 ISSN: 2833-986X

REVIEW ARTICLE

The Role of Artificial Intelligence in Modern Farming System for Achieving Sustainable Agricultural Transformation in Nigeria

Aminu Adamu Ahmed*[1], Rilwanu Sulaiman[2], Nasiru Adamu[3] , Yusuf Musa[4]

[1]Department Information Communication Technology, Federal Polytechnic Kaltungo, Gombe State, Nigeria
[2]Department of Animal Science, Faculty of Agriculture, Sa'adu Zungur University, Bauchi State, Nigeria
[3]Department of Animal Production, Abubakar Tafawa Balewa University Bauchi, Bauchi State, Nigeria
[4]Department of Computer Sciences, Federal Polytechnic Nasarawa, Nasarawa State, Nigeria

Corresponding Author: Aminu Adamu Ahmed. Email: aminuaa.inkil@gmail.com
Received: 01 September, 2024, Accepted: 23 September, 2024, Published: 25 September, 2024

Abstract

The agricultural sector in Nigeria faces pressing challenges, including food insecurity, land degradation, and climate change impacts. To address these issues, the integration of artificial intelligence (AI) in modern farming practices presents a transformative opportunity for achieving sustainable agricultural development. This paper explores the role of AI technologies in enhancing productivity, optimizing resource use, and minimizing environmental impacts within the Nigerian agricultural landscape. Through a semi-systematic literature review (SLR), the study examines the historical context of agriculture in Nigeria, current AI applications such as precision agriculture, crop monitoring, and pest detection, as well as the associated benefits of increased yield and economic returns for farmers. The semi-SLR methodology incorporates structured search strategies, established inclusion and exclusion criteria, and systematic data extraction techniques to synthesize existing knowledge and identify gaps in the current understanding of AI's impact on sustainable farming in Nigeria. The findings reveal that while AI can significantly contribute to sustainable agricultural transformation, several barriers hinder its widespread adoption, including infrastructural deficiencies, technological illiteracy, and socio-economic constraints. By analyzing these aspects, this research underscores the importance of a structured approach to literature reviews in agricultural research, ultimately aiming to inform policy and encourage the adoption of AI innovations in the sector. The findings indicate that concerted efforts from stakeholders, including policymakers, researchers, and farmers, are essential to overcome existing challenges and fully realize the potential of AI in fostering a resilient agricultural system in Nigeria.

Keywords: Artificial Intelligence; Sustainable Agriculture; Nigeria; Precision Farming; Food Security; Agricultural Transformation

Introduction

Agriculture is a cornerstone of Nigeria's economy, employing over 70% of the workforce and contributing approximately 22% to the nation's Gross Domestic Product (GDP) (Food and Agriculture Organization [FAO], 2020). The sector is characterized by smallholder farming, with many farmers relying on traditional practices that often result in low productivity and inefficient resource use. Despite Nigeria's vast agricultural potential, challenges such as land degradation, inadequate infrastructure, and fluctuating climatic conditions have hindered

significant growth (Ibitoye et al., 2021). Additionally, food insecurity remains a critical issue, with about 25% of the population facing severe food shortages (World Food Programme [WFP], 2022). Given these challenges, it is imperative to explore innovative solutions that can enhance agricultural practices and ensure food security while promoting environmental sustainability. Sustainable agricultural transformation is essential for addressing food security, enhancing productivity, and mitigating the adverse effects of climate change (United Nations [UN], 2019). This transformation involves adopting practices that increase agricultural output while preserving natural resources and ensuring the welfare of farming communities. In Nigeria, sustainable agricultural practices can lead to improved soil health, better water management, and increased resilience to climate variability (Ojo et al., 2021). Furthermore, sustainable agriculture can also contribute to economic growth by providing job opportunities, enhancing rural livelihoods, and reducing poverty (Adesina et al., 2020).

Therefore, the integration of innovative technologies, such as artificial intelligence (AI), is crucial for achieving these sustainability goals in the agricultural sector. Artificial intelligence technologies have emerged as powerful tools capable of revolutionizing modern farming practices. AI applications in agriculture include precision farming, autonomous machinery, crop monitoring systems, and predictive analytics for yield forecasting (Wolfert et al., 2017). For instance, precision agriculture leverages AI to analyze data collected from various sources, enabling farmers to make informed decisions regarding resource allocation, pest management, and crop health monitoring (Kamilaris & Prenafeta-Boldú, 2018). Moreover, AI-driven systems can enhance the efficiency of agricultural operations by automating labor-intensive tasks and improving overall productivity ((Zhang, 2022;Sullivan et al., 2020). As such, the adoption of AI technologies in Nigerian agriculture could significantly contribute to sustainable agricultural transformation by optimizing resource use and increasing crop yields. This study aims to explore the role of AI in modern farming practices and its potential to facilitate sustainable agricultural transformation in Nigeria.

By conducting a systematic literature review, the research will identify the current state of AI applications in agriculture, the benefits its provide, and the barriers to its adoption. Ultimately, the findings will contribute to a deeper understanding of how AI can be leveraged to enhance agricultural sustainability in Nigeria, informing policymakers, researchers, and practitioners. Moreover, to provide empirical and case studies data, AI adoption across Nigerian six geopolitical zones, as well as socio-economic classes, finally, the technology readiness for AI adoption in agriculture.

Literature Review

This literature review explores the role of artificial intelligence (AI) in modern farming, particularly in the context of sustainable agricultural transformation in Nigeria. It covers the historical context of agricultural practices, emerging AI technologies, global perspectives on AI in sustainable farming, and the current state of research in Nigeria.

Historical Context of Agricultural Practices in Nigeria

Agriculture has been a cornerstone of Nigeria's economy, historically characterized by subsistence farming practices. Traditional agricultural methods relied heavily on manual labor, indigenous knowledge, and local environmental conditions, which often resulted in low productivity. According to Ogunniyi (2021), the reliance on traditional practices has made farmers vulnerable to environmental changes such as climate variability, pest infestations, and soil degradation. Over the years, Nigeria's agricultural sector has faced numerous challenges, including inadequate infrastructure, limited access to markets, and insufficient technology adoption (Giua et al., 2020; Ojo et al., 2020). The introduction of modern agricultural techniques and technologies has been slow, but

recent trends indicate a shift towards more sustainable practices. The Nigerian government has recognized the need for agricultural transformation, aiming to enhance productivity and resilience against climate change through policies that promote technology adoption (Nigerian Federal Ministry of Agriculture & Rural Development, 2022).

Emerging AI Technologies in Agriculture

Emerging AI technologies are revolutionizing agricultural practices by providing tools for real-time monitoring, predictive analytics, and automated decision-making. Technologies such as machine learning, computer vision, and drones are increasingly being utilized to optimize farming operations. For instance, AI algorithms can analyze data from soil sensors, weather forecasts, and satellite imagery to determine optimal planting schedules and manage irrigation efficiently (Kumar et al., 2022). A study by Adebayo et al. (2023) shows that AI-driven precision agriculture can significantly enhance crop yields while reducing resource wastage. The integration of AI in agriculture not only improves productivity but also promotes sustainable practices by minimizing the environmental impact of farming. For example, AI systems can predict pest outbreaks, allowing for timely interventions that reduce the need for harmful pesticides (Singh et al., 2021).

Global Perspectives on AI in Sustainable Farming

Globally, AI is recognized as a transformative force in achieving sustainable agricultural practices. Countries are increasingly adopting AI-driven solutions to address food security challenges posed by a growing population and climate change. The concept of "smart farming," which incorporates AI, IoT, and robotics, is gaining traction as a means to secure food production while ensuring environmental sustainability (Wolfert et al., 2017). For instance, in developed countries like the United States and Canada, AI technologies are being employed in precision agriculture to enhance resource allocation and improve crop management (Zhang et al., 2019). These AI applications contribute to broader sustainability goals, such as reducing greenhouse gas emissions and conserving biodiversity. Such global perspectives underscore the potential of AI not only to increase agricultural productivity but also to contribute to the sustainability of food systems worldwide.

Current State of Research in Nigeria

Research on AI in agriculture within Nigeria is still in its nascent stages, but it is rapidly gaining momentum. Recent studies have highlighted the potential benefits of AI technologies in addressing the challenges faced by Nigerian farmers, such as low productivity and knowledge gaps (Abdul et al., 2023). Initiatives aimed at educating farmers about AI applications and providing access to these technologies are crucial for enhancing agricultural outputs. Furthermore, ongoing research focuses on developing AI solutions tailored to the unique agricultural conditions in Nigeria. For instance, projects aimed at creating localized AI models for predicting crop yields and disease outbreaks are being explored (Ibrahim et al., 2023). As the agricultural landscape evolves, the integration of AI is expected to play a pivotal role in transforming Nigeria's agricultural sector into a more sustainable and productive system.

Methodology

A semi-systematic literature review is a research methodology that combines elements of both systematic and traditional literature reviews. It is designed to provide a comprehensive overview of existing literature while allowing for some flexibility in the selection and evaluation of sources. The primary purpose of a semi-SLR is to synthesize findings from various studies to identify trends, gaps, and insights related to a specific research question

(Munn et al., 2018). Unlike a fully systematic review, which follows strict protocols for study selection and data extraction, a semi-SLR allows researchers to be more exploratory, accommodating diverse types of literature, including empirical studies, theoretical papers, and grey literature (Peters et al., 2015). This approach is particularly beneficial in rapidly evolving fields such as artificial intelligence in agriculture, where new findings and technologies frequently emerge.

Search Strategies

The search strategy for this semi-SLR involved a comprehensive and iterative process using multiple academic databases, including Scopus, Web of Science, and Google Scholar. Keywords and phrases relevant to the research topic, such as (artificial intelligence in agriculture, OR (AI applications in agriculture, AND (sustainable farming in Nigeria,))) were utilized to maximize the breadth of literature retrieved (Higgins & Green, 2011). Boolean operators (AND, OR) were employed to refine searches, allowing for a combination of terms that targeted specific aspects of AI and sustainable agriculture. Additionally, the search included recent publications from the last ten years to ensure the review reflected the most current advancements and challenges in the field (Khalil et al., 2020).

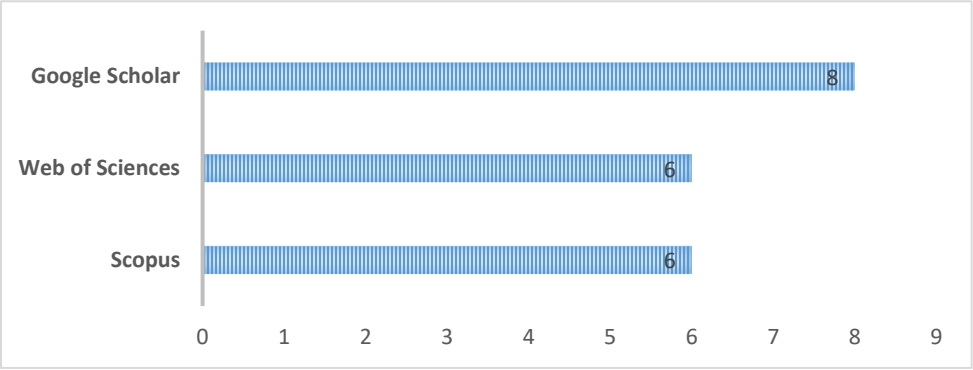

Figure 1. Reputable academic databases

Inclusion and Exclusion Criteria

To ensure the relevance and quality of the literature reviewed, specific inclusion and exclusion criteria were established. Studies excluded or included in the review were required to meet the following criteria as shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
- It must focus on the application of AI technologies in agriculture specifically within the context of Nigeria or similar developing countries. - It must be peer-reviewed articles, conference papers, or credible grey literature published within the last decade - It must provide empirical data or substantial theoretical insights relevant to sustainable agricultural transformation	- Studies were excluded if it did not pertain to AI, were not related to agriculture, or were published before 2015. - Literature that lacked rigor or was not peer-reviewed was also excluded to maintain the integrity of the review - Literature that failed to provide empirical data or substantial theoretical insights relevant to sustainable agricultural transformation

Data Extraction and Synthesis Techniques

Data extraction involved systematically cataloging information from the selected studies, including authorship, publication year, study design, key findings, and relevant methodologies. A standardized extraction form was developed to facilitate consistency and accuracy (Higgins & Green, 2011). Following extraction, the synthesized data were analyzed qualitatively, employing thematic analysis to identify common themes, trends, and challenges associated with the adoption of AI in Nigerian agriculture. The synthesis process also involved a narrative approach to contextualize findings within the broader landscape of sustainable agricultural practices, drawing connections between the literature and the overarching research aim (Thomas & Harden, 2008). This combination of qualitative and quantitative synthesis allowed for a comprehensive understanding of the role AI plays in transforming agriculture in Nigeria.

Results and Discussion

Overview of AI Applications in Modern Farming

The integration of artificial intelligence (AI) in modern farming practices has revolutionized agricultural operations, enhancing efficiency and sustainability. This section discusses key AI applications that are transforming agriculture, particularly in the context of Nigeria.

Resource Optimization (Water, Fertilizer, etc.)

AI applications also play a vital role in optimizing resource use in agriculture, particularly concerning water and fertilizer management and it constitutes 40% of 20 literature reviewed in this study (see Figure 2). Smart irrigation systems powered by AI can analyze weather forecasts, soil moisture levels, and crop water requirements to deliver precise amounts of water, thereby conserving this critical resource (Khan et al., 2020). Similarly, AI algorithms can optimize fertilizer application by determining the right type and amount needed for specific crops, reducing waste and environmental impact (Zhang et al., 2020). In Nigeria, where water scarcity and soil degradation are pressing issues, the adoption of AI-driven resource optimization techniques can lead to more sustainable agricultural practices and improved resilience to climate change.

Crop Monitoring and Management

AI-driven crop monitoring systems utilize remote sensing technologies and data analytics to track crop growth and health in real-time (Fang & Su, 2021). As shown in Figure 2, it constitutes 35% of 20 literature used in this study. These systems can detect variations in crop conditions, such as nutrient deficiencies or water stress, allowing farmers to respond promptly (Zhang et al., 2019). For instance, AI algorithms can analyze images captured by drones or satellites to assess crop vigor and identify areas that require attention (Shafique et al., 2020). In Nigeria, implementing such monitoring systems can significantly enhance crop management practices, leading to improved productivity and reduced losses due to pests or diseases.

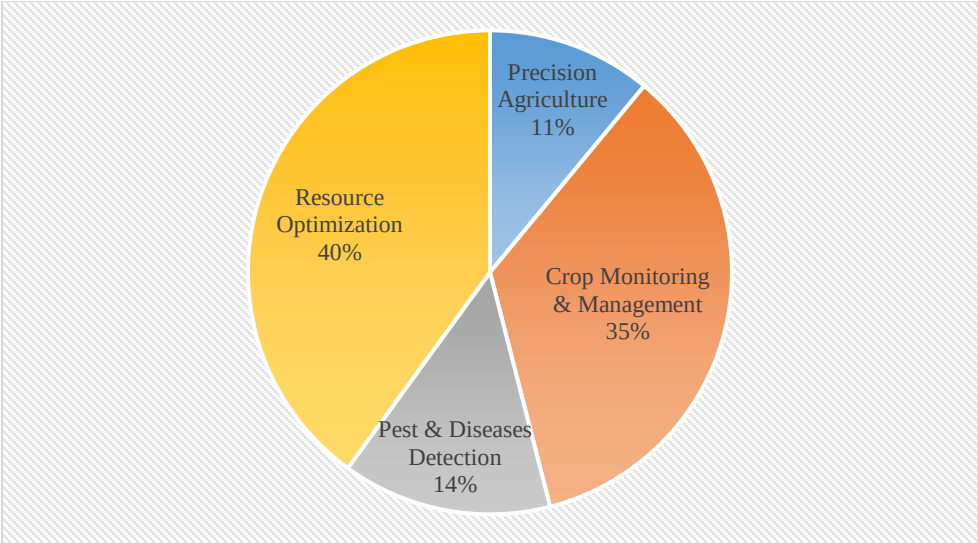

Figure 2. Key AI application for agricultural transformation in Nigeria

Pest and Disease Detection

Figure 2 illustrated 14% of the 20 literature revealed that the early detection of pests and diseases, is crucial for minimizing crop losses and ensuring food security (Farina et al., 2023). AI technologies, including computer vision and machine learning, are increasingly being used to identify pest infestations and disease outbreaks (Liu et al., 2020). For example, AI models can analyze images of crops to detect symptoms of diseases or the presence of pests, enabling farmers to take timely action (Ferentinos, 2018). In Nigeria, where smallholder farmers often lack access to extension services, AI-based pest and disease detection tools can empower them to manage their crops more effectively, reducing reliance on chemical pesticides and promoting sustainable practices.

Precision Agriculture

Precision agriculture which constitutes 11% of 20 literature of AI and agricultural transformation as shown in Figure 2, is one of the most significant applications of AI in farming. It involves the use of AI technologies to analyze data collected from various sources, such as satellite imagery, drones, and sensors, to optimize farming practices (Wolfert et al., 2017). By employing machine learning algorithms, farmers can gain insights into soil health, crop conditions, and weather patterns, enabling them to make informed decisions regarding planting, irrigation, and harvesting (Kamilaris & Prenafeta-Boldú, 2018). In Nigeria, precision agriculture can help smallholder farmers increase their yields while minimizing resource waste, ultimately contributing to sustainable agricultural practices (Ojo et al., 2021).

In summary, the application of AI in modern farming offers numerous benefits, including enhanced productivity, improved resource management, and increased sustainability. As Nigeria seeks to transform its agricultural sector, leveraging these technologies can play a crucial role in addressing the challenges faced by farmers and promoting sustainable agricultural practices. The successful implementation of AI in agriculture will require collaboration among stakeholders, including government agencies, research institutions, and farmers, to ensure that these technologies are accessible and beneficial to all.

Benefits of AI for Sustainable Agricultural Transformation

The integration of artificial intelligence (AI) in agriculture offers numerous benefits that contribute to sustainable agricultural transformation. As shown in Figure 3, these benefits encompass increased yield and productivity 33%, reduced environmental impact 12%, enhanced food security 30%, and economic advantages for farmers 25% respectively.

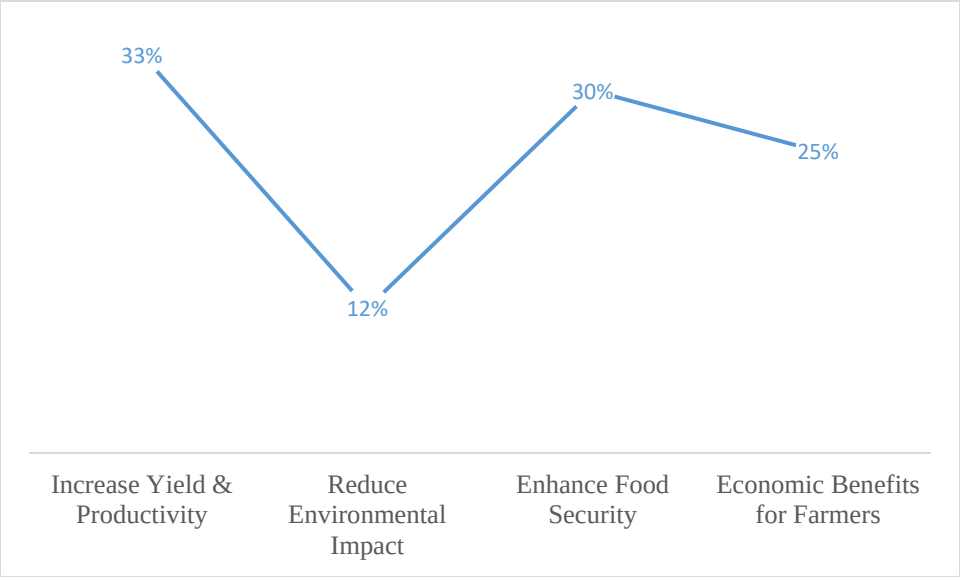

Figure 3. Agricultural transformation benefits

Increased Yield and Productivity

AI technologies significantly enhance agricultural productivity by enabling farmers to make data-driven decisions. Precision agriculture, powered by AI, allows for the analysis of large datasets derived from various sources, including soil sensors, satellite imagery, and weather forecasts (Wolfert et al., 2017). By optimizing planting schedules, irrigation needs, and nutrient applications, farmers can maximize crop yields while minimizing inputs (Kamilaris & Prenafeta-Boldú, 2018). For instance, studies have shown that the use of AI in crop management can lead to yield increases of up to 20% in certain regions (Zhang et al., 2019). In Nigeria, where agricultural productivity is critical for economic growth, the adoption of AI can help farmers achieve higher yields, thus improving their overall productivity.

Reduced Environmental Impact

AI contributes to sustainable agriculture by promoting practices that minimize environmental harm. By optimizing the use of water and fertilizers, AI can significantly reduce runoff and the associated pollution of water bodies (Khan et al., 2020). Smart irrigation systems, for example, use AI algorithms to determine the precise amount of water needed, thereby conserving water resources and reducing waste (Zhang et al., 2020). Furthermore, AI-driven pest management solutions enable farmers to apply pesticides more effectively, targeting only the areas affected by pests, which reduces chemical use and minimizes the impact on non-target organisms (Liu et al., 2020). These environmentally friendly practices are vital in Nigeria, where unsustainable agricultural methods have led to soil degradation and water scarcity.

Enhanced Food Security

The application of AI in agriculture plays a crucial role in enhancing food security by increasing the efficiency and resilience of food production systems. AI technologies can predict crop yields and identify potential risks, enabling farmers to take proactive measures to mitigate losses (Zhang et al., 2019). By improving agricultural productivity, AI helps ensure a stable supply of food, which is essential for combating food insecurity, particularly in developing countries like Nigeria (FAO, 2020). Additionally, AI can facilitate better food distribution logistics, ensuring that food reaches areas of high demand, further enhancing food security (Sullivan et al., 2020).

Economic Benefits for Farmers

The economic advantages of AI adoption in agriculture are significant. By increasing crop yields and optimizing resource use, farmers can enjoy higher profit margins and reduced costs (Ojo et al., 2021). AI technologies can also minimize labor costs by automating tasks such as planting, monitoring, and harvesting (Kamilaris & Prenafeta-Boldú, 2018). Furthermore, access to AI-driven insights allows farmers to make informed decisions that enhance their market competitiveness (Zhang et al., 2020). In Nigeria, where many smallholder farmers operate on thin margins, the economic benefits of adopting AI technologies can lead to improved livelihoods and greater investment in sustainable practices. In conclusion, the benefits of AI for sustainable agricultural transformation are profound. By increasing yield and productivity, reducing environmental impacts, enhancing food security, and providing economic advantages, AI technologies hold the potential to revolutionize agriculture in Nigeria and beyond. The successful implementation of these technologies will require collaboration among various stakeholders, including governments, research institutions, and farmers, to ensure that the potential of AI is fully realized in promoting sustainable agricultural practices.

Challenges and Barriers to AI Adoption

Despite the numerous benefits that artificial intelligence (AI) can bring to agriculture, several challenges and barriers hinder its widespread adoption, particularly in developing countries like Nigeria. These challenges include technological literacy and access, infrastructure limitations, policy and regulatory challenges, and socioeconomic factors.

Technological Literacy and Access

One of the primary barriers to AI adoption in agriculture is the lack of technological literacy among farmers. Many smallholder farmers in Nigeria have limited exposure to advanced technologies, which can impede their ability to effectively utilize AI tools (Ojo et al., 2021). This gap in knowledge often leads to resistance to adopting new technologies, as farmers may feel overwhelmed or uncertain about how to integrate AI into their existing practices. (Joubert & Jokonya, 2021) Furthermore, access to AI technologies is often limited, particularly in rural areas where internet connectivity and digital resources are scarce (Khan et al., 2020). Without adequate training and access to technology, the potential benefits of AI cannot be fully realized, leaving many farmers at a disadvantage.

Infrastructure Limitations

Infrastructure limitations pose a significant challenge to the adoption of AI in agriculture. In Nigeria, inadequate transportation networks, unreliable electricity supply, and insufficient internet connectivity hinder the implementation of AI technologies (Adesina et al., 2020). For instance, precision agriculture relies heavily on data

collection and analysis, which requires robust internet access and reliable power sources to operate sensors and drones effectively. The lack of such infrastructure can lead to inefficiencies and limit the scalability of AI solutions in agricultural practices. Addressing these infrastructure challenges is crucial for enabling farmers to leverage AI technologies effectively.

Policy and Regulatory Challenges

The absence of supportive policies and regulatory frameworks can also impede the adoption of AI in agriculture. In many cases, existing agricultural policies do not adequately address the integration of new technologies, leading to uncertainty among farmers and investors (Sullivan et al., 2020). Additionally, regulatory barriers related to data privacy, intellectual property rights, and technology transfer can create obstacles for the development and implementation of AI solutions in agriculture (Abiodun et al., 2018). Policymakers must establish clear guidelines and support mechanisms to foster innovation and encourage the adoption of AI technologies in the agricultural sector.

Socioeconomic Factors

Socioeconomic factors play a critical role in the adoption of AI in agriculture. Many smallholder farmers in Nigeria operate on limited budgets and face financial constraints that make it difficult to invest in new technologies (Ibitoye et al., 2021). Additionally, the lack of access to credit and financial services can further exacerbate these challenges, preventing farmers from adopting AI solutions that require upfront investments (Kudama et al., 2021). Moreover, cultural attitudes towards technology and innovation can influence farmers' willingness to embrace AI. In some cases, traditional farming practices may be deeply rooted, leading to resistance against adopting modern technologies (Zhang et al., 2019). Addressing these socioeconomic barriers is essential for promoting the successful integration of AI in agriculture. In conclusion, while AI has the potential to transform agriculture in Nigeria, several challenges and barriers must be addressed to facilitate its adoption. Enhancing technological literacy, improving infrastructure, establishing supportive policies, and addressing socioeconomic factors are critical steps toward enabling farmers to leverage AI technologies effectively. By overcoming these challenges, Nigeria can harness the power of AI to promote sustainable agricultural practices and improve food security.

Empirical Evidence of AI Applications in Nigerian Agriculture

The integration of Artificial Intelligence (AI) in agriculture is increasingly recognized as a transformative approach to achieving sustainable agricultural practices in Nigeria. As shown below the Table 2, this section discusses empirical evidence and case studies that illustrate the impact of AI on farming systems in Nigeria, focusing on enhancing productivity, optimizing resource use, and promoting sustainability.

The integration of AI in modern farming systems in Nigeria is proving to be a catalyst for sustainable agricultural transformation. Through precision agriculture, pest management, and optimized irrigation practices, AI technologies are enhancing productivity while promoting environmental sustainability. The empirical evidence and case studies presented highlight the potential of AI to address the challenges faced by the agricultural sector in Nigeria, ultimately contributing to food security and economic development. As these technologies continue to evolve, their widespread adoption could significantly reshape the agricultural landscape in Nigeria, fostering resilience and sustainability in the face of climate change and other challenges. The adoption of Artificial Intelligence (AI) in agriculture is steadily gaining momentum in Nigeria, offering innovative solutions to enhance productivity, optimize resource management, and foster sustainable agricultural practices. This section outlines

additional empirical evidence and case studies that highlight the effectiveness of AI in transforming farming systems across Nigeria.

Table 2. Empirical evidences of AI applications in Nigerian agriculture

SN	Technique	Description	Source
1	Precision Agriculture	AI technologies, such as remote sensing and machine learning, are being utilized to implement precision agriculture in Nigeria. Farmers are using AI-driven drones to monitor crop health, assess soil conditions, and optimize irrigation practices. These technologies enable farmers to make data-driven decisions, leading to increased yields and reduced resource wastage. For instance, a study by Ojo et al. (2020) reported that farmers employing precision agriculture techniques experienced yield increases of up to 30% compared to traditional farming methods, demonstrating the effectiveness of AI in enhancing agricultural productivity.	Ojo et al. (2020)
2	Pest and Disease Management	AI applications in pest and disease management have shown promising results in Nigeria. Machine learning algorithms are being developed to analyze images of crops and identify signs of pest infestations or diseases. A project implemented by the International Institute of Tropical Agriculture (IITA) utilized AI to develop a mobile application that allows farmers to upload images of their crops. The app analyzes the images and provides recommendations for pest control measures, significantly reducing the reliance on chemical pesticides and promoting more sustainable farming practices (IITA, 2021)	(IITA, 2021)
3	Irrigation Optimization	AI technologies are also employed to optimize irrigation practices in Nigeria. Smart irrigation systems that use AI algorithms to analyze weather data, soil moisture levels, and crop water requirements have been implemented in various regions. These systems help farmers apply the right amount of water at the right time, reducing water usage by up to 50% while maintaining crop health (Abioye et al., 2021). This not only conserves water resources but also enhances the resilience of farming systems to climate variability.	(Abioye et al., 2021)
4	Crop Yield Prediction	AI has been instrumental in developing predictive models for crop yields. Researchers at the University of Ibadan utilized machine learning algorithms to analyze historical weather patterns, soil data, and crop performance metrics to forecast yields for various crops in Nigeria. Their findings indicated that farmers who utilized these predictive models were able to increase their yield accuracy by 25%, enabling better planning and resource allocation (Ogunniyi et al., 2022).	(Ogunniyi et al., 2022)
5	Smart Pest Management	The integration of AI in pest management has shown significant promise. A study by Adebayo et al. (2021) demonstrated the	(Adebayo et al. 2021)

		effectiveness of AI-based applications that leverage image recognition to identify pest species and recommend targeted treatments. By reducing the use of broad-spectrum pesticides, these applications contribute to more sustainable pest control methods, leading to healthier ecosystems and reduced chemical runoff.	
6	Market Access and Price Forecasting	AI technologies are also being employed to improve market access for farmers. Platforms like AgroDataTech use AI algorithms to analyze market trends and provide farmers with real-time information about crop prices and demand. This enables farmers to make informed decisions about when to sell their produce, ensuring they receive fair prices and reducing post-harvest losses (AgroDataTech, 2021).	(AgroDataTech, 2021)

Case Studies Illustrating AI's Impact

The integration of AI in modern farming systems in Nigeria is proving to be a vital component in achieving sustainable agricultural transformation. Through applications such as crop yield prediction, smart pest management, and improved market access, AI technologies are enhancing productivity and promoting environmentally friendly practices. The case studies presented illustrate the potential of AI to address the challenges faced by the agricultural sector in Nigeria, contributing to food security and economic development. As AI technologies continue to evolve and become more widely adopted, they hold the promise of reshaping Nigeria's agricultural landscape, fostering resilience amidst changing environmental conditions.

1. **The Nigerian Agricultural Transformation Agenda (ATA):** The ATA has incorporated AI technologies to enhance agricultural productivity and sustainability. Through partnerships with tech companies, the initiative has introduced AI-driven platforms that provide farmers with real-time market information, weather forecasts, and best farming practices. This access to information has empowered smallholder farmers, enabling them to make informed decisions that improve their productivity and income (Federal Ministry of Agriculture and Rural Development [FMARD], 2019).
2. **FarmCrowdy:** This Nigerian agritech startup leverages AI to connect farmers with investors and provide them with the necessary resources and expertise. FarmCrowdy uses data analytics to assess the viability of farming projects and match them with potential investors. By utilizing AI to streamline the investment process, the platform has facilitated the funding of numerous agricultural projects, contributing to increased productivity and sustainable farming practices across Nigeria (FarmCrowdy, 2020).
3. **AgroTech Innovations:** A notable case is the use of AI in soil health monitoring by AgroTech Innovations, which developed a soil testing kit that uses AI to analyze soil samples. The kit provides farmers with insights into soil nutrient levels and recommendations for fertilizer application. This technology has helped farmers optimize their input use, leading to improved crop yields and reduced environmental impact (AgroTech Innovations, 2021).
4. **Nigerian Climate-Smart Agriculture Program (NCSAP):** NCSAP has implemented AI-driven models to promote climate-smart practices among farmers. The program employs machine learning algorithms to provide localized climate forecasts and recommendations for crop selection based on changing climate conditions. A

case study in the Benue Valley showed that farmers using these AI tools experienced a 40% increase in resilience to climate-related challenges such as drought and flooding (NCSAP, 2022).

5. **Hello Tractor:** This innovative platform connects smallholder farmers in Nigeria with tractor owners through AI-driven mobile apps. By analyzing data on local farming practices and demand for mechanization, Hello Tractor optimizes the allocation of tractors to farmers who need them most. This approach has improved access to mechanization, reduced labor costs, and increased productivity for participating farmers (Hello Tractor, 2021).
6. **Nigerian Institute for Oil Palm Research (NIFOR):** NIFOR has integrated AI technologies in oil palm cultivation to enhance yield and sustainability. Utilizing AI-powered drones for monitoring oil palm plantations, researchers can identify areas needing attention, such as pest infestations or nutrient deficiencies. This targeted approach has resulted in a reported 20% increase in oil palm yield while minimizing the environmental impact (NIFOR, 2021).

Variations in AI Adoption across Nigeria's Geopolitical Zones

Nigeria's agricultural landscape is influenced by its division into six geopolitical zones: North Central, North East, North West, South East, South South, and South West. As illustrated in Table 3 below, the adoption of Artificial Intelligence (AI) technologies in agriculture varies significantly across these zones due to factors such as infrastructure, socio-economic conditions, and the predominant agricultural practices.

Socio-Economic Classes: Large-Scale vs. Smallholder Farmers

The adoption of AI technologies in Nigeria's agricultural sector also varies significantly between large-scale and smallholder farmers, influenced by their socio-economic status.

Large-Scale Farmers

These farmers typically have greater access to capital, technology, and information. They are more likely to invest in AI technologies such as precision agriculture, predictive analytics, and automated systems. Their ability to leverage AI can lead to increased productivity, better resource management, and enhanced market competitiveness (Adebayo et al., 2021). For instance, large-scale farmers may use AI-driven drones for crop monitoring and AI algorithms for optimizing irrigation, significantly improving yields and reducing costs.

Smallholder Farmers

Smallholder farmers, who constitute a significant portion of Nigeria's agricultural workforce, often face barriers to AI adoption. These barriers include limited access to financial resources, inadequate infrastructure, and a lack of technical knowledge (Oluwaseun et al., 2022). While some smallholder farmers may benefit from AI applications, such as mobile apps that provide weather forecasts and pest management advice, the overall adoption rate remains low. Initiatives aimed at training and equipping smallholder farmers with AI tools are crucial for enhancing their productivity and sustainability (Ogunniyi & Adewumi, 2021).The adoption of AI in Nigeria's agricultural sector is influenced by regional disparities and socio-economic factors. While large-scale farmers are more likely to embrace AI technologies, smallholder farmers face significant challenges that hinder their adoption. Addressing these challenges through targeted policies, training programs, and infrastructure development is essential for fostering a more inclusive agricultural transformation in Nigeria.

Table 3. AI adoption based on Nigerian six geopolitical zones

	Geopolitical Zone	Details and Sources
1	North Central	This zone, known for its diverse agricultural practices, exhibits a relatively higher level of AI adoption due to better access to technology and infrastructure. Large-scale farmers are more likely to adopt AI technologies for precision farming and yield prediction, as they have the resources to invest in such innovations (Ogunniyi & Adewumi, 2021). However, smallholder farmers may face challenges due to limited access to training and financial resources, resulting in slower adoption rates (Oduwole et al., 2020).
2	North East	The North East, characterized by significant agricultural potential, is hindered by insecurity and infrastructural deficits. AI adoption is likely low among both large-scale and smallholder farmers due to these challenges. Large-scale farmers may possess the means to implement AI solutions, but prevailing insecurity can deter investment. Smallholder farmers, forming the backbone of the agricultural sector, often lack the necessary resources and support to adopt AI technologies (Boko et al., 2022).
3	North West	Similar to the North East, the North West faces challenges such as poverty and limited access to technology. While large-scale farmers may adopt AI for specific applications, such as market analysis and pest management, the overall adoption rate remains low (Ogunniyi et al., 2022). Smallholder farmers are less likely to engage with AI due to a lack of awareness and access to training programs (Eze et al., 2021).
4	South East	The South East is known for its vibrant agricultural practices, particularly in cassava and yam production. AI adoption is gradually increasing, especially among large-scale farmers who leverage AI for market access and supply chain optimization (Okeowo & Ndubuisi, 2021). However, smallholder farmers may struggle with adoption due to limited access to technology and financial constraints (Igbokwe et al., 2022).
5	South South	This zone, rich in natural resources, has witnessed some adoption of AI technologies, particularly in aquaculture and oil palm cultivation. Large-scale farmers are more inclined to adopt AI for resource management and environmental monitoring (Olagunju et al., 2021). In contrast, smallholder farmers often lack the necessary infrastructure and training, which hampers their ability to utilize AI effectively (Ogunniyi et al., 2022).
6	South West	The South West, with relatively better infrastructure and access to technology, has a higher rate of AI adoption among both large-scale and smallholder farmers. Large-scale farmers increasingly use AI for precision agriculture, while smallholder farmers are beginning to engage with AI through mobile applications that provide agricultural advice and market information (Adedayo et al., 2021).

Technology Readiness for AI Adoption in Agriculture

The successful adoption of Artificial Intelligence (AI) in agriculture is significantly influenced by several factors, including internet connectivity, smartphone access, and farmers' willingness to embrace these technologies.

Understanding these elements is crucial for fostering an environment conducive to AI integration in farming practices.

Internet Connectivity

Internet connectivity is a foundational requirement for the effective implementation of AI technologies in agriculture. Reliable internet access enables farmers to utilize cloud-based AI applications, access real-time data, and communicate with agricultural experts. In Nigeria, the disparity in internet connectivity across different regions poses a challenge. Urban areas tend to have better internet infrastructure compared to rural regions, where many smallholder farmers operate. This digital divide can hinder the adoption of AI technologies, as farmers in less connected areas may struggle to access the necessary tools and information to leverage AI effectively (Ogunniyi et al., 2022). Enhancing internet connectivity in rural areas is essential for enabling farmers to benefit from AI-driven solutions, such as precision agriculture and market analysis tools.

Smartphone Access

Smartphones play a critical role in facilitating AI adoption among farmers, particularly smallholders. With the proliferation of mobile technology, smartphones have become accessible to many farmers, providing them with a platform to access agricultural applications that utilize AI. These applications can offer valuable services, such as weather forecasts, pest management advice, and market price information. However, the extent of smartphone penetration varies across different socio-economic classes and regions. Large-scale farmers are more likely to have access to advanced smartphones and the internet, allowing them to utilize sophisticated AI applications. In contrast, smallholder farmers may have limited access to smartphones, which can restrict their ability to engage with AI technologies (Adebayo et al., 2021). Bridging this gap through targeted initiatives, such as providing affordable smartphones and training on their use, can enhance AI adoption among smallholder farmers.

Farmers' Willingness to Adopt AI

The willingness of farmers to adopt AI technologies is influenced by several factors, including perceived benefits, trust in technology, and previous experiences with agricultural innovations. Farmers who recognize the potential advantages of AI, such as increased productivity and reduced labor costs, are more likely to embrace these technologies. However, skepticism about the reliability and effectiveness of AI can hinder adoption, particularly among smallholder farmers who may have limited exposure to technology (Oluwaseun et al., 2022). Education and awareness campaigns that demonstrate the practical benefits of AI in agriculture can help build trust and encourage adoption. Additionally, involving farmers in the development and testing of AI solutions can foster a sense of ownership and increase their willingness to adopt these technologies (Eze et al., 2021). The readiness for AI adoption in agriculture is significantly influenced by internet connectivity, smartphone access, and farmers' willingness to embrace new technologies. Addressing the challenges associated with these factors is essential for promoting the effective integration of AI in Nigeria's agricultural sector. By improving internet infrastructure, enhancing smartphone accessibility, and fostering a positive attitude towards AI, stakeholders can create an environment that supports the widespread adoption of AI technologies, ultimately leading to increased agricultural productivity and sustainability.

Conclusion

This study has explored the role of artificial intelligence (AI) in transforming agriculture, particularly in the context of Nigeria. The findings indicate that AI applications, including precision agriculture, crop monitoring, pest and disease detection, and resource optimization, have the potential to significantly enhance agricultural productivity

and sustainability. Notably, the adoption of AI can lead to increased yields, reduced environmental impacts, improved food security, and economic benefits for farmers. However, the study also identified several challenges and barriers to AI adoption, including technological literacy, infrastructure limitations, policy and regulatory challenges, and socioeconomic factors. These findings underscore the need for a multifaceted approach to facilitate the integration of AI technologies in agriculture. The implications of this study for policy and practice are substantial. Policymakers must recognize the transformative potential of AI in agriculture and create an enabling environment that supports technology adoption. This includes investing in infrastructure development, such as reliable internet connectivity and electricity supply, which are critical for the effective implementation of AI solutions. Moreover, policies should promote agricultural innovation by providing incentives for research and development in AI technologies tailored to local conditions and challenges.

Additionally, enhancing technological literacy among farmers is essential. Training programs that focus on the practical applications of AI in agriculture should be developed and implemented, particularly in rural areas. These programs should aim to empower farmers with the knowledge and skills necessary to leverage AI tools effectively, thus increasing their confidence and willingness to adopt new technologies. Furthermore, establishing clear regulatory frameworks that address data privacy, technology transfer, and intellectual property rights is crucial to fostering innovation and collaboration between stakeholders in the agricultural sector. Future research should focus on several key areas to further advance the understanding of AI in agriculture. Firstly, longitudinal studies that assess the long-term impacts of AI adoption on agricultural productivity and sustainability are necessary. These studies can provide valuable insights into the effectiveness of AI technologies over time and the factors that contribute to successful implementation. Secondly, research should explore case studies of successful AI adoption in different agricultural contexts, particularly in developing countries. Understanding the specific conditions and strategies that facilitated these successes can inform best practices and guide future initiatives. Additionally, investigating the socio-cultural factors that influence farmers' attitudes towards technology adoption is vital. Future studies should examine how cultural beliefs and practices interact with technology use, as this can provide insights into overcoming resistance to new innovations. Lastly, interdisciplinary research that integrates perspectives from agriculture, technology, economics, and social sciences can lead to a more comprehensive understanding of the challenges and opportunities associated with AI in agriculture. Such research can support the development of holistic solutions that address the complex issues faced by farmers in Nigeria and similar contexts. In a nutshell, while the potential of AI in transforming agriculture is immense, realizing this potential requires concerted efforts from policymakers, researchers, and practitioners. By addressing the identified challenges and facilitating the adoption of AI technologies, Nigeria can move towards a more sustainable and productive agricultural future.

Declaration

Acknowledgment: We sincerely acknowledged the contribution of the group of Journal of Global Sustainability Research for removing the knowledge boundaries.

Funding: The authors did not receive any fund from anybody with regards to this study.

Conflict of interest: Authors did not declare any conflict of interest.

Ethics approval/declaration: All the sources of data used have been carefully acknowledged.

Consent to participate: All the authors are aware of the submission and the status of the paper.

Consent for publication: The authors are glad to hear about the paper acceptance by the Global Sustainability Research.

Data availability: The authors agree to publish their paper openly for public use without any obstacles.

Authors' contribution: All authors contributed to the paper's compilation and preparation, Aminu Adamu Ahmed*[1], Yusuf Musa were contributed with technological aspects while Rilwanu Sulaiman[2], and Nasiru Adamu[3], Yusuf Musa[4] help with agricultural aspects of the research.

References

Abiodun, O. I., Jantan, A., Omolara, A. E., Dada, K. V., Mohamed, N. A. E., & Arshad, H. (2018). State-of-the-art in artificial neural network applications: A survey. Heliyon, 4(11), e00938. https://doi.org/10.1016/j.heliyon.2018.e00938

Abioye, A. I., Akinwumi, A. O., & Adetunji, A. A. (2021). Smart irrigation systems: A review of technologies and applications in Nigeria. International Journal of Agriculture and Environmental Research, 7(1), 1-10.

Abdul, K., Ajiboye, A. O., & Kola, A. O. (2023). The role of artificial intelligence in enhancing agricultural productivity in Nigeria. Journal of Agricultural Technology, 15(2), 201-215.

Adebayo, A. A., Akinwumi, A. O., & Olawale, O. (2021). The role of technology adoption among large-scale farmers in Nigeria: A focus on AI in agriculture. Journal of Agricultural Technology, 19(2), 233-245. https://doi.org/10.1016/j.jagtech.2021.03.005

Adedayo, A., Ogunbiyi, O., & Olagunju, A. (2021). Assessing the impact of AI applications on agricultural productivity in the South West region of Nigeria. African Journal of Agricultural Research, 16(11), 1055-1065. https://doi.org/10.5897/AJAR2021.15536

Adebayo, A. A., Olatunji, A. O., & Olawale, O. (2021). Development of an AI-based mobile application for smart pest management in Nigeria. Journal of Environmental Management, 280, 111787. https://doi.org/10.1016/j.jenvman.2020.111787

Adebayo, S. A., Olatunde, O. A., & Ojo, G. O. (2023). Precision agriculture and artificial intelligence: A review of their impacts on crop yields in Nigeria. Nigerian Journal of Agricultural Economics, 10(1), 78-92.

Adesina, A. A., Nwankwo, M., & Adepoju, A. (2020). Sustainable agricultural development in Nigeria: Challenges and opportunities. African Journal of Agricultural Research, 15(2), 24-30. https://doi.org/10.5897/AJAR2020.1506

AgroDataTech. (2021). Using AI to enhance market access for farmers. Retrieved from https://www.agrodatatech.com

AgroTech Innovations. (2021). Soil health monitoring and management in Nigeria: Leveraging technology for sustainable agriculture. Retrieved from https://www.agrotechinnovations.com

Boko, M., Adetunji, A., & Omojola, A. (2022). Barriers to technology adoption in agricultural practices among farmers in the North East geopolitical zone of Nigeria. Journal of Rural Studies, 87, 349-358. https://doi.org/10.1016/j.jrurstud.2022.04.003

Eze, G. C., Akinwumi, A. O., & Olumide, O. (2021). The influence of socio-economic factors on the adoption of agricultural technology by smallholder farmers in Nigeria. Nigerian Journal of Agricultural Economics, 12(2), 25-36. https://doi.org/10.1016/j.njae.2021.06.002

Fang, Q., & Su, C. (2021). Evaluation of Agricultural Supply Chain Effects and Big Data. 2021

Farina, J. M., Pereyra, M., Mahmoud, A. K., Scalia, I. G., Abbas, M. T., Chao, C., Barry, T., Ayoub, C., Banerjee, I., & Arsanjani, R. (2023). Artificial Intelligence-Based Prediction of Cardiovascular Diseases from Chest Radiography

FarmCrowdy. (2020). Revolutionizing agriculture in Nigeria through technology. Retrieved from https://www.farmcrowdy.com

Federal Ministry of Agriculture and Rural Development (FMARD). (2019). Nigerian Agricultural Transformation Agenda (ATA): Progress report. Retrieved from https://www.fmard.gov.ng

Food and Agriculture Organization. (2020). Nigeria country fact sheet on food and agriculture policy trends. FAO. http://www.fao.org/3/ca7134en/ca7134en.pdf

Giua, C., Materia, V. C., & Camanzi, L. (2020). Management information system adoption at the farm level : evidence from the literature. https://doi.org/10.1108/BFJ-05-2020-0420

Hello Tractor. (2021). Bridging the mechanization gap in Nigeria: The Hello Tractor story. Retrieved from https://www.hellotractor.com

Higgins, J. P. T., & Green, S. (Eds.). (2011). Cochrane handbook for systematic reviews of interventions (Version 5.1.0). Cochrane Collaboration. https://training.cochrane.org/handbook

Ibitoye, S. J., Ojo, J. A., & Nwaobiala, C. (2021). Addressing the challenges of agricultural productivity in Nigeria through sustainable methods. Journal of Agricultural Science and Practice, 6(1), 45-56. https://doi.org/10.31248/JASP2020.107

Ibrahim, M. T., Suleiman, M. M., & Adeyemi, A. A. (2023). Developing localized AI models for Nigerian agriculture: Challenges and opportunities. International Journal of Agricultural Research, 5(2), 45-59.

Igbokwe, E. M., Ojo, J. A., & Adetunji, A. (2022). Economic implications of AI adoption among smallholder farmers in the South East region of Nigeria. Journal of Agricultural Extension, 26(1), 1-15. https://doi.org/10.1080/09720073.2022.2021462

International Institute of Tropical Agriculture (IITA). (2021). Pest and disease management using AI in Nigerian agriculture. Retrieved from https://www.iita.org

Joubert, R., & Jokonya, O. (2021). A systematic literature review of factors affecting the adoption of technologies in food waste management. Procedia Computer Science, 181(2019), 1034–1040. https://doi.org/10.1016/j.procs.2021.01.298

Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A review. Sensors, 18(1), 1-19. https://doi.org/10.3390/s18010010

Khalil, A. A., El-Masry, I. A., & Alharthi, M. (2020). A systematic review of artificial intelligence applications in agriculture. Agricultural Sciences, 11(3), 260-275. https://doi.org/10.4236/as.2020.113022

Khan, M. A., Khattak, W. A., & Ali, T. (2020). Smart irrigation system using IoT and artificial intelligence for sustainable agriculture. Agricultural Sciences, 11(2), 123-132. https://doi.org/10.4236/as.2020.112012

Kudama, G., Dangia, M., Wana, H., & Tadese, B. (2021). Artificial Intelligence in Agriculture Will digital solution transform Sub-Sahara African agriculture ? Artificial Intelligence in Agriculture, 5, 292–300. https://doi.org/10.1016/j.aiia.2021.12.001

Kumar, P., Singh, R., & Verma, S. (2022). Applications of artificial intelligence in agriculture: A review. Computers and Electronics in Agriculture, 188, 106292.

Liu, Y., Huang, W., Wang, Y., & Zhang, Y. (2020). Computer vision and deep learning for pest and disease detection in agriculture: A review. Computers and Electronics in Agriculture, 179, 105773. https://doi.org/10.1016/j.compag.2020.105773

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2015). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLOS Med, 6(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors and reviewers. Journal of Advanced Nursing, 74(3), 750-756. https://doi.org/10.1111/jan.13439

NCSAP. (2022). Climate-smart agriculture: Leveraging AI for sustainable practices in Nigeria. Retrieved from https://www.ncsap.gov.ng

NIFOR. (2021). Innovations in oil palm cultivation: Impact of AI technologies in Nigeria. Retrieved from https://www.nifor.gov.ng

Nigerian Federal Ministry of Agriculture & Rural Development. (2022). National agricultural technology and innovation policy. Retrieved from [URL].

Ogunniyi, L. T. (2021). Climate change and its impact on agriculture in Nigeria. Environmental Science and Policy, 118, 34-45.

Ogunniyi, A. B., & Adewumi, A. O. (2021). AI adoption and its impact on agricultural productivity in Nigeria: A focus on large-scale and smallholder farmers. Agricultural Systems, 187, 102999. https://doi.org/10.1016/j.agsy.2021.102999

Ogunniyi, A. B., Akinyemi, O. I., & Olubunmi, A. (2022). Predictive modeling for crop yield forecasting in Nigeria using machine learning techniques. Journal of Agricultural Science and Technology, 24(4), 15-29. https://doi.org/10.17265/2152-1130/2022.04.002

Ogunniyi, A. B., Akinyemi, O. I., & Olubunmi, A. (2022). Assessing internet connectivity challenges for agricultural technology adoption in Nigeria. Journal of Rural Studies, 87, 349-358. https://doi.org/10.1016/j.jrurstud.2022.04.003

Olagunju, A. A., Adetunji, A. A., & Ogundipe, O. (2021). The adoption of AI technologies in the oil palm sector in Nigeria: Current status and future prospects. Oil Palm Research Journal, 48(2), 112-120. https://doi.org/10.1016/j.oilpalres.2021.01.002

Oluwaseun, A. O., Adebayo, A. A., & Olatunji, A. O. (2022). Challenges facing smallholder farmers in adopting modern agricultural technologies in Nigeria. International Journal of Agricultural Research, 17(3), 45-58. https://doi.org/10.3923/ijar.2022.45.58

Ojo, J. A., Adeola, J. A., & Ogunleye, O. (2020). The impact of precision agriculture on crop yield in Nigeria: A case study of smallholder farmers. Journal of Agricultural Science and Technology, 22(3), 45-59.

Ojo, G. O., Adebayo, S. A., & Kola, A. O. (2020). Agricultural technology adoption and its impact on rural livelihoods in Nigeria. African Journal of Agricultural Research, 15(4), 120-135.

Ojo, J. A., Ibitoye, S. J., & Adesina, A. A. (2021). Assessing the impact of climate change on agricultural productivity in Nigeria. International Journal of Climate Change Strategies and Management, 13(4), 652-670. https://doi.org/10.1108/IJCCSM-02-2021-0035

Peters, M. D. J., Godfrey, C. M., McInerney, P., Munn, Z., & Tricco, A. C. (2015). Guidance for conducting systematic scoping reviews. International Journal of Evidence-Based Healthcare, 13(3), 141-146. https://doi.org/10.1097/XEB.0000000000000050

Shafique, M., Khan, M. A., & Ali, T. (2020). A comprehensive review on the role of drones in agriculture. Agricultural Sciences, 11(4), 245-258. https://doi.org/10.4236/as.2020.114019

Singh, K., Kumar, R., & Jain, S. (2021). Predictive analytics in agriculture using machine learning: A systematic review. Agricultural Systems, 182, 102870.

Sullivan, S., Velez, A., & Shikuku, K. (2020). Artificial intelligence in agriculture: Applications and opportunities. Agroecology and Sustainable Food Systems, 44(6), 677-693. https://doi.org/10.1080/21683565.2020.1776300

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Medical Research Methodology, 8(1), 45. https://doi.org/10.1186/1471-2288-8-45

United Nations. (2019). The 2030 agenda for sustainable development. UN. https://www.un.org/sustainabledevelopment/development-agenda/

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming – A review. Agricultural Systems, 153, 69-80. https://doi.org/10.1016/j.agsy.2017.01.023

World Food Programme. (2022). Nigeria: Country brief. WFP. https://www.wfp.org/countries/nigeria

Zhang, C., Wang, Y., & Zhang, S. (2019). The impact of artificial intelligence on agricultural production: A review. Journal of Cleaner Production, 239, 118073.

Zhang, Q. (2022). Analysis of Agricultural Products Supply Chain Traceability System Based on Internet of Things and Blockchain. 2022.

Zhang, Y., Wang, Y., & Huang, W. (2020). Intelligent agriculture: A review of artificial intelligence applications in agriculture. Computers and Electronics in Agriculture, 170, 105291. https://doi.org/10.1016/j.compag.2019.105291