INNOVATIVE TECHNOLOGIES: ARTIFICIAL INTELLIGENCE (AI)-DRIVEN PRECISION AGRICULTURE APPROACH; CHALLENGES AND OVERCOMING IT ADOPTION

***[1]ETTAH, O. I., [2]UDUMO, B. O., [1]EDET, E. O., [3]ETTAH, G. I., [1]AGBACHOM, E. E., [1]OGAR, S. O., [2]ODEY, E. A.**

[1]Department of Agricultural Economics, Faculty of Agriculture, University of Calabar Nigeria
[2]Department of Environmental Education, Faculty of Sciences Education, University of Calabar, Nigeria
[3]Department of Public Administration, Faculty of Management Sciences, University of Calabar, Nigeria
**Corresponding author e-mail: oiettah@unical.edu.ng*

Abstract
The potential of AI in agriculture is very large; it not only has the capability of changing the face of agriculture, but also increasing crop output. AI-powered solutions are envisioned to infiltrate with the advancement of technology and its affordability, bringing about radical changes in food production, processing, and delivery, especially because of climate change and population expansion. In order to sustain and boost agricultural output, new and creative technology must be used. This review explored how AI powered PF has supported decision processes in crop management, providing real-time monitoring and predictive analytics. Higher agricultural yields, resource optimization and resilience are made possible by genetic advancements through AI powered PF. However, due to technological, economic, societal, and legal obstacles, the promise for AI in agriculture has not yet materialized. The following are recommended: holistic policy frameworks, education, and stakeholder engagement as countermeasures to such challenges of adoption. The following recommendations were made based on this review: sociocultural barriers should be surmounted through educational programs and outreach initiatives, showing the real benefits of AI in crop yield and reducing labor, this would likely build trust and confidence in the technology, economic challenges to adoption should require governments and other institutions to provide subsidies or fiscal incentives and customized curricula must be designed to cater to the particular requirements of diversified farming communities.

Keywords*: Innovative technologies, Artificial intelligence, Precision farming, Crop productivity*

Introduction

Agricultural growth remains unsatisfactory especially when measured in terms of improved productivity- food insecurity and malnutrition. According to Federal Ministry of Agriculture, Water Resources and Rural Development (FMAWRRD) (2023) experts believe that the perceived increase mainly coming from increase in land area and not more efficient use of resources. Food production gains have not kept pace with population growth, resulting in rising food imports and declining levels of national food self-sufficiency. This could be because of the rapid growth of the Nigeria population, which presents unprecedented pressure on agriculture to sustainably increase production. With the added challenges of dwindling water resources, shifting climate patterns, and the loss of agricultural land. There is therefore an urgent need for innovative solutions to boost farm productivity and efficiency. Among the most promising of

these solutions are innovative technologies, which have the potential to revolutionize agricultural practices worldwide (United Nations Conference on Trade and Development (UNCTAD, 2023).
Experts are worried that current rates of increase in agricultural yields will not double crop production by 2050. Ninety percent (90%) of agricultural production in Nigeria is the output of inefficient methods and very low technologies use and low system of production by small-holder farmers (UNCTAD, 2023; FAO (2023). Increased demand for food must be met with greater agricultural intensification based on a combination of technologies and other improved practices with minimal effect on the environment. Eighty percent of the increase in production in Nigeria will have to come from improved technologies and higher cropping intensity, which could be achievable through AI agriculture.

AI gives new meaning to modern agriculture and, in particular, precision farming, in developing integrated farm management. Large scale and export (or revenue generation) oriented agriculture have suffered great setback in recent times. But with the recent quest of the Federal and some State governments into the development of large scale agriculture and mechanized farming in order to shore up food security and foreign exchange earnings, there is need for adoption of innovative technologies, which offer a wide range of applications in order to effectively harness human, natural and man-made resources for sustainable agricultural production and improved crop yields in Nigeria (Von-Loon *et. al.*, 2018)

Innovative technologies

Innovative technologies provide accurate data based on which informed decisions can be made regarding irrigation, fertilization, and pest control. Commonly used technologies include according to Finger *et al*., (2022):

i. **Robots:** this helps in efficiency of labor by automating large tasks such as sowing, weeding, and harvesting, thus reducing reliance on manual labor.
ii. **AI:** in Agriculture helps in precision farming via Global positioning system (GPS) and IoT sensors.
iii. **Machine learning (ML):** for yield prediction.
iv. **IoT** sensors monitor soil moisture and nutrient levels.
v. **Drones** detect plant diseases in early stages.

AI is a transformative force for sustainable agriculture which further supports the analysis and maintenance of key environmental variables such as soil pH, ambient temperature, and rainfall . Predictive models using AI highlight trends in weather patterns that enable farmers to take necessary actions and reduce the negative consequences of extreme weather conditions. The integration of AI into agriculture offers enormous opportunities for better resource use, waste reduction, and environmental sustainability. Beyond mere automation of agriculture, it involves several technologies to make farming intelligent, accurate, and productive.

These technologies will help fully control the production settings and results because they go beyond the optimization of existing techniques. For example, AI-driven precision agriculture determines the best possible conditions for planting, watering, and harvesting schedules based on information received from satellite imagery and IoT sensors. Machine-learning algorithms identify plant diseases before they turn up in plain human vision and estimate crop yields with an astounding degree of precision. However, there are many societal, technological, and financial barriers to full-scale application of AI in agriculture as discussed below. AI is a key factor in future agricultural practices because of its potential to increase production, sustainability, and profitability despite existing obstacles.

AI application in Agriculture

United Nations Development Programme (UNDP) (2022) noted that AI is changing the face of agriculture from environmental effect forecasts to efficient resource use and crop management. AI facilitates data collection from agricultural environments using GPS and IoT devices for precision farming. This dataset can be used to obtain the temperature, crop health, fertilizer availability, and soil moisture levels. AI algorithms assess these data to provide relevant and helpful recommendations to farmers regarding the sowing, irrigation, and harvesting of crops. AI-powered systems can recommend the optimum quantity of water and fertilizer to be treated on each field, reduce waste, and ensure proper crop development. The core of precision farming is that it provides for the collection of data in real time through GPS and IoT devices for constant monitoring of key factors: soil condition, weather pattern, and health of the crop. These real-time data form the backbone of AI algorithms that support decisions on variable resource applications, including the optimization of water, fertilizer, and pesticide applications.

This section reviews three critical AI applications in agriculture for enhancing production and sustainability: Precision farming (PF), agricultural robotics and machine learning

Precision Farming (PF)

Precision Agriculture

The need to increase crop production efficiency in Nigeria using improved technology has been identified. This is to ensure food security and improve the standard of living in the country. Despite the engagement of about 70% of Nigerians in the agricultural sector, crop production has not been sufficient enough to fulfill demand (UNDP 2022; FMAWRRD). This is due to the utilization of conventional farming techniques and management practice adopted, soil or environmental characteristics (Davis, Casady & Massey, 2021). The soil characteristics include texture, structure, nutrients status, organic matter, moisture and landscape. The environmental characteristics include weather, weeds, insects and diseases etc. Precision Agriculture is a new concept in agricultural production which is becoming an attractive idea in managing natural resources and realizing modern sustainable development of agriculture based on information technology (Davis *et. al*., 2021). It is bringing agriculture into the information and digital age and incorporates technologies such as Geographic Information System (GIS), Satellite Remote Sensing and Global Positioning System (GPS). With the recent launch of the NigeriaSat-1, an earth observing satellite for the meteorological, natural resources, hazard observation and management purposes, Nigeria now joins the league of nations that have access to the opportunities afforded by Satellite Remote Sensing in revolutionizing their agriculture. Costs, technology and economies of scale have driven commercial farmers around the world to change, and precision farming is beginning to gain popularity (T'Mbiebaka, 2021).

Adoption of PF technologies have apparent benefits for agricultural production management, cost savings, and environmental sustainability. However, these technologies are also extremely complicated and influenced by various social and economic forces, which impact their adoption rate, particularly in developing nations. Precision Agriculture has evolved from a concept some decades ago into an emerging technology today. The catalyst for the emergence of PF has been satellite positioning and navigation. The combination of Global Positioning System (GPS) and mobile mapping provide the agriculturist with a new capability of gathering information for implementing decision-based PF (Finger *et al*., 2022).

Precision farming utilizes a number of sophisticated tools to monitor and manage variations in crop yield, soil characteristics and environmental characteristics. The tools required for the effective practice of PF are:

i. Global positioning system (GPS) receivers

GPS receivers provide a means for determining the geographic location of objects anywhere on the earth (Pfost, Casady and Shannon, 2020). The receiver which is either mounted on implements (e.g combine harvester) or carried to the field allow farmers to automatically collect site specific soil and crop information for identification and management of crop fields.

ii. Remote sensing

Remote sensing is the non-contact collection of information relating to plant health, soil quality, topography, weed patches, etc. from a distance. It consists of the sensors and the platform; an aircraft, unmanned aerial vehicle, balloons, satellite, rockets etc. on which the sensors reside. The data collected are used for mapping plants condition for later treatment.

iii. Geographic information system (GIS)

GIS is a software application that is used to store layers of information such as crop yield, soil maps, remotely sensed data, etc. for the projection of current and future fluctuations in precipitation, temperature, crop output etc.

iv. Yield mapping

Yield sensors connected to on board computer coupled with a GPS receiver are used to automatically record crop yield as the harvester operates within the fields (Abdulsalam, 2022). The raw yield data is processed by a software programme, such as QGIS, Agro-Map, and Farm TM Works, etc. to produce yield map. Yield maps provide feedback information on how crops respond to certain soil and crop management practices and are used to determine recommendation rates for many inputs (Zagorda and Walczykova, 2018). The map shows the low and high performing areas of the fields.

v. Soil mapping

In-season variability can be identified through the systematic collection of soil samples with precise locations. The interpretation of the grid soil samples in the laboratory resulted in the production of an application map that shows the nutrients and water requirements of the soil samples by location.

Precision farming is one of the most prominent applications of AI, which was developed with an enhanced version of accuracy and control over agricultural techniques. PF, offer a wide range of applications in order to effectively harness human, natural and man-made resources for sustainable agricultural production and improved crop yields in Nigeria (Von-Loon *et. al.*, 2018).

PF would make easy incursion to our agriculture because of the fact that our farm sizes are already in small units and therefore easily adaptable to PA practice and the fact that widespread use of mobile phones provide new info delivery and collection mechanisms, since marginal cost of distributing information via mobile phones is close to zero (Zagorda and Walczkova, 2018). Precision farming also seeks to protect vital resources, such as groundwater, by ensuring that the use of agriculture has minimal impact on water tables and ecosystems.

Enhancing crop productivity with AI

AI is a key factor that influences future agricultural productivity which can significantly improve farming efficiency. In this regard, the mechanisms through which AI results in genetic improvement, efficient use of resources, and practical applications help to increase crop yields and further enhance resistance (FMAWRRD, 2023).

AI-driven genetic modification and breeding

AI is an important aspect of crop breeding and genetic modification, because it can develop crops that can sustain various diseases, pests, and environmental extremes. Analysis of large databases of genetic information and interactions with the environment will enable AI systems to predict the likeliest changes to succeed in crop production. This will hasten the breeding process and enhance the possibility of viable crops. Such techniques using AI can help identify the genes responsible for drought resistance and support crop engineering in areas formerly unsuitable for agriculture, thereby improving agricultural productivity (T'Mbiebaka, 2021).

In addition to drought resistance, AI-based genetic analysis can also identify other desirable attributes, such as enhanced nutrition, faster growth rates, and reduced requirements for chemical inputs, such as pesticides and fertilizers. Hence, new hope is emerging for the development of more sustainable and nutritious crops adapted to variable conditions. Von-Loon *et. al.,* (2018) posited that it will be feasible to grow high-yielding climate-resilient crops in areas that are usually not conducive for farming or have otherwise been inefficient, further driving global food security through AI farming.

Optimizing Resource Use

AI has been influential in the agricultural sector, especially in terms of increasing the efficiency of resource use, including water, fertilizers, and pesticides (UNCTAD, 2023). Such AI systems leverage data obtained from indicators of crop health, meteorological predictions, and soil sensors to determine application timing and quantity. It is through such a meticulous approach to farming that crop health and yield are maximized at the same time as the minimization of waste and environmental impacts. For instance, AI-powered irrigation systems can automatically adjust the quantity of water supplied to crops according to the relative moisture in the soil to ensure that crops obtain the exact amount of moisture required for healthy growth.

More importantly, AI-driven systems ensure far more precise application of fertilizers and pesticides, further reducing the likelihood of overuse, which often results in soil degradation and water pollution. With current levels of soil nutrients and infestations from pests, for instance, AI can recommend exactly how much input is needed in each section in a given field to enhance efficiency in resource use. This narrowcasting not only saves precious resources, but also makes farming more sustainable to keep the ecological footprint as low as possible (T'Mbiebaka, 2021).

Barriers to Adoption

International Institute for Tropical Agriculture (IITA) (2023) noted that the implementation of AI-integrated agricultural systems encounters several obstacles, notwithstanding the significant opportunities that AI presents to the farming sector. To maximize the capacity of AI to enhance crop yields, these challenges can be classified into three main categories: technological, social, regulatory impediments and economic constraints. However, it is imperative to address these issues.

Technological Challenges

AI adoption in agriculture requires a huge technological infrastructure, which can be unaffordable to most farmers, especially those from developing countries. This includes sensors, sophisticated robotics, and data analysis. Given that AI systems are complex, they require data processing power and reliable access to the Internet, which are not always available in rural areas. Challenges related to technological system reliability and maintainability exist; quite often, AI frameworks need to be continuously modified and fixed (Zagorda and Walczykova, 2018).

Besides, access to and maintenance of these systems in AI are very expensive, let alone the training that farmers must know in the use of these systems. Again, this would be the case for smallholder farmers and those in the developing world, where they might not enjoy this privilege if their governments or private organizations do not make huge investments in closing the digital divide. With the increased dependencies of agricultural operability on digital platforms for storing and processing data via cloud-based services, other challenges arise, such as cybersecurity and data privacy (Davies *et al*., 2021). However, one key factor in the successful adoption of AI in agriculture will be to make the solutions scalable, affordable, and easy to maintain to work equally well in areas with less technological advancement. These challenges will require cooperation among the providers of the technology, governments, and other stakeholders involved in agriculture to ensure that the advantages of AI become available to every type of farmer, irrespective of their geographical or economic conditions.

Sociocultural Barriers

There are societal obstacles to AI integration into agriculture. Many farmers who are conservatives and hence skeptical of new technologies and use old farming methods frequently oppose this. Such a shift towards AI-driven techniques requires gradual, challenging adjustments in practice and mentality alike. Moreover, farmers require considerable knowledge and training to acquire the skills necessary to efficiently employ AI. Adoption would also be low in the event of a lack of knowledge and confidence in the created systems (Grisso *et al*., 2021).

In addition to skepticism, attachment to traditional farming techniques and practices may further frustrate acceptance of AI. Many rural communities pass down farming techniques over generations, making it difficult to convince farmers to apply novel, unfamiliar systems. There is also a generational gap in technology adoption, where older farmers may not be as willing to adopt AI solutions as tech-savvy farmers. Similarly, Pfost et al., (2020) posited that it is important that AI systems be designed in a user-friendly interface that ensures accessibility for all farmers, irrespective of their technical background.

Regulatory and Ethical Concerns

Another main barrier to AI adoption in agriculture is AI-related regulation. Agriculture often involves sensitive information that farmers may not feel like sharing with other people, corporations, or governments. In addition, ethical concerns linked to the use of AI in genetic engineering and breeding might even result in new regulations (IITA, 2023). Unless there is wide-ranging testing together with long-term effect assessments, governments do not approve GMOs created with the help of AI. Delays such as these can tamper with the implementation of potentially useful technology.

In addition, data privacy legislation and agricultural data ownership are concerns that have grown equally because most AI systems require extensive data from farms for efficient operation. Hence, farmers may be very concerned with who owns this data and how it is used, calling for stricter data protection measures. Another ethical aspect according to Zagorda and Walczykova (2018) has to do with the use of AI in the manipulation of genetic material, which many say creates questions about the impacts this could have in the longer term on biodiversity, food security, and the balance of ecosystems. This may trigger debate concerning the sustainability of AI-driven genetic modifications and lead to the development of control over the use of genetic modifications. There needs to be a clear regulatory framework regarding the use of AI that considers ethical concerns and issues related to data privacy without being harmful to innovation. In this light, direct discussions with farmers, policymakers, and other experts within the agricultural sphere constitute the first step toward framing guiding principles that weigh the benefits of AI against social and ethical responsibility (Abdulsalam, 2022).

Economic Constraints

The most noteworthy are economic constraints, which may involve high capital investment at the beginning and long periods to recoup the ROI. Grisso *et al*., (2021) noted that such economic considerations may reduce the appeal of these advanced technologies to producers of agricultural produce, and more so for smallholder farming practitioners. Moreover, economic justifications for resisting automation and mechanization can be derived from employment repercussions for conventional agriculture-dependent rural communities.

Apart from the already high upfront costs, maintenance and general upgrades over time can also be financially costly to farmers in developing areas. In a wider sphere, the economic effects of adopting AI are felt within labor markets through increased automation of tasks traditionally done by human labor; consequently, job losses particularly affect rural populations whose livelihoods depend on agriculture.

Overcoming the Barriers

Overcoming such challenges requires the combined efforts of government entities, technology companies, and academic institutions. Some of the more successful means by which farmers can help overcome financial obstacles include subsidies or other substitute financial incentives. Further confidence and skill building for all farmers is possible through comprehensive training programs with follow-up. Appropriate regulatory frameworks need to be developed to address respect for data privacy and ethical considerations, while ensuring innovation. By addressing these issues, farming can achieve a more productive and sustainable future, driven by AI (Finger *et al*., 2022).

Further, collaboration among these stakeholders could also result in more accessible and affordable AI for the needs of smallholder farmers or rural farmers beyond those provided by financial and training support. The simplification of user interfaces and making AI tools adaptable to different agricultural systems will encourage wider adoption (Grisso *et al*., 2021). This will also ensure that best practices and successful stories of AI applications in agriculture are shared internationally, instilling confidence and calming skepticism. Policymakers can stimulate innovation through public-private partnership models in such a way that the technologies being developed address all farmers, regardless of economic status. Ultimately, addressing these barriers will accelerate the integration of AI in agriculture through a combined effort that will contribute to the resilient, efficient, and sustainable development of the world's agricultural sector.

Conclusion

Analysis of AI-driven precision farming demonstrated that the technology can improve yield outcomes, increase operational efficiency, and reduce environmental impact. The review also highlighted its ability to enhance crop production, optimize resource usage, and address critical challenges such as environmental sustainability and global food security. However, certain challenges need to be overcome for the full deployment of AI-driven PF, including technological, societal, and regulatory barriers. In addressing these challenges, emphasis be placed on collaboration among policymakers, technology developers, agricultural stakeholders, and educational institutions**.** The following recommendations are made based on this review: sociocultural barriers should be surmounted through educational programs and outreach initiatives, showing the real benefits of AI in crop yield and reducing labor would be more likely to build trust and confidence in the technology, economic challenges to adoption may require governments and other institutions to provide subsidies or fiscal incentives and customized curricula must be designed to cater to the particular requirements of diversified farming communities.

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