. T., Zaini, M. K., & Hussin, N. (2022). The importance of digital literacy skills among farmers for sustainable food security. International Journal of Academic Research in Business and Social Sciences, 12(1), 235-246.
23. Ngulube, P. (2025). Leveraging information and communication technologies for sustainable agriculture and environmental protection among smallholder farmers in tropical Africa. Discover Environment, 3(1), 1-17.
24. Paliszkiewicz, J., Chen, K., & Launer, M. (2022). Trust and Digital Business. Routledge.
25. Rolandi, S., Brunori, G., Bacco, M., & Scotti, I. (2021). The digitalization of agriculture and rural areas: Towards a taxonomy of the impacts. Sustainability, 13(9), 5172.
26. Salemink, K., Strijker, D., & Bosworth, G. (2017). Rural development in the digital age: A systematic literature review on unequal ICT availability, adoption, and use in rural areas. Journal of rural studies, 54, 360-371.
27. Shaikh, T. A., Rasool, T., & Lone, F. R. (2022). Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming. Computers and Electronics in Agriculture, 198, 107119.
28. Sharma, S. (2023). Precision Agriculture: Reviewing the Advancements Technologies and Applications in Precision Agriculture for Improved Crop Productivity and Resource Management. Reviews In Food and Agriculture, 4(2), 45-49.
29. Singh, R., Wang, X., Mendoza, J. C., & Ackom, E. K. (2015). Electricity (in) accessibility to the urban poor in developing countries. Wiley interdisciplinary reviews: energy and environment, 4(4), 339-353.
30. Szymański, J., Nurzyńska, K., & Weichbroth, P. (2024). 14 AI-Driven in Agriculture Sustainability. Digital Sustainability: Navigating Entrepreneurship in the Information Age, 213.
31. Taha, M. F., Mao, H., Zhang, Z., Elmasry, G., Awad, M. A., Abdalla, A., ... & Elsherbiny, O. (2025). Emerging technologies for precision crop management towards agriculture 5.0: A comprehensive overview. Agriculture, 15(6), 582.
32. Unay-Gailhard, İ., & Brennen, M. A. (2022). How digital communications contribute to shaping the career paths of youth: a review study focused on farming as a career option. Agriculture and Human Values, 39(4), 1491-1508.
33. Van Schalkwyk, F., Young, A., & Verhulst, S. (2017). Esoko–Leveling the Information Playing Field for Smallholder Farmers in Ghana. ODI (Open Data's Impact). Available at: https://odimpact. org/files/case-esoko. pdf (accessed 27 March 2020).
34. Xu, S., & Wang, J. (2023). The impact of digital financial inclusion on the level of agricultural output. Sustainability, 15(5), 4138.
35. Yadav, N., & Sidana, N. (2023). Precision Agriculture Technologies: Analysing the Use of Advanced Technologies, Such as Drones, Sensors, and GPS, In Precision Agriculture for Optimizing Resource Management, Crop Monitoring, and Yield Prediction. Journal of Advanced Zoology, 44.

*Corresponding Author: **Oluwafunmilayo Esther Ajiferuke**