

# Effect of the Use of Natural Products, Biodiversity, AI, and Digital Innovations in Agricultural Improvement in Southeast, Nigeria

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## ABSTRACT

This study explored how natural products, biodiversity, artificial intelligence (AI), and digital innovations can enhance agriculture in Southeast Nigeria. It identified available natural products for crop production and examined their impact on agricultural progress and sustainability. The research also assessed AI tools and digital innovations in farming, analyzing their effects on crop management and accessibility to agricultural information, while addressing challenges in implementing these technologies. Conducted with 450 respondents through structured questionnaires, the study indicated that farmers utilized resources like animal manure, compost, and neem extract, which support soil fertility, boost crop yields, reduce dependence on chemical fertilizers, and enhance environmental quality. The study indicates that mixed cropping, agroforestry, local crop varieties, legumes, natural pollinators, organic matter, and livestock are key components of biodiversity in farming. This diversity enhances soil fertility, boosts crop yields, protects local species, controls pests naturally, and fosters climate resilience. Additionally, mobile applications, weather forecasts, pest control apps, GPS, GIS technologies, drones, smart farming tools, and irrigation systems constitute the digital innovations in agriculture. These tools aid in increasing crop production and optimizing farm management, improving access to agricultural information, and enhancing decision-making. However, challenges persist, including limited technical knowledge, subpar extension services, financial constraints, high technology costs, inadequate infrastructure, and a lack of policy support. The study suggests that integrating biodiversity and digital innovations can enhance agricultural production and food security in Southeast Nigeria. Recommendations include promoting farmer training, improving extension services, developing strong digital infrastructure, offering financing for advanced technologies, and fostering collaborations among government, researchers, industry, and farmers for sustainable agricultural growth.

**Keywords:** Natural products, biodiversity conservation, AI, digital innovations, sustainable agriculture, agricultural productivity, Southeast Nigeria.

## Introduction

Agriculture is a significant economic sector in Nigeria, contributing to employment, food, and industrial raw materials production, as well as settling millions of people. Southeast Nigeria is amongst the leading agricultural regions in the country that consist of Abia, Anambra, Ebonyi, Enugu, and Imo states. The region has abundant resources suitable for agriculture, including cassava, yam, rice, maize, vegetables, cocoyam, and oil palm cultivation. However, agricultural production has been on the rise due to land degradation, biodiversity loss, climate change, pests and diseases outbreak, inadequate agronomic inputs, and poor extension services in the area [1,2]. Currently, the use of natural products combined with biodiversity conservation, artificial intelligence (AI), and digital innovations is considered an effective way to achieve sustainable agricultural development. Natural products are gaining significant attention in many parts of the world as bio-fertilizers, compost, botanical pesticides, microbial inoculants, and organic manures.

These products provide an alternative to chemical agrochemicals by restoring soil fertility, improving plant yield, and reducing environmental pollution, especially in Southeast Nigeria, which has been facing environmental degradation and poor agricultural production.

On the other hand, biodiversity plays an essential role in maintaining productive and resilient agricultural systems. It includes a wide range of above-ground plants, below-ground microorganisms, beneficial insects, forest heritages, and other resources that help support and maintain crop production processes. Biodiversity sustains vital ecological functions, such as nutrient cycling, biological control of pests, pollination, climate regulation, and ensuring food and farm income security for the locals. For instance, conserving indigenous crop species and traditional knowledge systems supports climate change adaptation and food security while providing opportunities for developing new and resilient crop varieties and managing pests and diseases[3]

Further, the development of new technologies, such as AI-based solutions, has changed the agricultural landscape in recent years.

These digital solutions provide farmers with information on the best cropping systems, weather conditions, and irrigation management that can boost farm production while reducing the negative impact on the environment. For instance, AI uses computer vision and machine learning to help identify diseased plants, monitor the overall health of crops, and predict weather conditions during planting periods. Moreover, AI applications can help monitor, evaluate, and forecast agricultural production trends while supporting farmers in making precise and profitable decisions based on the generated insights [4,5]. Besides AI technology, the use of digital innovations has also been considered a viable option for boosting agricultural production and making it more profitable and sustainable.

The term digital innovations refers to a wide range of digital technologies used in different aspects of farming activities, including crop production, harvesting, storage, and selling. Some of the digital technologies currently used in agriculture include Geographic Information Systems (GIS), Global Positioning Systems (GPS), blockchain technology, agricultural phones, cloud computing, digital extension services, electronic trading platforms, sensors, and Internet of Things (IoT) applications. These technologies offer farmers the best agricultural practices, weather forecasting, digital extension services and advisory, agricultural insurance, better market access, digital financing options and data services, and early detection of plant diseases and field pests [6,7]. Further, these innovations help farmers maximize crop yield, minimize losses, and make informed decisions while conserving the environment.

Currently, Nigeria has been gradually embracing digital agriculture through various programs and investments to increase agricultural productivity and ensure food security. However, the adoption of digital agriculture faces significant challenges hindering its growth and development in the country's farming systems. Southeast Nigeria has a high potential for adopting digital agriculture solutions due to the general literacy and entrepreneurial activities in the region. However, the adoption of these technologies is limited by several factors, such as insufficient digital skills, inadequate internet services, high installation costs, poor electricity, and a lack of proper support structures [8].

Natural products, biodiversity conservation, AI applications, and digital innovations could offer numerous benefits to farmers in Southeast Nigeria. These products and technologies are valuable in improving agricultural production while conserving the environment. Further, the combined use of natural products, biodiversity, AI, and digital innovations can help achieve sustainable agricultural development, raise farm profits, increase crop yields, minimize production risks, enhance climate change adaptation, conserve biodiversity and the environment, and ultimately boost farm income [9,4,6,3]. However, there is a lack of information on how these products and technologies influence agricultural improvement in the study area. Most of the previous literature on agriculture has focused on the importance of natural products, biodiversity conservation, AI, and digital innovations in sustainable agricultural development. However, there is limited information on how these technologies and products influence agricultural improvement in Southeast Nigeria [6,3]. Therefore, this study aims to establish the effect of the use of natural products, biodiversity, AI, and digital innovations on agricultural improvement in Southeast Nigeria.

## Statement of the Problem

Agricultural production in Southeast Nigeria has faced numerous challenges over the years, including poor soil Fertility, biodiversity loss, climate change, pests and diseases, and inadequate extension services. These problems have significantly reduced crop production, lowered food security, and caused environmental degradation in the region despite the area's high agricultural potential [9]. Natural products such as organic manure and botanical pesticides have been identified as appropriate solutions for improving soil Fertility and minimizing environmental pollution in Southeast Nigeria. Even though biodiversity conservation helps maintain essential ecological functions that support sustainable agricultural production, conservation efforts have not been successful in the study area.

Meanwhile, AI and digital innovations have been increasingly used in precision farming to enhance agricultural production and sustainability worldwide. Farmers across Southeast Nigeria have access to various digital technologies that can help maximize crop yields and profits. These technologies include drones, robotics, computer vision systems, remote sensing, and virtual reality. These innovations can help farmers achieve profitable agricultural production while conserving the environment. However, farmers have not fully utilized these technologies due to inadequate digital skills, poor internet connections, financial constraints, lack of proper support structures, and poor policy implementation [4,8].

Most studies conducted in Nigeria have focused on the use and benefits of natural products, biodiversity conservation, AI, and digital innovations in agriculture. However, there is limited information on how these technologies and practices influence agricultural improvement in Southeast Nigeria [6,3]. This research gap is vital to address since it will help develop integrated strategies for sustainable agricultural improvement in Southeast Nigeria based on evidence-based findings. The general objective of this research is to examine the effect of the use of natural products, biodiversity, artificial intelligence, and digital innovations on agricultural improvement in Southeast Nigeria. Specific Objectives include to – a) identify natural products for crop farming available in the area; b). determine the effect of natural products on agricultural productivity in Southeast Nigeria, c). ascertain biodiversity components in the farming system of the area; d). assess the contribution of biodiversity conservation to sustainable agricultural improvement in Southeast Nigeria; e). identify AI tools available in the area for agriculture, f).examine the influence of artificial intelligence on crop production and farm management in Southeast Nigeria; g)identify digital innovations in agriculture ; h). Evaluate the effect of digital innovations on agricultural productivity and farmers' access to agricultural information in Southeast Nigeria; i). Identify the challenges limiting the adoption of natural products, biodiversity conservation, AI, and digital innovations among farmers in Southeast Nigeria; k).Recommend strategies for enhancing the integration of natural products, biodiversity, AI, and digital innovations for sustainable agricultural development in Southeast Nigeria. The justification for this study is that agriculture is a primary need for food security, employment generation, poverty reduction, and economic growth in Southeast Nigeria. There is a need to increase agricultural production through environmentally sustainable and technology-informed methods in the face of environmental challenges, loss of biodiversity, and rising demand for food.

The results of the study will add value by providing evidence for the policymakers, agricultural extension agents, researchers, development partners, and agribusinesses on the benefits of promoting agriculture production using natural products, biodiversity conservation, artificial intelligence, and digital technologies. It will also add value by helping to formulate policies that promote the use of climate-smart agriculture, precision farming, and biodiversity-friendly techniques and technologies in agricultural production in Nigeria. Additionally, the study will add empirical evidence on the effect of utilizing ecological and digital innovations on agricultural advancement in Southeast Nigeria. This knowledge will support researchers and the government in developing appropriate interventions for sustainable agriculture development in the region. There is a gap in research on the combined impact of ecological and digital innovations on sustainable agricultural development in Southeast Nigeria. The study's results will add to the existing body of knowledge by providing evidence on the effectiveness of ecological and digital innovations for sustainable agriculture development in Southeast Nigeria. The results will also benefit universities, research institutions, and scholars who may conduct further studies on the topic.

### Methodology

The research was conducted in Southeast Nigeria, which includes the states of Abia, Anambra, Ebonyi, Enugu, and Imo. This area is situated between latitudes 4°30'N and 7°30'N and longitudes 6°45'E and 8°45'E. Southeast Nigeria has a humid tropical climate with distinct wet and dry seasons, receiving annual rainfall ranging from about 1,500 mm to 2,500 mm and average temperatures between 26°C and 30°C. The primary occupation in the region is agriculture, with farmers growing crops like cassava, yam, maize, rice, cocoyam, vegetables, oil palm, plantain, and various fruits. The area is known for its fertile soils, diverse plant and animal life, extensive agroforestry systems, and increasing use of digital agricultural technologies, making it ideal for studying the combination of natural resources, biodiversity conservation, artificial intelligence, and digital advancements in sustainable farming. The study utilized a descriptive survey approach to gather information from a representative sample of farmers on the impact of natural products, biodiversity, artificial intelligence, and digital innovations on agriculture in Southeast Nigeria. The survey method allowed for the collection of quantitative data on farmers' views, experiences, and practices without altering the study variables. The target population consisted of 4,500 registered crop farmers and agricultural extension workers in the five states of Southeast Nigeria. A sample size of 450 respondents, representing 10% of the total population, was selected to ensure reliable results and geographic diversity. A multistage sampling technique was employed to select participants from different regions, ensuring fair representation and reducing bias. Data were collected using a structured questionnaire called "Natural Products, Biodiversity, Artificial Intelligence, Digital Innovations, and Agricultural Improvement Questionnaire (NPBAIDIAIQ)." The questionnaire underwent validation by experts in relevant fields and was tested for reliability before being administered. Data analysis was performed using SPSS software, and frequencies and percentages were used to analyze the data.

### Result and Discussions

#### Identify natural products for crop farming available in the area

Table 1 showed that animal manure is the most prevalent natural product used in crop farming, with (91.6%) reporting its availability. Following closely are poultry droppings (89.8%), and compost manure (88.4%). Wood ash also appears to be a popular choice (83.3%) identified it as a valuable natural resource for crop production. Green manure garnered the attention of (76.9%), while neem extracts were reported by (73.8%), highlighting a strong awareness of botanical methods for pest control. Additionally, crop residues utilized as mulch were acknowledged by 320 respondents (71.1%), reflecting a common practice of recycling waste on farms. Botanical pesticides made from locally accessible plants like pepper, garlic, and tobacco were mentioned by 287 respondents (63.8%). Biochar was recognized by 214 respondents (47.6%), indicating moderate availability among farmers. Other natural products, such as bone meal (41.3%), fish waste or fish emulsion (37.6%), and earthworm castings (33.8%), were noted but are not yet widely embraced, signaling that while they are available, further adoption may be needed. Overall, these findings suggest that farmers have access to a diverse array of local natural products, particularly organic manures and plant-based materials, which could significantly boost sustainable crop production while lowering reliance on synthetic agricultural inputs. Natural products are natural substances of plant, animal, microbial, and mineral origin used to improve the fertility of the land, boost production, and control pests and diseases [1]. There is a growing need for the use of natural products due to their active roles in conserving the environment while improving the quality and quantity of crops and food production. The use of these natural resources has been promoted worldwide and has attracted much attention in recent years because of their significance in climate-smart agricultural production. With respect to crop production, examples of natural products include poultry, cattle, goat, compost, green manure, wood ash, charcoal, bone meal, fish emulsion, vermicompost, and botanical pesticides such as neem ( *Azadirachta indica* ), garlic ( *Allium sativum* ), pepper ( *Capsicum* spp.), and tobacco ( *Nicotiana tabacum* ) [1,10]. Natural products like manures, compost, and green manure improve the physical properties of the soil, boost the quantity and quality of crops. Biochar, for instance, is becoming a new agricultural product used to improve water retention, carbon sequestration, and nutrient retention in the tropical soil [11]. Similarly, compost and green manure enhance microbial activity and humus formation in the soil, which boosts the production of food crops [10].

On the other hand, botanical pesticides such as neem, tobacco, and garlic have been used traditionally as effective means of controlling pests and diseases in crops production. They are environmentally friendly and healthy to use compared to the synthetic pesticides currently in use [12]. Thus, there is great potential for using natural products to enhance production while conserving the environment. Firstly, using organic manures and compost to enhance production reduces the need for inorganic fertilizers that have adverse effects on the environment. The use of natural products such as compost, manure, wood ash, and crop residues has been widely promoted in Nigeria and other developing countries as a way of boosting production while conserving the environment.



Secondly, such practices are cost-effective and at the same time increase food security while promoting sustainable production in sub-Saharan Africa [1].

**Table 1: Natural Products for Crop Farming Available in the Area**

| S/N | Natural Products Available for Crop Farming                   | Frequency | Percentage |
|-----|---------------------------------------------------------------|-----------|------------|
| 1   | Animal manure (poultry, cattle, goat manure)                  | 412       | 91.6       |
| 2   | Compost manure                                                | 398       | 88.4       |
| 3   | Wood ash                                                      | 375       | 83.3       |
| 4   | Green manure (cover crops/leguminous plants)                  | 346       | 76.9       |
| 5   | Neem extracts (biopesticide)                                  | 332       | 73.8       |
| 6   | Crop residues/mulch                                           | 320       | 71.1       |
| 7   | Poultry droppings                                             | 404       | 89.8       |
| 8   | Biochar                                                       | 214       | 47.6       |
| 9   | Botanical pesticides (e.g., pepper, garlic, tobacco extracts) | 287       | 63.8       |
| 10  | Bone meal                                                     | 186       | 41.3       |
| 11  | Fish waste/fish emulsion                                      | 169       | 37.6       |
| 12  | Earthworm castings (vermicompost)                             | 152       | 33.8       |

### Effect of natural products on agricultural productivity in Southeast Nigeria

The results in table 2 showed that most survey participants viewed enhanced soil fertility as the primary impact of organic substances on farm productivity, with 418 individuals (92.9%) acknowledging this advantage. Following closely was the rise in crop production, noted by (90.2%), indicating a significant contribution of natural products to higher farm yield. 389 participants (86.4%) mentioned improved soil structure and water retention, emphasizing the role of biological materials in enhancing soil physical characteristics. Moreover, 375 individuals (83.3%) stated that organic products decrease reliance on synthetic fertilizers, while 361 participants (80.2%) felt they improve pest and disease management. 358 respondents (79.6%) highlighted better long-term soil conditions, and 348 participants (77.3%) pointed out reduced farming expenses, showing key economic and sustainability advantages. Additionally, 336 respondents (74.7%) reported enhanced crop quality, 322 respondents (71.6%) noticed an increase in beneficial soil microbes, and 315 participants (70.0%) believed natural products support environmental sustainability. While fewer participants recognized improved resilience to climate fluctuations (64.2%) and increased farmers' earnings (61.3%), these responses still reveal that a significant number of farmers acknowledge the broader economic and environmental benefits of utilizing organic products. Natural products are critical to advanced agricultural production because they improve the fertility of the land, raise yields, improve the properties of the soil, and reduce reliance on chemical inputs. Natural products comprise compost, manure, poultry droppings, green manure, biochar, and botanical pesticides. These organic materials are crucial for their fertility and ability to make nutrient-rich soil that boosts food production [1]. They are integral components of productive and environmentally appropriate agricultural production systems. This paper discusses the importance of natural products in agricultural production, their benefits, and how they may impact future agricultural sustainability in Southeast Nigeria. Natural products have become popular in Southeast Nigeria because many farmers cannot afford to buy inorganic manure and pesticides. Organic materials such as poultry manure, compost, wood ash, crop residues, and neem pesticides are cheap sources of adding organic matter to most farmers' fields in Southeast Nigeria [13]. These organic products are beneficial for increasing the organic content and tilt of the soil, which are critical in raising high agricultural yields. Neem pesticides are helpful in controlling insect pests, diseases, and fungi in crops.

The use of natural products is essential in appropriate pest control and improving the fertility of the soils in Southeast Nigeria. Organic soil conditioners such as compost, manure, and poultry dropping are critical in improving the nutrient content of the soil, tilth, and controlling pests and diseases in the crops [12]. Neem pesticides and biochar are essential in promoting humus, which is critical in ensuring food security. Neem pesticides are effective against most agricultural insect pests. Their effectiveness has been demonstrated by their ability to lower the incidence of pests and diseases in most crops.

In addition to providing fertility to the soil and controlling pests, natural products are essential in promoting sustainable agricultural production in Southeast Nigeria. Their use is helpful in reducing the negative impact of chemical pesticides and fertilizers in the environment while also promoting biodiversity in the region [11]. Manure and compost are critical in promoting good aeration of the soil, which is essential in enhancing nutrient mineralization and improved agricultural yields. Organic farming is also important because it reduces the emission of greenhouse gases and the effect of chemical toxins in the soil, thereby conserving the environment. Farmers who use organic products are also in a position to mitigate the effects of climate change on agricultural production, since organic matter in the soil ensures good water retention and nutrients in the soil. As a result, most farmers who use natural products record high agricultural yields and profits from their sales.

The use of natural products is low in Southeast Nigeria because of insufficient knowledge of appropriate organic farming practices among most farmers. Organic farming requires proper application of organic materials to enhance agricultural production while meeting the quality control standards of organic farming. Farmers also need to be trained on how to process these materials into value-added products that meet international organic farming standards [1]. Organic farming is also laborious, which makes it unavailable to most smallholder farmers who lack the skills and resources to engage in organic farming practices. Therefore, promoting organic farming by providing extension services to farmers and conducting more research to promote organic farming practices will be beneficial in increasing the use of natural products in organic farming in Southeast Nigeria.

**Table 2: Effect of Natural Products on Agricultural Productivity in Southeast**

| S/N | Effect of Natural Products on Agricultural Productivity | Frequency | Percentage |
|-----|---------------------------------------------------------|-----------|------------|
| 1   | Improved soil fertility                                 | 418       | 92.9       |
| 2   | Increased crop yield                                    | 406       | 90.2       |
| 3   | Improved soil structure and water retention             | 389       | 86.4       |
| 4   | Reduced dependence on chemical fertilizers              | 375       | 83.3       |
| 5   | Enhanced pest and disease control                       | 361       | 80.2       |
| 6   | Reduced cost of crop production                         | 348       | 77.3       |
| 7   | Improved crop quality                                   | 336       | 74.7       |
| 8   | Increased beneficial soil microorganisms                | 322       | 71.6       |
| 9   | Improved environmental sustainability                   | 315       | 70.0       |
| 10  | Enhanced resilience to climate variability              | 289       | 64.2       |
| 11  | Increased farmers' income through higher productivity   | 276       | 61.3       |
| 12  | Improved long-term soil health                          | 358       | 79.6       |

### Biodiversity components in the farming system of the area

Table 3 results suggest that mixed cropping, identified by 416 respondents (92.4%), was the most widespread biodiversity element in the farming system. This was followed by agroforestry trees with 397 respondents (88.2%), indigenous crop varieties with 384 respondents (85.3%), and leguminous crops with 372 respondents (82.7%).

These results indicate that farmers in the research area commonly embrace diverse farming methods that incorporate various crop types, native varieties, and trees to enhance productivity and preserve ecological equilibrium. Additionally, 356 respondents (79.1%) recognized the importance of pollinators like bees and butterflies, while 341 respondents (75.8%) acknowledged the significance of soil biodiversity, such as earthworms and helpful microorganisms, in enhancing soil fertility and crop yield. Integrated crop-livestock farming, reported by 329 respondents (73.1%), demonstrates the practice of merging crop and livestock activities to enhance nutrient recycling and farm sustainability. Medicinal and aromatic plants (68.2%) and natural vegetation or hedgerows (63.6%) were commonly integrated into farming systems, aiding in habitat preservation and ecosystem services. However, wetlands and aquatic biodiversity were mentioned by only 194 respondents (43.1%), making them the least prevalent biodiversity components in the region. In summary, the outcomes show that farming systems in the study area feature abundant agricultural biodiversity, focusing on crop variety, agroforestry, native plant species, beneficial organisms, and integrated farming methods that promote sustainable agricultural production and environmental protection. Biodiversity in farming systems entails the existence and variation of different organisms involved in food production and ecosystem functions. It consists of a diversity of crops, animals, trees, beneficial insects, soil macro and microorganisms, wild species, and vegetation that take part in food production processes and promote agricultural sustainability [14]. Agricultural biodiversity is significant to food production because of its ability to provide goods and services such as nutrient cycling, pollination, biological pest control, soil formation, and water regulation. Crop diversity remains the most significant form of biodiversity in agricultural production. It comprises multiple crop plants and cultivars through mixed cropping, crop rotations, and intercropping. Agricultural biodiversity also includes cultivating indigenous crop varieties, legumes, vegetables, and fruits. Crop diversity provides nutrients and control of pests and diseases, and it also mitigates risks in bad weather and poor yields [15]. Legumes and vegetables provide a basis for maintaining and restoring soil fertility, while indigenous varieties are resistant to insects, pests, and diseases. Trees constitute an essential component of biodiversity in farming systems that provide food directly and indirectly through various products. Trees add to agricultural biodiversity by providing firewood, timber, forage, fruit, herbs, construction materials, and medicines that raise farm incomes [16]. Moreover, trees help improve and maintain soil quality, enhance biodiversity, lower environmental pollution, and influence the microclimate. For example, many farmers in Southeast Nigeria grow economic trees such as palms, mangoes, avocados, citrus, and native forest trees alongside food crops to produce a wide range of agricultural products. The diversity of soil macroorganisms and microorganisms also plays an essential role biodiversity within agricultural systems. Soil microorganisms are critical to decomposition and nutrient cycles, as well as the improvement of the properties of the soil. Thus, biodiversity in the form of microorganisms needs to be maintained for sustainable agriculture and food production for millions of people and decades ahead [10]. Beneficial insects, farm animals, and livestock are vital components of biodiversity in agricultural production.

They contribute to nutrient recycling in the soil, the control of pests and diseases, and pollination of crops and soils [17]. For example, livestock produces a wide range of products, including manure that enhances nutrient recycling and the creation of various agricultural goods. Maintaining biodiversity encourages sustainability in agricultural production while conserving the genetic diversity of valuable species of plants and animals. Sustainable farming biodiversity is critical for enhancing the adaptation of crops and livestock to the impacts of climate change while also ensuring food and agricultural production. However, biodiversity and diversity in farming systems are under serious threat from such activities as deforestation, monoculture, the use of pesticides, desertification, and others. Consequently, the importance of biodiversity in agricultural production cannot be emphasized enough because it facilitates adaptation, resilience, and sustainability in farming systems.

**Table 3: Biodiversity Components in the Farming System of the Area**

| S/N | Biodiversity Components in the Farming System                | Frequency | Percentage |
|-----|--------------------------------------------------------------|-----------|------------|
| 1   | Mixed cropping (crop diversity)                              | 416       | 92.4       |
| 2   | Agroforestry trees                                           | 397       | 88.2       |
| 3   | Indigenous crop varieties                                    | 384       | 85.3       |
| 4   | Leguminous crops (nitrogen-fixing plants)                    | 372       | 82.7       |
| 5   | Pollinators (bees, butterflies and other beneficial insects) | 356       | 79.1       |
| 6   | Soil biodiversity (earthworms and beneficial microorganisms) | 341       | 75.8       |
| 7   | Livestock integrated with crop production                    | 329       | 73.1       |
| 8   | Medicinal and aromatic plants                                | 307       | 68.2       |
| 9   | Natural vegetation/hedgerows around farms                    | 286       | 63.6       |
| 10  | Wetlands and aquatic biodiversity                            | 194       | 43.1       |

### Contribution of Biodiversity Conservation to Sustainable Agricultural Improvement

Table 4 showed that enhancing soil fertility and nutrient cycling was widely acknowledged as a significant benefit of biodiversity conservation for sustainable agricultural enhancement, with 93.1% recognizing this advantage. Following closely were the increase in crop productivity and yield at 90.4%, and the preservation of native crop varieties and genetic resources at 87.1%. These findings indicate that survey participants view biodiversity conservation as crucial for improving agricultural output and safeguarding valuable genetic resources for future farming endeavors. Moreover, 83.6% of respondents noted that biodiversity conservation supports natural pest and disease control, while 80.9% believed it encourages pollination and other vital ecosystem services. The survey also revealed that 78.0% of participants recognized that biodiversity conservation enhances resilience to climate change and environmental disturbances, underscoring the role of biodiversity in fortifying the adaptive capacity of agricultural systems. Additionally, 74.9% concurred that biodiversity conservation decreases reliance on artificial fertilizers and pesticides, with 72.0% acknowledging its importance in preserving soil and water resources. Biodiversity conservation was also seen as a means to support sustainable livelihoods and boost farmers' income by 68.7%, while simultaneously maintaining wildlife habitats and ecological equilibrium at 63.8%. Biodiversity conservation supports sustainable agricultural improvement by maintaining food production sustainability and promoting the number and variety of plants, animals, and micro-organisms that contribute to health, food security, and well-being in society. It also aids in supplying ecosystem services such as nutrient cycling, pollination, natural Pest control, soil formation, and water provision that enhance productive and resilient agricultural

systems [14]. Sustainable agricultural improvement is attained when processes and functions that maximize the delivery of goods and services are promoted while conserving agricultural biodiversity.

The importance of biodiversity conservation in sustainable agricultural improvement cannot be underestimated. This is because biodiversity conservation provides fertile lands and promotes agricultural production through enhanced soil productivity and nutrient cycling [10]. It also promotes adaptation and build resilience in agriculture against the adverse effects of climate change and extreme weather conditions. Biodiversity conservation also achieves food security by providing a continuous yield of food crops, medicinal herbs, timber, forage, fuelwood, and a wide range of other agricultural products. It also promotes and maintains natural biological control agents that suppress agricultural pests and diseases infesting farmlands while also boosting pollination rates of agricultural crops. For example, biodiversity conservation promotes the proliferation of natural enemies such as predatory insects, mites, and bacteria that suppress agricultural pests, diseases, and weeds in farms [17]. It also sustains natural pollinators such as insects and other animals that contribute to higher crop production.

Biodiversity conservation plays a significant role in sustainable agricultural improvement in Southeast Nigeria by promoting and sustaining diverse agricultural resources and systems that benefit the region's economy while also providing food security. Some of these agricultural resources and systems that enhance sustainable agricultural improvement while providing food security in Southeast Nigeria are the conservation of indigenous crops and varieties, agroforestry systems such as forests and wetlands, and farmers' adoption of improved methods that promote agricultural production, such as enhancing soil fertility and water conservation practices. For example, biodiversity conservation provides ample yields of timber, food grains, forage, and fuelwood while promoting sustainable agricultural development practices in Southeast Nigeria. Also, biodiversity conservation provides adaptation and resilience to agriculture in Southeast Nigeria by adapting agricultural practices such as water and land conservation, improving soil organic matter and carbon stocks, and increasing the amount of carbon stored in the biosphere to achieve sustainable agriculture and food security in the region [18]. Although biodiversity plays a pivotal role in promoting agricultural improvement, it is currently threatened with extinction due to environmental factors such as deforestation, habitat loss, overexploitation of natural resources, urbanization, climate change, and poor agricultural practices. Therefore, promoting biodiversity conservation will require implementing strict environmental policies, sensitizing and educating the community and farmers, adopting agroecology principles and practices, and promoting sustainable agricultural practices [18]. Moreover, biodiversity conservation will promote agricultural production while also conserving biodiversity in Southeast Nigeria, benefitting the community economically while also promoting sustainable agricultural improvement.

**Table 4: Contribution of Biodiversity Conservation to Sustainable Agricultural Improvement**

| S/N | Contribution of Biodiversity Conservation                      | Frequency | Percentage |
|-----|----------------------------------------------------------------|-----------|------------|
| 1   | Improves soil fertility and nutrient cycling                   | 419       | 93.1       |
| 2   | Increases crop productivity and yield                          | 407       | 90.4       |
| 3   | Conserves indigenous crop varieties and genetic resources      | 392       | 87.1       |
| 4   | Enhances natural pest and disease control                      | 376       | 83.6       |
| 5   | Promotes pollination and ecosystem services                    | 364       | 80.9       |
| 6   | Improves resilience to climate change and environmental shocks | 351       | 78.0       |
| 7   | Reduces dependence on synthetic fertilizers and pesticides     | 337       | 74.9       |
| 8   | Conserves soil and water resources                             | 324       | 72.0       |
| 9   | Supports sustainable livelihoods and increases farmers' income | 309       | 68.7       |
| 10  | Preserves wildlife habitats and ecological balance             | 287       | 63.8       |

### AI tools available in the area for agriculture,

The results indicate that AI-driven mobile agricultural advisory apps were the most prevalent digital tools in the region, with an availability of 89.1%. Following closely were weather prediction and climate forecasting apps at 86.4%, and AI-based tools for diagnosing pests and diseases at 82.4%. These findings suggest that AI technologies focused on information and advice are easily accessible to farmers in Southeast Nigeria. Moreover, precision farming tools enabled with GPS/GIS were available to 78.2% of farmers, while AI-powered tools for soil testing and recommending fertilizers were accessible to 74.2% of them. This hints at the growing availability of technologies that support precise agriculture methods and efficient resource management. Drone technology for monitoring and spraying crops was available to 66.0% of farmers, while smart irrigation systems supported by AI were accessible to 62.4% of them. Additionally, platforms powered by AI for market information and price prediction were available to 59.6% of farmers, indicating a moderate level of access to digital market insights. Livestock health management systems were available to 52.0% of farmers, whereas farm management software and systems for digital record-keeping were the least accessible, with an availability of 48.7%.

Artificial Intelligence (AI) tools are useful for farmers because they support them in making decisions, improving production, increasing yields, and enhancing sustainability. AI tools use machine learning, computer vision, the Internet of Things, robotics, remote sensing, and big data to improve production processes [1]. Some of the AI tools used in farming and agriculture are mobile agricultural advisory applications, weather forecast and climate prediction applications, crop pest and disease diagnosis tools, and soil testing and fertilizer recommendation tools. Others are GPS, GIS and drones, smart irrigation systems, AI-powered market information systems, livestock supervision systems, and farm management software. Mobile agricultural advisory applications are among the many AI tools used in farming.

These applications provide advisory services to farmers about crop production, animal husbandry, and general farm management [19]. The use of mobile phones and smartphones to provide agricultural advisory services to farmers has become rampant, particularly in Nigeria. Agricultural advisory applications provide location-specific advice on crop and animal production. They assist farmers in making better decisions on their farms. Other AI tools used in farming are weather forecast and climate prediction applications. These tools use artificial intelligence to provide accurate weather forecasts to farmers.



They help farmers make better decisions about planting and harvesting their crops, applying fertilizers, and managing their farms in general. Farmers use AI-powered tools to scan their crops to detect the presence of diseases. The tools also recommend appropriate interventions to reduce the impact of pests and diseases on crop yields. Besides using AI tools to scan their crops to detect pests and diseases, farmers also use the tools to test their soil and receive appropriate fertilizer recommendations.

Other AI tools used in farming include GPS, GIS and drones, smart irrigation systems, AI-powered market information systems, livestock supervision systems, and farm management software. GPS, GIS, and drones can be used to carry out various tasks, including crop monitoring, identifying nutrient needs, and monitoring farmland activities. Smart irrigation systems make it possible for farmers to irrigate their farms efficiently and effectively. AI-powered market information systems assist farmers in selling their produce according to demand and supply. Similarly, livestock supervision systems help farmers in ensuring animal health and responding to emerging issues in time [19]. Lastly, farm management software helps farmers manage their farms effectively and efficiently by storing electronic field data about the farm in one place. Farmers can also use the software to organize farm activities and manage farm records. Despite the many AI tools used in farming, their use in farming activities is growing in Nigeria. However, the tools' use is limited by the lack of adequate digital infrastructure, high installation costs, poor network connection, lack of electricity, poor digital literacy, and poor extension services. Improving rural infrastructure and promoting the proliferation of smartphones will enable more farmers to adopt AI tools and promote sustainable agricultural development in Southeast Nigeria.

**Table 5: AI Tools Available in the Area for Farming and Agriculture**

| S/N | AI Tools Available for Farming and Agriculture                | Frequency | Percentage |
|-----|---------------------------------------------------------------|-----------|------------|
| 1   | Mobile agricultural advisory applications (AI-powered)        | 401       | 89.1       |
| 2   | Weather forecasting and climate prediction applications       | 389       | 86.4       |
| 3   | AI-based pest and disease diagnosis applications              | 371       | 82.4       |
| 4   | GPS/GIS-enabled precision farming tools                       | 352       | 78.2       |
| 5   | AI-supported soil testing and fertilizer recommendation tools | 334       | 74.2       |
| 6   | Drone technology for crop monitoring and spraying             | 297       | 66.0       |
| 7   | Smart irrigation systems (AI-enabled)                         | 281       | 62.4       |
| 8   | AI-powered market information and price forecasting platforms | 268       | 59.6       |
| 9   | Livestock monitoring and health management systems            | 234       | 52.0       |
| 10  | Farm management software and digital record-keeping systems   | 219       | 48.7       |

### **Influence of artificial intelligence on crop production and farm management in Southeast Nigeria**

The results reveal that enhancing decision-making via real-time farm data stands out as the most frequently acknowledged benefit of artificial intelligence (AI) in agricultural production and management, with 411 respondents (91.3%) recognizing this advantage. Following closely is the rise in crop productivity and yield, reported by 399 respondents (88.7%), along with improved early detection of pests and diseases, indicated by 387 respondents (86.0%). These findings imply that AI technologies are seen as pivotal in boosting agricultural productivity through timely insights and precision farming techniques.

Moreover, 371 respondents (82.4%) highlighted that AI enhances the accuracy of fertilizer and pesticide application, while 358 respondents (79.6%) noted that it improves weather forecasting and aids in climate-smart farming decisions. The need for better farm planning and record management was echoed by 344 respondents (76.4%), underscoring the increasing significance of digital technologies in farm operations and decision-making. Additionally, 327 respondents (72.7%) agreed that AI helps decrease labor demands and production costs, and 309 respondents (68.7%) felt it optimizes irrigation and water management. Improved access to markets and price forecasting was acknowledged by 294 respondents (65.3%), while 281 respondents (62.4%) stated that AI contributes to greater farm profitability and income.

Artificial Intelligence (AI) is a disruptive technology in modern agriculture that has improved crop production and management through decision-making, intelligent automation, computer vision, and surveillance of the farm. AI includes technologies such as machine learning, robotics, remote sensing, the Internet of Things, and big data analytics to improve agricultural activities and intensify food production [1]. These technologies enable farmers to make better decisions and improve the utilization of resources and agricultural production. Amongst the many impacts of AI on agricultural production, precision farming is the most significant. AI technologies can monitor the progress of cultivation using drones, weather data, satellites, and sensors to increase farm production while also reducing the costs of cultivation [20]. For example, precision farming can help farmers monitor the progress of their crops, the fertilizer requirements of the farmland, and respond to the environmental changes affecting their farms to increase productivity. These technologies can also help monitor the use of chemicals to ensure they are applied in appropriate doses to increase sustainable production while also reducing environmental pollution.

In addition, AI can help increase crop production by assisting farmers in monitoring crop diseases and insects to increase food production sustainably. For example, farmers can monitor crop diseases and insects using computer vision and machine learning technology to ensure they control infections before they spread to healthy crops by using their mobile phones to take pictures of the affected plants and analyze them accordingly [21]. This AI technology can also help farmers reduce the usage of synthetic chemicals to control pests and diseases, thus promoting organic farming practices. Another way in which AI can impact crop production is by improving weather forecasts to help farmers make informed decisions when planting, harvesting, and applying manure and pesticides to their farms. Farmers can also predict the best time to sow, harvest, and apply chemicals to their farms to increase agricultural production while also maximizing on profits [1].

Farmers can also utilize AI in farm management to improve the overall production of their farms. These technologies can help in managing the farm, planning, recording, and tracking farm activities. Additionally, the technologies can also help improve labor, inventory management, and planning to increase agricultural production. For example, farm planning enables farmers to make informed decisions by analyzing the production records on the farm to help them maximize farm production and profit margins [19].

Moreover, these technologies can help farmers analyze market trends to understand what they should produce to ensure they meet the market demands and increase profitability while also managing resources wisely. Overall, these technologies can improve farm management practices by increasing the efficiency of farm activities, which in turn can increase agricultural production.

The impact of AI on crop production and farm management in the 'Southeast,' Nigeria, has been enormous since its adoption in the agricultural sector through smartphones, GPS, GIS, drones, and smart irrigation systems. The use of these technologies has improved sustainable farming practices while also promoting increased crop production. However, some of the major challenges affecting the widespread adoption of these technologies in the Southeast are inadequate digital literacy, frequent power shortages, unreliable internet connections, high capital investment, and weak agricultural policies. There is a need for better digital infrastructure, continuous training on the use of these technologies, and supportive policies to promote the extensive adoption of AI technologies to increase crop yields and farm production in the region.

**Table 6: Influence of Artificial Intelligence on Crop Production and Farm Management**

| S/N | Influence of Artificial Intelligence on Crop Production and Farm Management | Frequency | Percentage |
|-----|-----------------------------------------------------------------------------|-----------|------------|
| 1   | Improves decision-making through real-time farm information                 | 411       | 91.3       |
| 2   | Increases crop productivity and yield                                       | 399       | 88.7       |
| 3   | Enhances early detection of pests and diseases                              | 387       | 86.0       |
| 4   | Improves precision in fertilizer and pesticide application                  | 371       | 82.4       |
| 5   | Enhances weather forecasting and climate-smart farming decisions            | 358       | 79.6       |
| 6   | Improves farm planning and record management                                | 344       | 76.4       |
| 7   | Reduces labour requirements and production costs                            | 327       | 72.7       |
| 8   | Optimizes irrigation and water management                                   | 309       | 68.7       |
| 9   | Improves market access and price forecasting                                | 294       | 65.3       |
| 10  | Increases farm profitability and income                                     | 281       | 62.4       |

### Digital innovations in agriculture and farming systems

The results indicate that mobile apps for agricultural advice and extension were the most commonly recognized digital advancements in agriculture and farming, as noted by 413 participants (91.8%). Following this, weather and climate data services were acknowledged by 401 respondents (89.1%), and GPS/GIS-based technologies for precise farming were mentioned by 382 participants (84.9%). These findings suggest that technologies offering information and decision-making support are the most popular innovations among farmers in the surveyed region. Furthermore, digital platforms for market updates and online trading were recognized by 366 respondents (81.3%), indicating that many farmers now rely on digital channels to access market rates, potential buyers, and farming supplies. Drone technology for monitoring crops and mapping fields was mentioned by 341 respondents (75.8%), while smart irrigation systems and automated water management were highlighted by 327 participants (72.7%), showing a gradual acceptance of precise farming technologies. Additionally, tools for digital soil testing and nutrient management were acknowledged by 314 respondents (69.8%), and software for farm management and electronic record-keeping systems were recognized by 298 participants (66.2%), illustrating an increased use of digital solutions for farm planning and resource management. Remote sensing and satellite monitoring technologies were identified by 284 respondents (63.1%), whereas Internet of Things (IoT)-enabled sensors for farm monitoring were the least recognized innovation, reported by 251 participants (55.8%).

**Table 7: Digital Innovations in Agriculture and Farming Systems**

| S/N | Digital Innovations in Agriculture and Farming Systems         | Frequency | Percentage |
|-----|----------------------------------------------------------------|-----------|------------|
| 1   | Mobile agricultural advisory and extension applications        | 413       | 91.8       |
| 2   | Weather and climate information services                       | 401       | 89.1       |
| 3   | GPS/GIS-based precision farming technologies                   | 382       | 84.9       |
| 4   | Digital market information and e-commerce platforms            | 366       | 81.3       |
| 5   | Drone technology for crop monitoring and field mapping         | 341       | 75.8       |
| 6   | Smart irrigation and automated water management systems        | 327       | 72.7       |
| 7   | Digital soil testing and nutrient management tools             | 314       | 69.8       |
| 8   | Farm management software and electronic record-keeping systems | 298       | 66.2       |
| 9   | Remote sensing and satellite monitoring technologies           | 284       | 63.1       |
| 10  | Internet of Things (IoT)-enabled sensors for farm monitoring   | 251       | 55.8       |

### Effect of Digital Innovations on Agricultural Productivity and Farmers' Access to Agricultural Information

Table 8 showed that the primary impact of digital advancements was the enhancement of farmers' access to timely agricultural information, as noted by 421 participants (93.6%). This was followed by a rise in crop productivity and yield, mentioned by 408 respondents (90.7%), and improved access to weather and climate updates, identified by 394 respondents (87.6%). These results highlight the crucial role of digital technologies in enhancing farmers' access to essential information needed for efficient agricultural practices. Furthermore, 381 respondents (84.7%) pointed out that digital innovations enhance decision-making and planning on farms, while 367 respondents (81.6%) indicated that they streamline access to markets and current price details. Better communication with agricultural advisors and experts was highlighted by 352 respondents (78.2%), underscoring the significance of digital platforms in reinforcing agricultural advisory services. Additionally, 338 respondents (75.1%) concurred that digital advancements cut down production costs by improving the efficient utilization of farm resources, while 326 respondents (72.4%) believed they facilitate swift detection and control of pests and diseases. Improved record-keeping and farm management were acknowledged by 311 respondents (69.1%), while (65.6%) stated that digital innovations lead to increased farmers' earnings and profitability.

Digital innovations have played a critical role in transforming agriculture by boosting productivity, enhancing information dissemination, and supporting sustainable agricultural practices. Some of these innovations include mobile agriculture, digital extension, geographic information systems, remote sensing, drones, the internet of things, artificial intelligence, big data analytics, blockchain, and digital farming platforms among others. Digital innovations have enhanced the delivery of information, improved decision-making, and increased farm productivity [1]. Digital innovations have improved farmers' access to agricultural information. Weather reports, information on pests and diseases, hybrid seeds, fertilizer, market information, and best practices are some of the information that farmers access using farm management information systems and mobile phones. The information guides them and supports them in addressing challenges they encounter in farming activities [22]. Agricultural innovations such as mobile extension services have helped improve information access among Nigerian farmers, thereby facilitating knowledge dissemination and promoting agricultural production.



The use of digital innovations has enhanced farm productivity by promoting precision agriculture. GPS, GIS technologies, drones, remote sensing, and artificial intelligence have facilitated informed decision-making in agriculture. Farmers are able to monitor their farms, detect insect pests and diseases, and respond to them promptly and appropriately. Farmers are also able to apply manure, fertilizers, pesticides, and herbicides in a targeted and sensitive manner. The responsible use of agricultural inputs has promoted sustainable farming practices while also boosting crop yields and reducing environmental pollution [20]. Sensors in internet of things can help monitor and regulate farms to maximize production while minimizing waste [21]

Digital innovations have enhanced information exchange and communication between farmers and extension officers. Digital extension services have facilitated faster exchange of information and knowledge on farming practices and climate change. Farmers are able to access information using mobile phones and social media networks to address challenges they encounter in agricultural production (FAO, 2022). The use of digital technology has increased the rate of adoption of innovations, thus boosting agricultural development. Information and communication technologies have also improved farmers' access to agricultural markets. Digital marketing and e-commerce have enabled farmers to sell their products directly to potential buyers, thus eliminating intermediaries and boosting profit margins. Farmers are able to access market information through mobile phones, thereby facilitating profitable sales of their produce. Digital innovations such as mobile banking have promoted financial inclusion, facilitating commercial farming activities, and supporting agricultural development [19]. Overall, digital technologies have augmented farm profits and boosted agricultural development. The impact of digital innovations on agricultural development is manifested in Southeast Nigeria, where mobile agriculture, weather information systems, digital soil analysis, artificial intelligence in pest control, drones and precision farming have enhanced knowledge, management, and productivity of farms. However, the high cost of technology, weak extension services, lack of electricity, and low levels of technology adoption are some of the challenges that hinder the use of digital innovations in the region. Enhancing digital infrastructure, promoting digital literacy, adopting low-cost technologies and improving extension services will promote digital innovations and agricultural development in Southeast Nigeria.

**Table 8: Effect of Digital Innovations on Agricultural Productivity and Farmers' Access to Agricultural Information**

| S/N | Effect of Digital Innovations on Agricultural Productivity and Access to Agricultural Information | Frequency | Percentage |
|-----|---------------------------------------------------------------------------------------------------|-----------|------------|
| 1   | Improves farmers' access to timely agricultural information                                       | 421       | 93.6       |
| 2   | Increases crop productivity and yield                                                             | 408       | 90.7       |
| 3   | Enhances access to weather and climate information                                                | 394       | 87.6       |
| 4   | Improves farm decision-making and planning                                                        | 381       | 84.7       |
| 5   | Facilitates access to markets and current price information                                       | 367       | 81.6       |
| 6   | Improves communication with extension agents and agricultural experts                             | 352       | 78.2       |
| 7   | Reduces production costs through efficient resource utilization                                   | 338       | 75.1       |
| 8   | Promotes rapid detection and management of pests and diseases                                     | 326       | 72.4       |
| 9   | Enhances record-keeping and farm management                                                       | 311       | 69.1       |
| 10  | Increases farmers' income and profitability                                                       | 295       | 65.6       |

### Challenges Limiting the Adoption of Natural Products, Biodiversity Conservation, AI, and Digital Innovations among Farmers

The results indicate that a lack of proper training and technical knowledge poses the main obstacle to embracing natural products, biodiversity conservation, artificial intelligence (AI), and digital innovations, according to 92.7% of the 417 participants surveyed. Following closely are the high expense associated with AI and digital technologies, highlighted by 89.3% of the 402 respondents, and the insufficient availability of agricultural extension services, mentioned by 86.4% of the 389 participants. These outcomes demonstrate that limited technical expertise and financial limitations serve as significant hindrances to the acceptance of modern agricultural advancements in Southeast Nigeria. Additionally, 83.8% of the 377 respondents pinpointed inadequate digital infrastructure, such as unreliable internet connectivity and electricity supply, as a crucial challenge, while 80.9% of the 364 participants cited restricted access to financial aid and agricultural loans. Moreover, 78.0% of the 351 respondents noted that a lack of awareness regarding the advantages of natural products and biodiversity conservation obstructs their adoption, emphasizing the necessity for increased education and awareness initiatives. The research also uncovered that inadequate government backing and ineffective enforcement of agricultural regulations (74.7% of the 336 respondents) and resistance to change and a preference for traditional farming methods (71.6% of the 322 respondents) persist as obstacles to the uptake of innovative agricultural techniques. Furthermore, insufficient availability of quality AI tools and digital agricultural services (68.0% of the 306 respondents) and poor research-farmer connections and information sharing (64.7% of the 291 respondents) were recognized as significant constraints. These results indicate that the integration of natural products, biodiversity conservation, AI, and digital innovations by farmers in Southeast Nigeria is hampered by a mix of technical, financial, infrastructural, institutional, and behavioral challenges. Overcoming these hurdles through enhanced farmer education, improved extension services, cost-effective digital technologies, enhanced rural infrastructure, accessible agricultural funding, and supportive government policies will promote wider adoption of sustainable agricultural innovations and enhance agricultural output.

**Table 9: Challenges Limiting the Adoption of Natural Products, Biodiversity Conservation, Artificial Intelligence, and Digital Innovations among Farmers in Southeast**

| S/N | Challenges Limiting Adoption                                                    | Frequency | Percentage |
|-----|---------------------------------------------------------------------------------|-----------|------------|
| 1   | Inadequate training and technical knowledge                                     | 417       | 92.7       |
| 2   | High cost of AI and digital technologies                                        | 402       | 89.3       |
| 3   | Poor access to agricultural extension services                                  | 389       | 86.4       |
| 4   | Inadequate digital infrastructure (internet/electricity)                        | 377       | 83.8       |
| 5   | Limited access to financial resources and credit                                | 364       | 80.9       |
| 6   | Low awareness of the benefits of natural products and biodiversity conservation | 351       | 78.0       |
| 7   | Poor government support and weak implementation of agricultural policies        | 336       | 74.7       |
| 8   | Resistance to change and preference for traditional farming practices           | 322       | 71.6       |
| 9   | Limited availability of quality AI tools and digital agricultural services      | 306       | 68.0       |
| 10  | Inadequate research-farmer linkage and information dissemination                | 291       | 64.7       |

## Strategies for Enhancing the Integration of Natural Products, Biodiversity, AI, and Digital Innovations for Sustainable Agricultural Development in Southeast Nigeria.

Table 10 showed that the most effective approach to boost the incorporation of natural products, biodiversity, artificial intelligence (AI), and digital advancements was by enhancing farmers' education and skills in sustainable agricultural methods, according to 425 participants (94.4%). Following this, enhancing agricultural extension services and digital guidance, as pointed out by 412 respondents (91.6%), and increasing government funding in rural ICT and agricultural infrastructure, as highlighted by 401 respondents (89.1%), were also crucial strategies. These results indicate that improving farmers' knowledge and reinforcing institutional backing are vital in speeding up the acceptance of sustainable agricultural innovations. Moreover, 389 respondents (86.4%) proposed offering accessible credit, subsidies, and grants to help farmers embrace AI and digital technologies, while 376 respondents (83.6%) stressed the importance of promoting natural products and biodiversity-friendly farming methods through awareness initiatives. These reactions underscore the significance of financial aid and awareness campaigns in promoting sustainable agricultural practices. Additionally, 362 respondents (80.4%) supported enhanced collaboration among scientists, technology innovators, extension services, and farmers to ease the transfer and acceptance of innovations. Enhanced internet connectivity and stable electricity supply (351 respondents, 78.0%) and the creation of AI and digital agricultural technologies adaptable to local conditions (338 respondents, 75.1%) were also deemed crucial strategies for advancing digital agriculture in the area. Lastly, 324 respondents (72.0%) advised enhancing biodiversity conservation regulations and offering rewards for sustainable farming, while 311 respondents (69.1%) highlighted the importance of encouraging public-private partnerships to stimulate investment and innovation in digital agriculture.

**Table 10: Strategies for Enhancing the Integration of Natural Products, Biodiversity, Artificial Intelligence, and Digital Innovations for Sustainable Agricultural Development in Southeast Nigeria**

| S/N | Recommended Strategies                                                                                      | Frequency | Percentage |
|-----|-------------------------------------------------------------------------------------------------------------|-----------|------------|
| 1   | Strengthen farmers' training and capacity building on sustainable agricultural technologies                 | 425       | 94.4       |
| 2   | Improve agricultural extension services and digital advisory support                                        | 412       | 91.6       |
| 3   | Increase government investment in rural ICT and agricultural infrastructure                                 | 401       | 89.1       |
| 4   | Provide affordable credit, grants, and subsidies for adopting AI and digital technologies                   | 389       | 86.4       |
| 5   | Promote the use of natural products and biodiversity-friendly farming practices through awareness campaigns | 376       | 83.6       |
| 6   | Encourage research–industry–farmer collaboration for technology transfer                                    | 362       | 80.4       |
| 7   | Improve internet connectivity and reliable electricity supply in rural communities                          | 351       | 78.0       |
| 8   | Develop and promote locally adaptable AI and digital agricultural technologies                              | 338       | 75.1       |
| 9   | Strengthen biodiversity conservation policies and incentives for sustainable farming                        | 324       | 72.0       |
| 10  | Foster public–private partnerships to scale up digital agriculture and innovation                           | 311       | 69.1       |

## Conclusion

Based on the study's results, it was concluded that using natural products, protecting biodiversity, applying artificial intelligence, and adopting digital innovations could help achieve sustainable agricultural improvement in Southeast Nigeria.

The study showed that using locally available natural products like organic manures, compost, botanical pesticides, and crop residues as soil amendments was key to fostering sustainable agricultural development. Likewise, conserving biodiversity through mixed cropping, agroforestry, traditional crops, pollinators, soil microorganisms, farm animals, and integrated farming systems could enhance agricultural improvement in the region. The study also indicated that artificial intelligence and digital innovations were important areas to consider for promoting sustainable development in agriculture. Utilizing these technologies is crucial for providing the information needed to improve farming practices. They help farmers make informed choices, implement precision farming, generate higher yields, lower farming costs, assist with weather forecasting, improve pest control, promote extension services, and enhance market access for farmers. However, the widespread use of sustainable agricultural technologies in Southeast Nigeria faced challenges, including poor technical knowledge, inadequate extension services, a lack of digital infrastructure, high technology costs, limited access to credit, and insufficient policies. Therefore, the study concluded that promoting sustainable agricultural development involves integrating local knowledge and biodiversity conservation while adopting modern digital technologies to increase production, reduce costs, and boost profits. Improving rural infrastructure, encouraging local technology development, enhancing access to digital tools, preserving biodiversity, supporting research and development, and advocating for effective agricultural policies were some key interventions necessary for sustainable agricultural growth and improving regional competitiveness in Southeast Nigeria.

## References

- Food and Agriculture Organization. (2022). *The state of food and agriculture 2022: Leveraging automation in agriculture for transforming agrifood systems*. FAO. <https://doi.org/10.4060/cb9479en>
- Yakubu, M., Yakubu, U., Yakubu, H., & Mayun, F. A. (2024). Artificial intelligence applications in sustainable agriculture in Nigeria: A comprehensive review. *Journal of Basics and Applied Sciences Research*, 2(4), 84–94.
- Adaaja, B. O., Akemien, N. N., Alawiye, M. A., Zaman, E. Y., Yahaya, U., & Khidir, H. Y. (2024). *Economic and ecological sustainability of non-timber forest products (NTFPs) in Nigeria: A review*. *FUDMA Journal of Sciences*, 8(6). <https://doi.org/10.33003/fjs-2024-0806-2909>
- Obasi, S. N., Tenebe, V. A., Obasi, C. C., Jokthan, G. E., Adjei, E. A., & Keyagha, E. R. (2024). Harnessing artificial intelligence for sustainable agriculture: A comprehensive review of African applications in spatial analysis and precision agriculture. *Big Data in Agriculture*, 6(1), 1–13.
- Adewusi, A. O., Asuzu, O. F., Olorunsogo, T., Iwuanyanwu, C., Adaga, E., & Daraojimba, D. O. (2024). AI in precision agriculture: A review of technologies for sustainable farming practices. *World Journal of Advanced Research and Reviews*, 21(1), 2276–2285.
- Barki, K., & Rachmah, M. A. (2024). Systematic literature review: Agricultural digitalization, technological transformation towards efficient and sustainable agriculture. *Journal of Agriculture Faculty of Ege University*, 61(2), 183–198.
- Akindele, S. O. (2024). Exploring trends of digitalization in natural resources and bio-conservation management. *E-Proceedings of the Faculty of Agriculture International Conference*, 9–18.

8. Omeje, E. E., Ukwuaba, I. C., Nwangwu, K. N., Umaru, I. I., Ibe, J. C., & Offorma, J. T. (2025). Rural-urban differentials in utilization of artificial intelligence for improved agricultural production among crop farmers in Southeast Nigeria. *Journal of Agricultural Extension*.
9. Food and Agriculture Organization. (2024). *The State of Food and Agriculture 2024*. FAO.
10. Lal, R. (2020). Soil organic matter and sustainable agriculture. *Journal of Soil and Water Conservation*, 75(5), 122A–127A. <https://doi.org/10.2489/jswc.2020.0620A>
11. Lehmann, J., & Joseph, S. (Eds.). (2015). *Biochar for environmental management: Science, technology and implementation* (2nd ed.). Routledge
12. Isman, M. B. (2020). Botanical insecticides in the twenty-first century—Fulfilling their promise? *Annual Review of Entomology*, 65, 233–249. <https://doi.org/10.1146/annurev-ento-011019-025010>
13. Akanbi, W. B., & Ojeniyi, S. O. (2021). Organic nutrient management and sustainable crop production in Nigeria. *Nigerian Journal of Soil Science*, 31(1), 45–58.
14. Food and Agriculture Organization. (2019). *The state of the world's biodiversity for food and agriculture*. FAO.
15. Altieri, M. A., & Nicholls, C. I. (2020). *Agroecology: A brief account of its origins and currents of thought in Latin America*. *Agroecology and Sustainable Food Systems*, 44(6), 674–688.
16. Nair, P. K. R. (2011). *Agroforestry systems and environmental quality: Introduction*. *Journal of Environmental Quality*, 40(3), 784–790.
17. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2016). *The assessment report on pollinators, pollination and food production*. IPBES Secretariat.
18. Food and Agriculture Organization. (2021). *The state of the world's land and water resources for food and agriculture: Systems at breaking point*. FAO. <https://doi.org/10.4060/cb7654en>
19. World Bank. (2019). *Harvesting prosperity: Technology and productivity growth in agriculture*. World Bank.
20. 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>
21. Javaid, M., Haleem, A., Singh, R. P., Khan, S., & Suman, R. (2023). Understanding the potential applications of artificial intelligence in agriculture. *Advanced Agrochem*, 2(1), 15–30. <https://doi.org/10.1016/j.aac.2022.10.001>
22. Aker, J. C. (2011). Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, 42(6), 631–647. <https://doi.org/10.1111/j.1574-0862.2011.00545.x>