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# ROLES OF IOT, BIG DATA AND MACHINE LEARNING IN PRECISION AGRICULTURE: A SYSTEMATIC REVIEW

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## ABSTRACT

*Precision agriculture utilizes information technologies to efficiently manage water and soil resources in agriculture. This technological revolution has been sparked by the big data analytics, machine learning and Internet of Things (IoT)in numerous industries. This game-changing technology has influence on houses, grids, smart cities, and health. Machine learning and data-intensive decision-making have been made possible, which has created new possibilities for efficiency and innovation in various fields. In several fields, the convergence of IoT, big data analytics, and machine learning has opened the way for cutting-edge solutions and enhanced results.The application of machine learning in the agricultural sector can increase production quantity and quality to meet increasing food demand. These advancements are transforming current agrarian approaches and generating new opportunities, despite some limitations. This paper presents a systematic appraisal of the role of IoT, big data analytics, and machine learning in precision agriculture, highlighting the potential benefits and challenges in this rapidly evolving field.*

**Keywords**: Internet of things, Big data analytics, Machine learning, Precision agriculture, smart farming.

## INTRODUCTION

In the twenty-first century, humanity faces profound sustainability challenges. One of the pressing concerns revolves around agricultural systems, as the world grapples with the imperative to enhance agricultural production to ensure food security for a burgeoning global population projected to reach 9 to 10 billion individuals in the coming decades. Concurrently,the looming specter of climate changes, which threatens the sustainability of our agricultural practices must be addressed.

Amid these challenges, the concept of Precision Agriculture (PA) emerges as a beacon of hope. PA, characterized by the utilization of cutting-edge sensor and analysis systems, strives to augment agricultural yields and facilitate informed management decisions. This innovative approach has gained substantial traction, delivering benefits such as increased output, reduced labor hours, and more efficient resource allocation, encompassing fertilizers and irrigation management (Dholu&Ghodinde, 2018). It harnesses vast volumes of data and information to enhance agricultural resource utilization, yields, and crop quality.

Projections indicate that by 2050, the global population will expand by 34%, necessitating a 70% surge in food production to feed everyone (Tantalaki*et al.,* 2019). Consequently, the imperative to enhance agricultural productivity while mitigating its environmental impact looms large. Two pivotal factors; namely, overpopulation and urbanization, jointly contribute to an escalating global scarcity of agricultural resources. Urbanization, in particular, transforms vast tracts of agricultural land into non-agricultural zones, as urban centers encroach upon these areas, amplifying the overall demand for agricultural products. This trend, which diminishes arable rural regions, poses a potential threat to food production.

In response to these challenges, the path to salvation lies in judicious resource utilization. Precision agriculture emerges as a paradigm designed explicitly to curtail resource wastage. It operates by precisely apportioning resources based on the specific needs of crops at any given time. Contrastingly, traditional irrigation practices adhered to a fixed schedule, often leading to unnecessary water consumption when crops do not require immediate hydration.

Addressing this issue, our study introduces a soil moisture detection sensor that measures soil moisture content and provides crop-specific irrigation recommendations. This innovation not only conserves water but also mitigates the risk of crop diseases associated with over-irrigation. Moreover, factors like temperature, relative humidity, and light conditions around plants play pivotal roles, much like soil moisture, in ensuring optimal crop growth.

The complexity and precision inherent in sustainable precision agriculture underscore the need for geographic data management, a domain traditionally dominated by Geographic Information Systems (GIS). PA harnesses geospatial data and sensors to tailor resource allocation, including fertilizers, water, and pesticides, drainage management, and agrochemical distribution, while accounting for the variances inherent in heterogeneous agricultural landscapes. This transition from treating production fields as homogenous surfaces to recognizing their inherent variability is pivotal in the pursuit of sustainable precision agriculture.

As technology advances, we anticipate a more widespread adoption of PA and precision agriculture tools. This evolution will witness the development of advanced sensors and systems that provide real-time decision support to farmers. These tools, primarily prevalent in developed nations, empower farmers to make on-the-fly adjustments in resource inputs, such as water, fertilizers, and pesticides, as they traverse their fields, implement drainage systems, and engage in wildlife conservation efforts.

The operation of PA systems, characterized by precise resource allocation based on crop needs at specific geographical coordinates, will increasingly rely on geospatial solutions. These solutions, informed by imagery from Earth Observation (EO) and integrated sensor networks, expedite the development of cutting-edge cropping systems. Immediate feedback loops between the field and research laboratories will further expedite innovation. To enable this feedback mechanism, we propose a "system of systems" approach, underpinned by a shared global IT platform encompassing machine learning and the Internet of Things (IoT), creating a scientific network that bridges the gap between the scientific and agricultural communities.

However, the exchange of data between farms and value-added services faces challenges, notably in regions lacking high-bandwidth data transmission infrastructure. While small farm operations in low-income nations will rely on local sensor networks, broadband

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expansion in developed nations promises to resolve this issue. Nevertheless, the efficacy of analytics, AI, and machine learning in agricultural contexts hinges on the accessibility of coherent and consistent data, necessitating further efforts to overcome data silos. These challenges are particularly pronounced when implementing complex modeling and sustainable precision agriculture practices.

For instance, the Denitrification and Decomposition (DNDC) model, a sophisticated tool used to simulate soil-crop interactions and geo-chemical arrangements of carbon and nitrogen. While initial PA endeavors may not prioritize measuring greenhouse emissions from agriculture, models like DNDC hold the potential to forecast nitrate leaching and Carbon/Nitrogen (C/N) C/Ngreenhouse gas emissions, demonstrating the utility of complex analytical methods in advancing sustainable precision agriculture. Robust regional datasets are indispensable for mapping and monitoring management practices, ensuring compliance, verification, and sustainability tracking.

**Abbreviations**

PA= Precision agriculture

PC = Precision conversation

AI = Artificial intelligence

ML= Machine learning

SPAE= Sustainable precision agriculture and environment

DNDC= Denitrification and decomposition

VRT= Variable rate technology

DSS= Decision support system

GPS= Global positioning system

GIS= Geographic information system

RS= Remote sensing

YM= Yield mapping

PRISMA**:** Preferred Reporting Items for Systematic Reviews and Meta-Analyses

## METHODS

The PRISMA guidelines, an evidence-based framework for conducting systematic reviews using the standard protocol, are followed in this study.IoT, Big Data Analytics, and Machine Learning in Precision farming are the only topics covered in this study. The search time-frame for study was from 2016 to 2022. Any article outside the scope of the search or unrelated to the researchers area of interest was thus ignored.For this systematic review, the methodology followed the PRISMA guidelines and included targeted questions, database search strategy, inclusion and exclusion criteria, data extraction process.

### Information sources

In accordance with the PRISMA guidelines, a systematic literature search was conducted using Google Scholar and IEEE Xplore, two digital journal databases.The references of a few papers in Google Scholar and IEEE Xplore were also used in some of the reference searches.

### Search strategy

Precision Agriculture, Precision Farming, IoT in Precision Farming, Big data analytics in Precision Farming, Machine learning in Precision Farming, and IoT, Big data analytics in Precision Farming are some of the search strategy terms. 'OR' was used to combine terms from the same group, and 'AND' was used to mix terms from different groups. "IoT, Big Data Analytics and Machine Learning in Precision Agriculture" served as the database's final search string for both Google Scholar and IEEE Xplore.The outcome comprised technical reports, articles, and other review papers that are only published in English.

### Eligibility Criteria

This systematic review highlights the roles played by IoT, Big Data Analytics and Machine Learning in Precision Agriculture.The eligibility criteria for the reviewed articles were set according to the application of these technologies in PA.The exclusion criteria for this review were as follows:

(i) The study was published before or in 2016
(ii) Study in the applied field of PA like food industry and other farm except agriculture.
(iii) Full text articles not available.
(iv) The study not published in English.

The inclusion criteria for this review were as follows:

(i) The study was published later than 2015
(ii) The study that focused on application of IoT, Big Data Analytics and Machine Learning in PA.
(iii) The study was published in English alone.

**Data extraction**

After screening, 25 articles were considered for qualitative analysis based on the eligibility criteria. These articles were thoroughly reviewed to collect significant information about how the IoT, Big Data Analytic and Machine Learning impact precision farming. The information includes application of these technologies in PA per year (2016–2021). The studied literature are compared based on the advantages and disadvantages of the technologies and the field of application.Table 1 shows the source journals and number of papers.

Table 1: Search Database Sources

| S/N | Sources | URL | N0: Of Articles |
|---|---|---|---|
| 1 | Google scholar | https://scholar.google.com/ | **30** |
| 2 | IEEE Xplore | https://ieeexplore.ieee.org/ | **9** |
| 3 | ElSevier | https://www.elsevier.com/ | **5** |

**Application of IOT, ML and Big Data Analytic in PA**

A summary of some literature on the application of ML, IOT and Big data in PA. Indicating problem identified and the method deployed to address the problem and also the results obtained, as shown in Table 2.

Table 2: Summary of application of ML, IoT and data analytics

| S/N | REFERENCES | TITLE OF PAPER | PROBLEM ADDRESSED | RESULT |
|---|---|---|---|---|
| 1 | (Kour & Arora, 2020) | Recent Developments of the Internet of Things in Agriculture: A Survey | The paper supports current IoT technologies in the agricultural industry along with the design and creation of hardware and software systems. Projects and startups launched by the public and commercial sectors around the world to offer intelligent and sustainable solutions in precision agriculture are also covered. | Result indicated that the world is being revolutionized by the Internet. Connected device communication has evolved into a survival strategy.<br>Precision farming is giving way to micro farming in the agricultural sector.<br>By facilitating communication between people and objects as well as environmental factors, IoT has expanded communication's potential. |
| 2 | (Coble *et al.*, 2018) | Big Data in Agriculture: A Challenge for theFuture | The article explores the benefits and challenges of big data and comes to the conclusion that these technologies will enable pertinent analysis | |

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| | | | throughout the entire agricultural value chain. | |
| 3 | (Briskin *et al.*, 2015) | Machine learning and data mining advance predictive big data analysis in precision animal agriculture1 | This article provided a framework for machine learning and data mining to overcome knowledge gaps and gavea sneak peek into how they may be used to address important issues in the animal sciences. | In addition to increasing data volumes, a fully automated data collection or simulation platform which allows precision animal agriculture was defined by the complicated and ever-evolving nature of data gathering in real time. Animals can be monitored continually during production with the use of data-intensive technologies, and this information can be used to improve health, welfare, performance, and environmental load. |
| 4 | (Bendre *et al.*, 2016) | Big Data in Precision Agriculture: Weather Forecasting for Future Farming. | The article presented a case study of the gathering and analysis of daily minimum, maximum, humidity, and rainfall data from the KVR (KrishiVidyapeethRahuri (KVR), Ahmednagar, India) weather station over the previous ten years. | The outcome of this study improved the precision of weather forecasting for use in precision agriculture in the future. The scenario can be used to collect large amounts of data using a variety of ICT tools. For the forecasting model, the preprocessing techniques produce superior data. With several datasets, this model performed the best. |

Table 3: Summary of some techniques used in IoT, ML and Data Analytics.

| REFERENCE | TITLE | YEAR | METHODOLOGY | RESULT |
|---|---|---|---|---|
| (Dholu & Ghodinde, 2018) | Internet of Things (IoT) for Precision Agriculture Application | 2018 | The creation of a sensor node that measured all of these and provided an actuation signal for every actuator was suggested in this research. Additionally, sensor nodes have the ability to transfer this data to the cloud. Furthermore, an Android app was created to give users access to all of these agricultural statistics. | The suggested system has the ability to gather data, control a parameter locally, and transfer information to Thingspeak's cloud, which the user may then access from a mobile device. |
| (Ahmed *et al.*, 2018) | Internet of Things (IoT) for Smart Precision Agriculture and Farming in Rural Areas | 2018 | In this research, an IoT network solution connecting rural areas with various agricultural and farming applications was provided. | The suggested fog computing technique reduces action delay and conserves network capacity. A developing nation's economy primarily depends on agriculture and farms in rural areas, therefore using conventional methods is insufficient. Utilizing cutting-edge technology like the Internet of Things with affordable and scalable solutions is crucial. |
| (Mat et al., 2016) | IoT in Precision Agriculture Applications Using | 2016 | IoT and WMSN uses in agriculture, especially in greenhouse environments. | The result of the study clearly demonstrated that a close loop system or automatic irrigation is |

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| | Wireless Moisture Sensor Network | | This research clarified and demonstrated the effectiveness of the feedback control system for agricultural irrigation in greenhouses. To compare the differences between these two approaches, a test was run. The techniques include irrigation on a timetable or irrigation based on feedback. The purpose of irrigation on a timetable was to irrigate the plant at predetermined times. | more effective than planned irrigation in a greenhouse environment employing WSN or WMSN. In general, the Green House Management System plays a crucial role in gathering information about the conditions of the environment where crops are produced, processing and analyzing it, and finally controlling all associated equipment to alter the climate and irrigation conditions in accordance with requirements. |
| (Andrew, 2018) | IoT solutions for precision agriculture | 2018 | In this work, two IoT solutions for automated irrigation feasibility studies and one study for automated animal monitoring were described. Each proof of concept was tested to ensure that it functions normally in the field. | The research conducted demonstrated the viability of wireless sensor networks as an upgrade over the conventional approach. Each system produced enormous amounts of data, which could be examined using big data analytics to uncover patterns and correlations. To increase crop yields and fertilizer usage, irrigation data would be incorporated into the systems that operate agricultural machinery. |
| (Lamrhari *etal.*, 2016) | A Profile-Based Big Data Architecture for Agricultural Context | 2016 | This paper proposed a robust big data architecture based on profiling system that can help producers, consulting firms, government agencies, and research labs (among others) to make better decisions by providing them with real-time data processing, as well as a dynamic big data service composition method. | The suggested system can make use of the data that are requested to be Flume-stored in HDFS. Mahout offers analytical tools and libraries that predict the onset and origin/cause of future diseases once data has been stored. |
| (Islam Sarker *et al.*, 2019) | Big Data Driven Smart Agriculture: Pathway for Sustainable Development | 2019 | In order to address the research questions, the study conducted a systematic review of literatures between January 2010 and December 2018. | For effective big data technology deployment at the level of the farmer's field, a conceptual model was established. The study highlighted the process for creating data, the availability of hardware and software, data gathering methods, and the method of analysis, as well as the suitability of using big data technologies for smart agriculture. |
| (Lokhande, 2021) | Effective use of Big Data in Precision Agriculture | 2021 | This essay suggests using historical agricultural data to improve farming's productivity and quality. | The year-by-year crop production and its anticipated value for each year are predicted in this paper using the multiple linear regression technique. |

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| (Wei *et al.*, 2020) | Carrot Yield Mapping: A Precision Agriculture Approach Based on Machine Learning | 2020 | This work employed a semi-automated carrot harvesting system with the goal of developing a technique for creating a carrot yield map using a random forest (RF) regression algorithm on a database made up of satellite spectral data and ground-truth carrot yield samples. | This study was able to successfully construct an RF regression model to forecast carrot yield based on satellite spectral bands and actual yield samples. |
| (Treboux & Genoud, 2018) | Improved Machine Learning Methodology for High Precision Agriculture | 2018 | In this research, state-of-the-art image identification techniques were applied to a dataset made up of finely detailed aerial photographs of vineyards. | After each algorithm and process was specifically tuned, the results were obtained. A thorough comparison of the baseline and DTE demonstrated the differences in accuracy and stand. |
| (Akshatha & Shreedhara, 2018) | Implementation of Machine Learning Algorithms for Crop Recommendation Using Precision Agriculture | 2018 | In order to recommend a crop for the site-specific parameters with high accuracy and efficiency, this study provides a recommendation system that employed an ensemble model with majority voting technique using Random tree, K-Nearest Neighbor, and Naive Bayes as learners. | Thus, in order to maximize production and profit from such a technique, the work assisted farmers in planting the appropriate seed depending on soil conditions. |

## The Various Techniques Deployed for PA: their Pros and Cons

The following paragraphs explains various technique deployed in PA, there pros and cons.

i. **VRT (Variable Rate Technology):** Variable Rate Technology (VRT) offers several benefits in agriculture. It significantly reduces resource waste and contributes to a healthier environment by minimizing the use of pesticides and herbicides. This environmental friendly approach has the potential to revolutionize farming practices. However, there are some limitations that need to be addressed. For instance, further research is required to develop a cost-effective variable rate control system that can cater to the needs of smallholder farmers. Additionally, the reliance on a single control unit for various sensor modules must consider the complex interdependence of soil parameters like soil type, water level, pH value, and N-P-K content.

ii. **DSS (Decision Support Systems):** Decision Support Systems (DSS) play a crucial role in agriculture by removing confusion, inaccuracy, and ambiguity from agricultural data through real-time analytics. While they offer valuable advantages, there are several challenges to overcome. Building an efficient and error-free DSS model that accounts for the interdependence of spatial and temporal parameters is a complex task. The automation of dynamic DSS for fragmented lands presents another challenge. Experiments are needed to explore the applicability of existing models in fragmented and disorganized field structures. Furthermore, it's worth noting that most available DSS models primarily cater to large-scale agricultural operations.

iii. **GPS (Global Positioning System):** GPS technology provides accurate positioning information for precise, real-time data collection in smart agriculture. However, it has its limitations. GPS signals can weaken or become unreliable in the presence of obstacles such as trees, buildings, or adverse weather conditions. This makes it less effective for small farms, especially when energy sources are limited.

iv. **GIS (Geographic Information System):** Geographic Information Systems (GIS) offer accurate geospatial data, topological field structures, and application maps with layered architecture for resource allocation. Despite these advantages, GIS has its challenges. Leading GIS packages like ArcView, ArcGIS, and IDRISI are expensive, posing budget constraints. Creating layer maps demands substantial geographic data, which can strain storage space and processing time. Additionally, GIS is not a cost-effective real-time solution for certain applications due to the time-consuming data processing and analysis requirements. Moreover, technical expertise is necessary for analyzing prescription maps.

v. **OTG-SENSOR (On-the-Ground Sensors):** On-the-ground sensors play a crucial role in transferring data while ensuring integrity and security. They provide continuous real-time monitoring of terrain and weather conditions, along with precise variable flow control. However, challenges exist, such as the unavailability of wireless ground sensors for commercial purchase. Simultaneous data transmission from multiple sensors poses an elevated risk of data tampering. Ensuring both data integrity and security during transfer is a challenging endeavor.

vi. **RS (Remote Sensing):** Remote Sensing (RS) technology offers a visual representation of field health and monitors plant and field conditions. While it is valuable, it does come with limitations. RS relies on expensive and advanced equipment, and professionals are required to assess the outcomes. A robust approach for analyzing images and data is essential. Additionally, RS often suffers from low resolution, which can result in reduced accuracy. It also comes with limited coverage areas at a significant expense. Furthermore, data collection errors can occur due to signal interruptions caused by obstacles like trees, buildings, weather, and natural disasters.

vii. **YM (Yield Monitoring):** Yield Monitoring automates the harvesting process and provides real-time yield information, which is highly beneficial. However, it may not be a viable solution for small, distributed land-based facilities due to the high cost of yield monitoring equipment. Technical expertise is necessary to operate these systems effectively. The precision of yield control can be influenced by various factors, including incorrect swath width, threshing device delay, GPS errors, grain loss, and sensor calibration issues.

**Scope of Adoption of PA in Nigeria and Future Strategy**

Nigeria's agriculture sector stands at the crossroads of transformation. As the nation grapples with the need to meet the demands of a growing population and adapt to climate change, Precision Agriculture, powered by the synergy of IoT (Internet of Things), big data, and machine learning, has emerged to improve the scope of PA in Nigeria.

According to (Nyaga *et al.*, 2021), PA studies in Nigeria has been carried out on soil and crop mapping to a large extent and little work done in animal husbandry. A lots research has been done on large farms supporting the assumption that small scale farming is prevalent leading to low interest in PA by Nigerian farmers.

**The Current State of Precision Agriculture Adoption in Nigeria:**

Nigeria's agricultural landscape is evolving, and the adoption of Precision Agriculture

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technologies is steadily gaining ground. Several factors contribute to the scope of Precision Agriculture adoption in the country:

1. Rapid Technological Advancements: The increasing affordability and accessibility of IoT sensors, big data tools, and machine learning algorithms have made precision farming practices more feasible for Nigerian farmers.
2. Climate Change Challenges: Nigeria, like many nations, faces the adverse effects of climate change. Precision Agriculture offers adaptive strategies to optimize resource use, reduce waste, and mitigate climate risks.
3. Food Security Imperative: With a burgeoning population, Nigeria's food production must rise to meet the growing demand, making the adoption of Precision Agriculture technologies imperative.
4. Government Commitment: The Nigerian government has shown its dedication to agricultural modernization through initiatives like the Green Alternative Policy and the National Digital Agriculture Infrastructure.

**The Scope of Adoption of Precision Agriculture in Nigeria:**

Though PA is still in its early stages, the adoption of Precision Agriculture in Nigeria offers promising opportunities, which includes:

1. IoT-Enabled Farming: IoT sensors can monitor soil conditions, weather patterns, and crop, and animal health in real-time, providing invaluable data for informed decision-making.
2. Data-Driven Insights: Data analytics and machine learning can turn raw data into actionable insights, optimizing crop management, resource allocation, and pest control.
3. Enhanced Crop and Yields: Precision Agriculture techniques can significantly increase agricultural productivity, ensuring food and animal security and economic growth.
4. Youth Engagement: The integration of technology in agriculture can attract younger generations to farming, rejuvenating the sector and creating opportunities for digital farming entrepreneurs.

**Future Strategy for Precision Agriculture in Nigeria**

To fully harness the potential of Precision Agriculture, Nigeria should embark on a comprehensive and forward-looking strategy such as;

1. Infrastructure Development: Build robust digital and physical infrastructure to support IoT connectivity in rural areas, ensuring that farmers can access and utilize Precision Agriculture technologies.
2. Education and Training: Offer training programs and workshops to educate farmers on the use of IoT devices, data analytics tools, and machine learning applications in agriculture.
3. Financial Support: Provide subsidies and low-interest loans to encourage farmers to adopt Precision Agriculture technologies, alleviating the initial cost burden.
4. Research and Development: Invest in agricultural research that customizes Precision Agriculture solutions to Nigeria's diverse agroecological zones, crops, and livestock.
5. Public-Private Partnerships: Foster collaborations between government, private sector stakeholders, and research institutions to accelerate the development and dissemination of Precision Agriculture technologies.
6. Market Access: Improve market access and create value chains that reward precision farming practices, ensuring that farmers can benefit financially from their adoption.
7. Sustainability Focus: Promote sustainable Precision Agriculture practices that prioritize long-term soil health and environmental preservation.

## CONCLUSION

This paper presented a review on precision agriculture in Nigeria. The papers reviewed showed in detail the potential of PA in Nigeria and the possibilities of removing the existing barriers of PA in Nigeria. From the comparison of enabling technologies already used, made intable 3 and section 3.1, this review showed the best applicable technologies to be adopted. Significant application of PA in Nigeria has been made despite being a relatively new concept in agriculture and the diverse limitations posed by technology and the social-economic reality of the country. Nigeria has adopted testing and use of PA and has made advances in technology shown by more published studies compared to other sub-Saharan African countries. Research on PA has been carried out majorly on soil and crop mapping as well as crop protection and plant nutrition. Insignificant work has been conducted on animal husbandry. PA is still just at its early stages in the country and it can be concluded that great potentials exist for adoption in the nearest future as the population of Nigeria is ever rising.

Therefore, as the world confronts mounting sustainability challenges in agriculture, precision agriculture and sustainable precision agriculture offer promising avenues for resource optimization, enhanced productivity, and ecological stewardship. The future of agriculture lies in the careful balance of technology, data, and environmental consciousness, driving us toward a more sustainable and food-secured world.

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