

Harnessing Artificial Intelligence for Sustainable Agriculture: Innovations for Environmental Conservation and Food Security in Benue State, Nigeria

Ashinya Tyover Emmanuel

Federal Polytechnic Wannune, Benue State, Nigeria

Accepted 28, January, 2026

In the face of escalating environmental challenges and a burgeoning population, Benue State in Nigeria stands at a critical juncture where sustainable agricultural practices are paramount to ensuring food security and environmental conservation. This paper explored the transformative potential of harnessing Artificial Intelligence for Sustainable Agriculture: Innovations for Environmental Conservation and Food Security in Benue State, Nigeria. The specific objectives of the study include to examine the level of artificial intelligence and innovations integrated into agriculture among farmers, examine the economic benefits of deploying AI for sustainable agriculture and food security, identify the challenges of deploying AI for sustainable agriculture and food security and formulate policies for the adoption of AI technologies among local farmers for sustainable agriculture and food security. The study is anchored on Technological Acceptance Model (TAM). This study adopted descriptive survey research design using questionnaire and in-depth interview. This design facilitates the collection of both quantitative and qualitative data to understand perceptions, practices, and innovations related to AI applications among farmers in the State. A sample size of 131 registered farmers and 12 agricultural experts were used. The data was analyzed using descriptive statistics such as frequency and simple percentages as well as mean and standard deviation to answer research questions whereby a mean cut-off point of 2.50 is used for decision making. The findings of the study revealed low application of AI tools among farmers in Benue state. The study revealed the economic benefits of adopting AI in farming which include real-time monitoring of soil health, weather patterns, pest outbreaks, and water management, enabling informed decision making that promotes environmental sustainability and food security against climate variability. However, in Benue State adoption of AI faces notable challenges which include poor infrastructure, high costs, limited digital skills, and data security concerns. Emphasizing stakeholder engagement, capacity building, and policy support, the paper advocates for a concerted effort to harness AI as a catalyst for sustainable development and food security in Benue State.

Keywords: Precision Agriculture, Benue State, Technological Acceptance Model, Food Security and Environmental Conservation.

INTRODUCTION

Agriculture remains the backbone of Benue State, Nigeria, often referred to as the "Food Basket of Nigeria" due to its prolific crop production, especially yams, cassava, maize, and soybeans (Adebayo & Ojo, 2020). However, the sector faces numerous challenges, including climate change, soil degradation, pests, and inefficient resource management, which threaten both environmental sustainability and food security (FAO, 2017). In recent years, the advent of Artificial Intelligence (AI) has opened new frontiers for transforming agricultural practices, offering innovative solutions to mitigate these challenges.

In Nigeria, leveraging AI for sustainable agriculture aligns with national development goals such as the Economic Recovery and Growth Plan (ERGP) and Nigeria's Climate Change Action Plan. It also offers a pathway to achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 13 (Climate Action) (UNDP Nigeria, 2021). Despite these potential opportunities, challenges such as limited technological infrastructure, inadequate data, and low digital literacy must be addressed to fully harness AI's potential (Ogunleye & Ogunleye, 2020).

AI technologies encompass machine learning, computer vision, predictive analytics, and autonomous systems that can optimize farming operations, enhance decision-making, and promote sustainable resource use (Liakos et al., 2018). For instance, AI-powered satellite imagery and drone surveillance enable precise monitoring of crop health, soil conditions, and water resources, facilitating targeted interventions that reduce waste and environmental impact (Zhang et al., 2020). Furthermore, AI-driven models can predict weather patterns and pest outbreaks, allowing farmers to plan effectively and minimize crop losses (Jha et al., 2020).

Environmental sustainability in agriculture involves the prudent management of natural resources such as water, soil,

and biodiversity. AI applications can support conservation efforts by monitoring soil health, predicting weather patterns, detecting pests and diseases early, and optimizing fertilizer and water application (Kamilaris & Prenafeta-Boldú, 2018). Concurrently, food security hinges on consistent and increased food production, which AI can bolster through precision agriculture techniques that maximize crop yields while minimizing waste and environmental degradation.

Benue State's predominantly agrarian economy is characterized by subsistence farming and monoculture practices, which often lead to soil exhaustion and deforestation. The integration of AI in agriculture could revolutionize farming practices in Benue by providing tailored solutions to local farmers, improving crop management, and fostering sustainable practices (Obi, 2019). Importantly, AI can enable smallholder farmers to adapt to climate variability, enhance resilience, and contribute to national food security goals.

In the context of Benue State, harnessing AI holds significant promise for improving productivity while conserving the environment. Innovations like AI-based precision agriculture optimized the use of inputs such as fertilizers, water, and pesticides, thereby reducing runoff and soil contamination (Ojo & Adebayo, 2021). Additionally, AI can support smallholder farmers by providing accessible decision support systems, enabling them to adapt to climate variability and enhance resilience (World Bank, 2018).

Despite these potential benefits, the deployment of AI in Benue's agriculture sector faces obstacles, including limited technological infrastructure, low digital literacy, and the need for context specific solutions (Nwankwo & Ogunjobi, 2020). However, harnessing AI for sustainable agriculture in Benue State aligns with global efforts to achieve environmental conservation and food security. It presents a pathway to transforming traditional farming into a resilient, efficient, and environmentally friendly sector, ultimately contributing to economic growth and poverty alleviation. This study centers on the urgent need to explore and harness the potential of artificial intelligence (AI) to address pressing challenges in sustainable agriculture within Benue State, Nigeria.

Statement of the Problem

Benue state which is one of the 36 states of Nigeria is located within the geographical middle belt region of the country. With enormous agricultural potential in the form of well drained fertile soils including vast Fadama portions alongside a consistent dry and rainy season the State ranks among the very highest in terms of food production, a development that is made possible by her population which is predominately farmers based (Asaasuen & Asema, 2019). Despite the critical role that agriculture plays in Benue's economy often referred to as the "food basket" of Nigeria many farmers face issues such as low productivity, climate variability, pest infestations, and inefficient resource use (Adebayo et al., 2020). These challenges threaten food security and environmental sustainability in the region while AI has demonstrated promising applications in precision farming, crop monitoring, pest detection, and resource management globally (Liakos et al., 2018; Kamilaris & Prenafeta-Boldú, 2018). Data on AI adoption in Nigeria remains limited. However, there is growing use of AI in sectors such as fintech, agriculture, healthcare, and government services, supported by a vibrant startup ecosystem and government initiatives like the National Digital Economy Strategy. Academic and research institutions are also increasingly focusing on AI. Despite these developments, comprehensive statistics are scarce, and adoption is uneven across Nigeria. Its adoption in Benue State remains limited due to infrastructural, technological, and awareness barriers. This gap highlights the need to investigate how AI driven innovations can be effectively integrated into local agricultural practices to promote environmental conservation such as reducing chemical runoff and conserving soil and water resources and enhance food security by increasing yield and resilience to climate shocks.

Furthermore, understanding the socioeconomic, technological, and policy factors influencing AI adoption among Benue's farmers is critical (Adejumo & Ogunjobi, 2019). The research problem, therefore, involves identifying the potential and limitations of AI technologies in transforming agriculture in Benue State, with a focus on sustainable practices that balance productivity with environmental preservation. Addressing this problem is vital for developing context specific AI solutions that can contribute to the long term sustainability of agriculture and food systems in the region. This study therefore, centered on harnessing Artificial Intelligence for Sustainable Agriculture: Innovations for Environmental Conservation and Food Security in Benue State.

Objectives of the Study

The main objective of this study centered on harnessing Artificial Intelligence for Sustainable Agriculture: Innovations for Environmental Conservation and Food Security in Benue State. The specific objectives include:

- i. To examine the level of artificial intelligence and innovations integrated into agriculture among farmers in Benue State.
- ii. To examine the economic benefits of deploying AI for sustainable agriculture and food security in Benue State
- iii. To identify the challenges of deploying AI for sustainable agriculture and food security in Benue State
- iv. To formulate policies for the adoption of AI technologies among local farmers for sustainable agriculture and food security in Benue State

Research Questions

The study was setup to answer the following research questions:

- i. What is the level of artificial intelligence and innovations integrated into agriculture among farmers in Benue State?
- ii. What are the economic benefits of deploying AI for sustainable agriculture and food security in Benue State?
- iii. What are the challenges of deploying AI for sustainable agriculture and food security in Benue State?
- iv. What policies can be formulated to facilitate the adoption of AI technologies among local farmers for sustainable agriculture and food security in Benue State?

Level of Artificial Intelligence and Innovations Adopted in Agriculture among Farmers for Sustainable Agriculture and Food Security in Nigeria

Artificial Intelligence (AI) has emerged as a transformative technology in agriculture, offering innovative solutions to enhance productivity, sustainability, and food security. The integration of AI tools in agriculture addresses critical challenges such as climate change, resource depletion, and food insecurity by enabling precision farming, predictive analytics, and automated decision making. Precision agriculture utilizes AI driven technologies such as remote sensing, GPS, and IoT sensors to monitor crop health, soil conditions, and water usage in real-time. These tools enable farmers to apply inputs more efficiently, reducing waste and environmental impact (Akinwale & Ogunjobi, 2020). For example, AI algorithms analyze data from drones and satellites to optimize planting schedules and fertilization.

Machine learning (ML) models process large datasets to forecast weather patterns, pest outbreaks, and crop yields. These predictive tools assist farmers in making informed decisions, thereby reducing risks and improving productivity (Liakos et al., 2018). For instance, MLbased pest detection systems can identify infestations early, minimizing pesticide use.

AI powered irrigation systems leverage weather forecasts and soil moisture sensors to automate water application, conserving water resources and ensuring optimal crop growth (Mulla, 2013). These systems adapt to changing environmental conditions, supporting sustainable water management. Robotics and autonomous vehicles, such as drones and harvesters, utilize AI for tasks like planting, spraying, and harvesting. These innovations increase efficiency while reducing labor costs and human exposure to hazardous chemicals (Bacco et al., 2019). AI driven decision support systems compile and analyze data from various sources, providing actionable recommendations to farmers and policymakers. These systems facilitate sustainable land use planning and resource allocation (Kamilaris & Prenafeta-Boldú, 2018).

Genomic selection and AI models accelerate crop breeding by predicting desirable traits, leading to the development of climate resilient and high yield varieties (Zhou et al., 2020). This enhances food security by ensuring crop adaptability to changing environmental conditions. AI algorithms also optimize supply chains by predicting demand, managing inventories, and reducing postharvest losses. Efficient logistics improve access to markets, especially for smallholder farmers (Tang, et al. 2018). AI tools facilitate environmental monitoring, enabling the detection of deforestation, soil degradation, and water pollution. These insights support conservation efforts and sustainable land management (Kumar et al., 2020).

Nigeria, being the largest economy in Africa and a major producer of agricultural products, faces significant challenges in ensuring food security and sustainable agriculture practices. The country's agricultural sector is characterized by low productivity, inefficient resource use, and vulnerability to climate change. Artificial Intelligence (AI) has emerged as a promising tool to address these challenges. Several studies have highlighted the limited adoption of AI in Nigeria's agricultural sector (Akinyemi et al., 2020). A survey of 200 farmers in Nigeria's major agricultural producing states found that only 15% of respondents had heard of AI, and 5% had some knowledge of AI applications in agriculture (Ogundipe et al., 2020). The lack of awareness and understanding of AI is a significant barrier to its adoption in the sector.

The Economic Benefits of Deploying AI for Sustainable Agriculture and Food Security

Artificial Intelligence (AI) has emerged as a transformative technology in agriculture, offering numerous opportunities to enhance productivity, reduce costs, and promote sustainability. The economic benefits of AI in agriculture are multifaceted, impacting farmers, agribusinesses, and national economies, particularly in developing regions. AI driven technologies such as precision agriculture systems, crop modeling, and predictive analytics enable farmers to optimize resource use and improve crop yields. For instance, AI powered tools like crop health monitoring through remote sensing and machine learning algorithms facilitate early detection of pests and diseases, reducing crop losses and increasing productivity (Liakos et al., 2018). This enhances farmers' income and contributes to food security.

AI applications help in reducing input costs by optimizing the use of water, fertilizers, and pesticides. For example, AI based irrigation systems analyze weather data and soil moisture levels to determine optimal watering schedules, thereby conserving water and reducing energy costs (Zhang et al., 2020). Similarly, AI enabled drone technology can survey large farms efficiently, minimizing labor costs.

AI facilitates better supply chain management through predictive analytics, demand forecasting, and logistics,

reducing postharvest losses and ensuring timely market access. This leads to higher revenues for farmers and stimulates local economies (Oliveira et al., 2021). AI models can predict weather patterns, droughts, and other climate related risks, enabling farmers to make informed decisions. Such resilience building measures can prevent crop failures, stabilize income, and reduce economic vulnerabilities (Fletcher et al., 2019). The deployment of AI fosters innovation in agricultural practices and the development of new agritech enterprises. Although concerns about automation displacing labor exist, AI also creates new employment opportunities in data analysis, technology maintenance, and agritech services, potentially boosting local economies (Ruttan, 2017).

AI's integration into agriculture encourages governments and investors to channel resources into innovative solutions, fostering economic growth. Policy frameworks supporting AI adoption can stimulate entrepreneurship and attract foreign direct investment (FAO, 2020). The economic benefits of deploying AI in agriculture extend beyond immediate productivity gains, influencing cost efficiencies, market dynamics, risk mitigation, and innovation driven growth. These benefits collectively contribute to sustainable agricultural development and enhanced food security, especially in regions facing resource constraints and climate challenges.

Challenges of Deploying AI for Sustainable Agriculture and Food Security

The integration of artificial intelligence (AI) into agriculture holds immense potential for enhancing productivity, environmental conservation, and food security. However, several challenges hinder its widespread adoption and effective deployment, especially in developing regions such as Benue State. These challenges are multifaceted, spanning technological, socioeconomic, infrastructural, and policy domains.

One of the primary barriers to deploying AI in agriculture is the lack of advanced technological infrastructure. Many rural areas lack reliable internet connectivity, electricity, and access to high quality data, which are crucial for AI applications (Kagoyire & Uwah, 2020). Additionally, AI systems require sophisticated hardware and software, which may be prohibitively expensive for smallholder farmers (Liakos et al., 2018).

AI systems rely heavily on large volumes of high quality, context specific data for training and decision making. In many developing regions, data scarcity and poor data quality impede the development of accurate AI models (Kamilaris et al., 2018). Lack of standardized data collection practices and inconsistent data formats further complicate data integration efforts. The high cost of AI technologies, including hardware, software, and maintenance, poses a significant challenge, especially for small-scale farmers and local governments with limited budgets (Fountas, et al., 2020). This financial barrier restricts access and hampers scaling up of AI driven solutions.

There is often a significant skills gap among farmers and agricultural extension workers regarding AI literacy and digital skills (Fountas et al., 2020). Limited technical knowledge hampers the understanding, acceptance, and proper use of AI tools, leading to underutilization.

Cultural resistance and skepticism toward AI technologies can impede adoption. Farmers may distrust automated decision making systems due to fears of job displacement or loss of traditional knowledge (Sarpong et al., 2020). Ethical issues related to data privacy, ownership, and transparency also pose challenges.

The absence of clear policies, regulations, and standards governing AI deployment in agriculture limits innovation and creates uncertainty for stakeholders. Governments need to develop supportive frameworks for data governance, intellectual property rights, and technology transfer (Adejumo & Ogunjobi, 2019). In conclusion, while AI offers transformative potential for sustainable agriculture and food security, addressing these multifaceted challenges is critical. Overcoming technological, financial, capacity, socio-cultural, and policy barriers will require coordinated efforts among governments, academia, industry, and local communities. Developing context specific solutions and fostering inclusive participation can enhance the effective deployment of AI in agriculture, especially in regions like Benue State.

THEORETICAL FRAMEWORK

Technological Acceptance Model (TAM)

The Technological Acceptance Model (TAM) is one of the most influential models in information systems research, focusing on users' acceptance and usage behaviors toward new technologies. Originally proposed by Davis (1989), TAM has been extensively expanded and refined over the decades to incorporate additional factors influencing technology adoption. Davis (1989) developed TAM based on the Theory of Reasoned Action (TRA; Ajzen & Fishbein, 1980), simplifying it to focus specifically on computer technology acceptance. TAM posits that Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) are the primary determinants of technology acceptance, leading to Attitude Toward Using (ATU), which influences Behavioral Intention (BI) and actual usage.

The application of the Technology Acceptance Model (TAM) in harnessing Artificial Intelligence (AI) for sustainable agriculture presents a promising avenue to enhance environmental conservation and food security, particularly in regions like Benue State, Nigeria. TAM, developed by Davis (1989), posits that perceived usefulness and perceived ease of use significantly influence users' acceptance of new technologies. Applying TAM to AI driven innovations in agriculture involves understanding farmers' attitudes, motivations, and barriers toward adopting AI solutions.

AI technologies such as remote sensing, drone surveillance and predictive analytics enable precision farming, optimizing resource use, reducing waste, and minimizing environmental impact (Klerkx et al., 2019). Farmers in Benue State can adopt AI tools to monitor soil health, weather patterns, and crop health, leading to sustainable practices. AI models can predict climate variability and assist farmers in implementing adaptive strategies to mitigate adverse effects,

thus conserving biodiversity and preventing land degradation (Sharma et al., 2020). Acceptance of these tools depends on farmers' perceived usefulness and ease of integration into existing practices.

AI powered decision support systems can enhance yield prediction, supply chain management, and market access, thereby increasing food security (Suresh et al., 2021). The TAM can help identify factors influencing farmers' willingness to adopt such systems. Government and NGOs can leverage TAM insights to design targeted training programs that improve perceived ease of use and usefulness of AI tools, encouraging widespread adoption (Ajzen, 1992).

Farmers' familiarity with technology influences acceptance. Training and user-friendly interfaces boost perceived ease. Demonstrating tangible benefits like increased yields and cost savings encourages adoption. However, social influence and economic capacity affect acceptance levels (Venkatesh & Davis, 2000). In conclusion applying TAM to AI innovations in Benue State's agriculture can facilitate understanding of farmers' acceptance levels, helping policymakers and developers tailor interventions that promote sustainable practices. Emphasizing perceived usefulness and ease of use through training and demonstration of tangible benefits can accelerate adoption, leading to environmental conservation and enhanced food security.

METHODOLOGY

This study adopted descriptive survey research design. The design facilitates the collection of quantitative data to understand perceptions, practices, and innovations related to AI applications among farmers. A mixed method approach is incorporated to enrich quantitative findings with qualitative insights. The target population comprises registered farmers and agricultural experts from agri-tech enterprises involved in agriculture in Benue State. A sample size of 138 farmers was obtained using Taro Yamane formula while purposive sampling technique was used to select 12 key agricultural experts from agri-tech enterprises who possess rich information relevant to the research objectives.

Structured questionnaires were designed to gather data on AI adoption levels and perceptions of AI innovations for sustainable agriculture using four-point Likert-scale varying from strongly agree (SA), agree (A), disagree (D) and disagree (SD) respectively. Content validation was carried out to ensure the content validity of the questionnaires by reviewing and refining them with experts in agriculture and AI while the reliability of the instrument was determined using Cronbach's Alpha to ascertain the internal consistency of the instrument. The reliability coefficient yielded 0.80 Cronbach's Alpha coefficient which is considered high enough to consider the instrument reliable for the study.

Structured questionnaire was developed and distributed to a broad sample of farmers in Benue State. The questionnaire was designed to capture quantitative data on the level of AI awareness, adoption, and perceived benefits and challenges. The questionnaires were administered through face-to-face interview to ensure wider coverage and inclusivity. A total of one hundred and thirty-eight (138) questionnaires were administered to farmers. However, out of this number only one hundred and thirty-one (131) (95%) were retrieved. Analysis of data is achieved using percentage count and mean and standard deviation whereby a mean cut-off point of 2.50 is used for decision making. Any mean score of 2.50 and above is accepted as having the desired effect or significant while any mean score below 2.50 is rejected as not having any significant. Qualitative data collected from key agricultural experts from agri-tech enterprises in Benue State through in-depth interview were analyzed using written text.

RESULT AND DISCUSSION OF FINDINGS

Table 1: Demographic Data of the Respondents

| S/N | Variables | No of respondents | (%) | |
|-----|-----------------------------|---------------------|------------|------------|
| 1 | Age | Below 18 year | 5 | 3.8 |
| | | 18-25 years | 21 | 16.0 |
| | | 26-32 years | 35 | 26.7 |
| | | 33-39 years | 55 | 42.0 |
| | | 40 years and above | 15 | 11.5 |
| | | Total | 131 | 100 |
| 2 | Educational Qualification | No formal education | 5 | 3.8 |
| | | Primary level | 15 | 11.5 |
| | | Secondary level | 55 | 42.0 |
| | | Tertiary level | 56 | 42.7 |
| | | Total | 131 | 100 |
| 3 | Years of Farming experience | 1-5 years | 10 | 7.6 |
| | | 6-10 years | 15 | 11.5 |
| | | 11-15 years | 50 | 38.1 |
| | | 16 years and above | 56 | 42.7 |
| | | Total | 131 | 100 |

Source: Field Survey, 2026

Table 1 presents data on the demographic data of respondents. The table revealed that, out of the total number of 131 respondents used, 5 respondents representing 3.8% were between the age below 18 years, 21 respondents representing 16.0% were between the age of 18-25 years, 35 respondents representing 26.7% were between the age of 26-32 years, 55 respondents representing 42.0% were between the age of 33-39 years while 15 respondents representing 11.5% were between age 40 years and above years. By implication, majority of farmers examined were between the age of 33-39. Education attainment of respondents is presented on table 4.1 indicates that, 5 respondents representing 3.8% had no formal education, 15 respondents representing 11.5% education level were primary level, 55

respondents representing 42.0% level education qualification was secondary level while 56 famers representing 42.7% attained tertiary level of education. It was also revealed that 10 respondents representing 7.6% of respondents has been farming between 1-5 years, 15 respondents representing 11.5% farming experience is between 6-10 years, 50 respondents representing 38.1% have farming experience of between 11-15 years while 56 respondents representing 42.7% reported farming experience of more than 16 years.

Table 2: Respondents view on the level of deployment of artificial intelligence and innovations (n=131)

| S/N | Items | SA (4) | A (3) | D (2) | SD (1) | Σ | N | (\bar{x}) | SD | Decision |
|---------------------|---|------------|-----------|--------------|--------------|----------|-----|---------------|-------------|----------|
| 1 | I deploy AI that detects pests and diseases early to ensure food availability. | 3 (12) | 2 (6) | 85 (170) | 41 (41) | 229 | 131 | 1.74 | 1.31 | Rejected |
| 2 | I used AI applications that support conservation efforts by monitoring soil health to enhance sustainability in agriculture and food security. | 1 (4) | 1 (3) | 51 (102) | 76 (76) | 460 | 131 | 1.41 | 1.19 | Rejected |
| 3 | I deploy AI that predicting weather patterns and optimizing fertilizer and water application. | 1 (4) | 2 (6) | 28 (56) | 100 (100) | 166 | 131 | 1.27 | 1.13 | Rejected |
| 4 | I used AI-powered satellite imagery and drone surveillance that enables precise monitoring of crop health. | 10 (40) | 5 (15) | 6 (12) | 110 (110) | 177 | 131 | 1.35 | 1.16 | Rejected |
| 5 | I made use of AI that facilitates targeted interventions that reduce waste and environmental impact. | 2 (8) | 2 (6) | 7 (14) | 120 (120) | 148 | 131 | 1.13 | 1.06 | Rejected |
| 6 | I deploy AI models accelerate crop breeding by predicting desirable traits, leading to the development of climate resilient and high yield varieties. | 1 (4) | 1 (3) | 100 (200) | 30 (30) | 239 | 131 | 1.82 | 1.34 | Accepted |
| Cluster Mean | | | | | | | | | 1.45 | |

Source: Field Survey, 2026

Mean Bench Mark = 2.50

Data presented on Table 2 show the mean ratings of the level of artificial intelligence and innovations integrated into agricultural sector for sustainable agriculture and food security in Benue State. The data indicate that the mean ratings of respondents for items 1 to 6 are 1.74, 1.41, 1.27, 1.35, 1.13 and 1.82 with standard deviation of 1.31, 1.19, 1.13, 1.16, 1.06, 1.34 and the cluster mean score of 1.45 were obtained and rejected as it is rated below the mean bench mark of 2.50. Based on this result which is below the mean bench mark of 2.50 it is therefore indicates that, there is low level of integration or adoption of artificial intelligence and innovations into agriculture among farmers for sustainable agriculture and food security in Benue State. By implication, it is indicated that the awareness and understanding of AI technologies among farmers are generally low, which hampers their willingness and ability to adopt such innovations.

Table 3: Respondents view on economic benefits of deploying AI for sustainable agriculture and food security (n=131)

| S/N | Items | SA (4) | A (3) | D (2) | SD (1) | Σ | N | (\bar{x}) | SD | Decision |
|-----|--|--------------|-------------|-----------|-----------|----------|-----|---------------|------|----------|
| 1 | I believe deploying AI in my farm will help to detect pests and diseases early to ensure high yield. | 79 (316) | 46 (138) | 5 (10) | 1 (1) | 465 | 131 | 3.54 | 1.88 | Accepted |
| 2 | I believe the use of AI applications will support conservation efforts by monitoring soil health to enhance sustainability in my farm. | 100 (400) | 26 (78) | 4 (8) | 1 (1) | 487 | 131 | 3.71 | 1.92 | Accepted |

Continuation of Table 3

| | | | | | | | | | | |
|---------------------|--|--------------|------------|-----------|----------|-----|-----|------|-------------|-----------------|
| 3 | I believe AI powered satellite imagery and drone surveillance will enables precise monitoring of crop health also, facilitates targeted interventions that will reduce waste and environmental impact. | 111 (444) | 13 (39) | 5 (10) | 2 (2) | 495 | 131 | 3.77 | 1.94 | Accepted |
| 4 | It is true that AI models will accelerate crop breeding by predicting desirable traits leading to the development of climate resilient and high yield varieties. | 110 (440) | 17 (51) | 2 (4) | 2 (2) | 497 | 131 | 3.79 | 1.95 | Accepted |
| Cluster Mean | | | | | | | | | 3.70 | |

*Source: Field Survey, 2026***Mean Bench Mark = 2.50**

Data presented on Table 3 show the mean ratings on the economic benefits of deploying AI for sustainable agriculture and food security in Benue State. The data indicate that the mean ratings of respondents for items 1 to 4 are 3.54, 3.71, 3.77 and 3.79 with standard deviation of 1.88, 1.92, 1.94, 1.95 and the cluster mean score of 3.70 were obtained and accepted as it is rated above the mean bench mark. Based on this result, which is above the mean bench mark of 2.50 it indicates that, there are economic benefits of deploying AI for sustainable agriculture and food security in Benue State. Farmers in Benue State acknowledged their awareness of the benefits of AI technologies not only in the area of improving agricultural productivity but also the tangible economic benefits which will include increase in their crop yields and income.

Table 4: Respondents view on challenges of deploying AI for sustainable agriculture and food security (n=131)

| S/N | Items | SA (4) | A (3) | D (2) | SD (1) | Σ | N | (\bar{x}) | SD | Decision |
|---------------------|---|--------------|-------------|-----------|-----------|----------|-----|---------------|-------------|-----------------|
| 1 | Limited awareness of AI's potential benefits, lack of advanced technological infrastructure and data scarcity and poor data quality impede the development of accurate AI models. | 111 (444) | 13 (39) | 5 (10) | 2 (2) | 495 | 131 | 3.77 | 1.94 | Accepted |
| 2 | High cost of AI technologies, including hardware, software, and maintenance, poses a significant challenge, especially for small scale farmers. | 76 (304) | 51 (153) | 1 (2) | 1 (1) | 460 | 131 | 3.51 | 1.87 | Accepted |
| 3 | Limited technical knowledge hampers the understanding, acceptance, and proper use of AI tools, leading to underutilization. | 85 (340) | 41 (123) | 3 (6) | 2 (2) | 471 | 131 | 3.59 | 1.89 | Accepted |
| 4 | The absence of clear policies, regulations, and standards governing AI deployment in agriculture limits innovation and creates uncertainty for stakeholders. | 100 (400) | 28 (84) | 2 (4) | 1 (1) | 489 | 131 | 3.73 | 1.93 | Accepted |
| Cluster Mean | | | | | | | | | 3.65 | |

*Source: Field Survey, 2026***Mean Bench Mark = 2.50**

Data presented on Table 4 show the mean ratings of the challenges of deploying AI for sustainable agriculture and food security in Benue State. The data indicate that the mean ratings of respondents for items 1 to 4 are 3.77, 3.51, 3.59 and

3.73 with standard deviation of 1.94, 1.87, 1.89, 1.93 and the cluster mean score of 3.65 were obtained and accepted as it is rated above the mean bench mark of 2.50 indicating that there are the challenges of deploying AI for sustainable agriculture and food security in Benue State. These challenges were revealed to include inadequate access to reliable internet, electricity, and digital infrastructure hampers the deployment and utilization of AI technologies, especially in rural farming communities, low digital literacy and skills gap, high costs of AI Technologies and limited awareness.

Analysis of Qualitative Data from Key stakeholders

The discussion on harnessing AI for sustainable agriculture in Benue State with the key agricultural experts highlights that AI adoption among farmers is still in early stages, mainly through pilot projects, with barriers like low awareness, high costs, and poor infrastructure. The findings on the benefits of deploying Artificial Intelligence (AI) for sustainable agriculture among farmers in Benue State from key agricultural experts interviewed. According a 45 years of female agricultural experts from TS-AGRIC CONNECT, AI-powered tools enable farmers to monitor crop health in real-time through satellite imagery, drones, and sensor data. This leads to more accurate identification of pests, diseases, and nutrient deficiencies, allowing for targeted interventions and reducing chemical use. She also acknowledged that AI-driven predictive analytics help forecast weather patterns, optimize planting and harvesting schedules, and improve yield predictions. This results in more reliable food production, reducing the risk of crop failure and enhancing food availability for local communities.

A 56 years old male agricultural experts from Omega Agric-Tech Limited emphasized that AI applications facilitate precision agriculture, which minimizes overuse of water, fertilizers, and pesticides. This promotes sustainable resource use, reduces environmental pollution, and preserves biodiversity in the region. He also state that AI technologies assist farmers in efficient resource allocation, such as optimized irrigation systems and input management, leading to cost savings and reduced environmental footprint.

Furthermore, a 46 years old male staff of Tractoria Agritech pointed out that the integration of AI tools, coupled with training and extension services, enhances farmers' knowledge and decision-making capacity, fostering a more resilient and sustainable farming community. He adds that AI models help farmers adapt to climate variability by providing localized climate data and adaptive strategies, thereby supporting sustainable farming practices amid changing environmental conditions. A 50 years old agricultural expert interviewed also stressed that AI tools such as GPS-guided equipment, crop monitoring systems, weather forecasting, and resource optimization are being integrated to promote sustainability and food security. These innovations can lead to increased yields, cost savings, market access, and job creation. Overall, deploying AI in Benue State's agriculture sector demonstrates significant potential to promote environmental conservation and improve food security through innovative, data-driven solutions that benefit farmers and the ecosystem alike. However, it was revealed by the interviewee that challenges remain, including limited infrastructure, low digital literacy, financial constraints, data privacy concerns, and lack of supportive policies. Addressing these barriers could enhance AI's role in transforming agriculture in Benue State.

DISCUSSION OF FINDINGS

The study explored how artificial intelligence (AI) can promote sustainable agriculture in Benue State, focusing on environmental conservation and food security. The respondents' insights reveal that the current level of Artificial Intelligence (AI) adoption among farmers in Benue State is relatively low. Most farmers have limited exposure to AI technologies, primarily due to infrastructural challenges, lack of awareness, and limited access to training and resources. Many farmers still rely on traditional farming methods, and only a small fraction have begun experimenting with AI-driven tools such as weather forecasting apps, pest detection systems, or precision agriculture equipment.

Despite the modest adoption level, respondents recognize the significant potential of AI to transform agriculture in Benue State. They believe that with increased awareness and access, AI could substantially improve farm productivity and sustainability. The respondents emphasize that AI can help optimize resource use like water and fertilizers reduce wastage, and improve pest and disease management, leading to more efficient farming practices.

Regarding the economic benefits, respondents overwhelmingly agreed that AI adoption can lead to notable financial gains and AI-powered decision support systems can help farmers identify the best planting times, optimal fertilizer use, and pest control measures, resulting in higher yields and more reliable harvests. By enabling precision agriculture, AI can reduce input costs such as fertilizers, pesticides, and water, thereby increasing profit margins for farmers. Also, AI-based weather forecasting and early warning systems can help farmers plan better, reduce losses from adverse weather conditions, and manage risks effectively. The respondents also note that these economic benefits can contribute to poverty reduction, improve household income, and foster local economic development. However, they caution that these benefits are contingent on overcoming barriers like limited digital literacy and infrastructural deficits.

These findings is in consistent with Oliveira et al., (2021) who acknowledged that AI facilitates better supply chain management through predictive analytics, demand forecasting, and logistics optimization, reducing postharvest losses and ensuring timely market access leading to higher revenues for farmers and stimulates local economies.

The study revealed challenges to adoption of AI by local farmers which include poor infrastructure, high costs, limited digital skills, and data security concerns. This finding is consistent with Aker et al. (2021), who reported challenges such as limited access to digital infrastructure, low awareness, and high costs as hindrances to widespread adoption of AI by farmers.

The study's findings align with the Technology Acceptance Model (TAM) adopted for the study, which emphasizes perceived usefulness and ease of use as key to technology adoption. Farmers are more likely to adopt AI if they see

clear benefits like increased productivity and resource efficiency, and if the technology is easy to understand and operate. Addressing technological literacy and infrastructure challenges can enhance acceptance. By demonstrating tangible benefits and simplifying AI tools, farmers' willingness to adopt these technologies increases, leading to positive environmental and food security outcomes. Overall, applying TAM helps explain and promote AI adoption for sustainable development in the region.

LIMITATIONS OF THE STUDY

The findings of this study are constrained by several limitations. Firstly, the relatively small or non-representative sample size reduces the statistical robustness of the analysis and may not fully capture the diversity of farmers' experiences, levels of technological adoption, or perceptions throughout Benue State. As a result, the ability to generalize these findings to the broader farming community within the region is limited. Additionally, the study's focus solely on Benue State confines the geographic scope, making it difficult to apply the insights universally. Agricultural practices, access to technology and environmental conditions can vary significantly across different regions, which means that the conclusions drawn may not be directly transferable to other areas with differing socio-economic or ecological contexts.

Furthermore, the reliance on self-reported data introduces potential biases, such as social desirability, recall inaccuracies, or misunderstandings of survey questions, which can compromise data accuracy. Respondents might overstate their use of AI technologies or perceived environmental benefits, thus skewing the results. Additional limitations include possible gaps in technological literacy among participants, the cross-sectional nature of the data that prevents analysis of changes over time, and infrastructural challenges affecting AI adoption that are not fully addressed within the scope of this study.

CONCLUSION

Harnessing Artificial Intelligence (AI) for sustainable agriculture presents a transformative opportunity for Benue State to enhance environmental conservation and achieve food security. While AI adoption among farmers in Benue State is still emerging, existing initiatives demonstrate the potential of AI-driven tools such as precision farming, pest detection systems, and weather forecasting models to optimize resource use and improve crop yields. These innovations can significantly contribute to sustainable practices by reducing environmental degradation, conserving water, and minimizing the overuse of agrochemicals. The deployment of AI technologies offers substantial economic benefits for Benue's State agricultural sector as it will enhance productivity and efficiency that will lead to increase income for smallholder farmers, reduced post-harvest losses, and improved food security for the region. Moreover, AI-driven data analytics facilitate better market access and inform policy decisions, fostering a resilient agricultural economy. However, the adoption of AI in Benue State faces notable challenges. Limited digital infrastructure, high costs of emerging technologies, low digital literacy among farmers, and data privacy concerns hinder widespread implementation. Addressing these barriers requires concerted efforts from government agencies, private sector stakeholders and development partners to build capacity, improve infrastructure and promote accessible, farmer-friendly AI solutions.

RECOMMENDATIONS

Based on the findings above, the following recommendations are made:

- i. Policy makers in agricultural sector in Benue State should endeavor to develop and deploy AI powered tools for soil health monitoring, crop health assessment, and optimized resource utilization to enhance yield and reduce environmental impact.
- ii. Benue State should Establish Local Data Collection and Management Systems to create platforms for collecting local agricultural data (weather, soil, crop health) to train AI models relevant to Benue State's unique environmental conditions.
- iii. Policy makers in Agriculture in Benue State should conduct training programs for farmers, extension workers, and local researchers on AI technologies, data analysis, and digital literacy to facilitate adoption.
- iv. There should be collaborations between government agencies, tech companies, research institutions, and NGOs to fund and develop AI based agricultural solutions.

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