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IoT-Based Intelligent System for Real-Time Soil Nutrient Monitoring and Decision Support in Farming: Potential for Deployment in Rice Farming in Nigeria

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Review Article

Abstract

This paper presents a comprehensive examination of the design, potential implementation, and existing technological landscape of Internet of Things (IoT)-based intelligent soil nutrient monitoring systems for rice farming. While the paper presents a model contextualized for Niger State, its findings offer insights relevant to rice-producing regions across Nigeria. Rice farmers face significant challenges related to soil fertility management, often due to reliance on inefficient traditional methods. By reviewing recent developments in sensor integration, embedded systems, and cloud-based platforms, this paper explores how such technologies can be applied to provide continuous, real-time monitoring of essential soil parameters like nitrogen (N), phosphorus (P), potassium (K), pH, temperature, and moisture. The findings suggest that IoT-enabled systems, complemented by mobile applications and decision-support tools, offer a low-cost and scalable solution to enhance yield, optimize fertilizer use, and improve data-driven decision-making for small and medium-scale farmers. This paper aims to provide a state-of-the-art overview of current trends and contextualize the proposed system within the global and local technological ecosystem.

Keywords: *IoT in Agriculture, Precision Farming, Soil Nutrient Monitoring, Smart Farming, Rice Production, Nigeria*
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1. Introduction

Agriculture remains a crucial pillar for food security, economic development, and employment, particularly in Sub-Saharan Africa. In Nigeria, rice is one of the most consumed staple foods and contributes significantly to household food demand. However, local production is insufficient due to multiple constraints including poor soil fertility management and lack of real-time data to guide decision-making. Although Niger State serves as the model environment for system demonstration, this review explores its broader potential for deployment across Nigeria's rice-farming zones. In Niger State, a leading rice-producing region in Nigeria, many farmers still depend on manual soil analysis, guesswork, or seasonal practices which lack precision, resulting in lower yield and inefficient fertilizer usage.

Traditional soil testing involves transporting samples to distant laboratories, which is costly and time-consuming. Moreover, farmers lack the knowledge or financial means to access such services regularly. Consequently, there is an urgent need for affordable, efficient, and user-friendly solutions to monitor and manage soil nutrients in real-time.

The Internet of Things (IoT) has capability to collect, transmit, and analyze real-time data through sensors and embedded systems, thus offering a compelling solution. When coupled with cloud computing and machine learning, IoT systems support intelligent decision-making in precision agriculture. This review explores the current state of such IoT-enabled agricultural technologies with a focus on soil nutrient monitoring in rice farming. In particular, a model tailored to the context of Niger State is presented as a case study, contributing to the ongoing discourse on smart farming practices. The paper aims to synthesize relevant research, examine implementation strategies, and evaluate how IoT-based systems can enhance productivity, reduce environmental impacts, and support small and medium-scale farmers in developing economies. The subsequent sections of this paper include a Review of Related Works and Technological Developments, a detailed System Design Approach: A Review with Case Application, and an outline of Expected Results and Outcomes from Reviewed Model. The paper concludes with a Discussion, followed by the Conclusion and Future Work.

2.0 Review of Related Works and Technological Developments

This section reviews advancements in precision agriculture and smart farming technologies, which have gained considerable attention globally as sustainable solutions to growing food demands and climate-related agricultural challenges.

Numerous studies have demonstrated that soil nutrient imbalances are a major factor affecting crop yield. As such, timely and precise nutrient management is critical for achieving optimal productivity.

Senapaty *et al.* [1] developed an IoT-based precision agriculture model using soil sensors and machine learning to optimize nutrient application in rice farms. Similarly, [2] reported a 10% increase in rice yield in China by employing IoT sensors for nutrient monitoring. Chaudhari *et al.* [3] demonstrated how sensor-based systems could effectively track soil moisture and nutrient content, providing tailored recommendations that improved yields.

The adoption of Agricultural Smart Technological Practices (ASTP), promoted by the FAO and the World Bank, offers a sustainable way to boost agricultural productivity and reduce environmental impact through digital tools like IoT, drones, and AI. In Nigeria, smallholder adoption of IoT remains low due to limited awareness, digital literacy, and cost, though affordable platforms like Arduino and open-source cloud systems now enable scalable deployment. Globally, agriculture contributes 6% ($6.822 trillion to the $113.7 trillion GDP but employs 34.6% of the labour force, 1.17 billion people [4]. With the world's population at 8 billion and projected to peak at 10.4 billion [5], food demand pressures intensify. Niger State exemplifies the challenges and potential of deploying smart farming technologies in Nigeria, where agriculture is vital for livelihoods. Addressing population growth, climate change, and food insecurity, set to impact one-third of the global population by 2050 unless food supply increases by 56%, ASTP provides a strategic path for local agricultural development amid tightening global trade conditions [6].

Simultaneously, the agricultural sector, which stands as the primary source of the global food supply, is highly affected by global warming and is estimated to lose 30 percent of its performance over the 21st century [7]. Africa has been noted as the continent most susceptible to agricultural change [8]. One main reason is that majority of African population live directly or indirectly on agriculture, largely in small holdings.

Crop yields from most countries in Africa are declining due to the consequences of agricultural change, with a more adverse future impacts under a business-as-usual scenario [9,10]. The livelihood of smallholder farmers who remain central to the continent's agriculture is affected and food security and poverty continue to thrive in most rural communities [11,12].

Recognizing the effects of agricultural change on developing countries, the Food and Agriculture Organization of the United Nations (UN) as well as the World Bank proposed the concept of Agricultural-Smart Practices (ASTP) [13]. ASTP is a form of technological practices that sustainably increases agricultural performance and incomes; enhances adaptation and builds resilience to agricultural change, reducing or removing Greenhouse Gases (GHGs) where possible and enhancing the achievement of national food security and the sustainable development goals [14].

The ASTP strategy focuses on the use of digital technology to create precision farming solutions, especially when combined with the application of information and communication technologies and other new interconnected equipment and techniques. The Internet of Things (IoT), drones, robots, big data, cloud computing, and artificial intelligence are all new resources that are expected to be applied to novel farming practices. The integration of precision farming systems and digital technology has become the most prevalent trend in agricultural development, contributing to fewer inputs, higher yields, and less damage in agricultural production.

ASTP presents a win-win scenario to both society and the environment; it helps to reduce agriculture vulnerability, enhance farmers' adaptive capacity, and increases food performance while leaving smaller ecological foot prints. According to [15], ASTP encompasses many of the field-based and farm based sustainable agricultural land management practices such as residue management, restoration of degraded lands, water management, agro-forestry and conservation tillage to achieve production goals. ASTP also enables farmers to use their knowledge and skills more effectively, share information, efficiently use pro-environmental technologies and build stronger associations that allows for negotiating of better market prices [16].

Agricultural production has declined in Nigeria, despite the country's vast economic potential and figures indicating that it is Africa's largest economy. As a result, food supply has been harmed, and instead of improving food supply through domestic production, Nigeria has relied heavily on food importation [17]. Rice is the fastest-growing commodities in Nigeria's food basket that has a likelihood of continued growth. The demand for rice has been increasing more rapidly in Nigeria compared to other West African countries. Since the 1970s, rice has increasingly become a major staple food for the Nigerian household in both urban and suburban areas of the country. This rapid increase in rice demand is being attributed to the continued population growth, increased urbanization and people's preference. Rice production takes place in all the ecological zones, in Nigeria and comparatively, the middle belt region has an advantage over other regions [18].

Niger state contributes about 16% of the national rice production in the country and can be called the second largest rice producing states, after Kaduna state 19.63% [19]. Rice yield in Nigeria is low, ranging from 2 to 32 tons per hectare as against the potential yield of 4 to 72 tons per hectare [20]. Crop producers' dependence on traditional technology and primitive methods to satisfy our growing population and global demand is suicidal. ASTP practices are currently an information-driven farming method, which necessitates increased monitoring. This method employs procedures that are both economically and environmentally beneficial to increase manufacturing output [21]. Agricultural growth and development is not possible without yield-enhancing technological options because merely expanding the area under cultivation to meet the increasing food needs of growing populations is no longer sufficient. Research and adoption of technological improvements are thus crucial to increasing agricultural performance and reducing poverty, while sustaining the agro-ecosystems that support livelihoods [22].

Within this growing body of work, this review highlights a model tailored to the local context of rice farming in Niger State, illustrating how IoT-based nutrient monitoring can be contextualized and implemented. It seeks to bridge the knowledge and technology gaps by providing a context-specific, scalable, and user-friendly tool for small- and medium-scale rice farmers.

3.0 System Design Approach: A Review with Case Application

This section reviews the design-oriented methodology and system architecture of the IoT-based intelligent soil nutrient monitoring prototype developed for rice farming in Niger State. The process comprises five core stages:

(i) selection of study locations
(ii) sensor and hardware design
(iii) data acquisition and calibration
(iv) software development and cloud integration and
(v) performance evaluation.

3.1 Study Area

The reviewed model is contextualized for six rice-producing locations within Niger State, Nigeria, distributed across the state's three senatorial zones to reflect diverse soil and climatic conditions. These case locations are used to illustrate how IoT-based systems can be adapted and replicated in other rice-producing regions across Nigeria. The senatorial zones are shown in Figure 1.

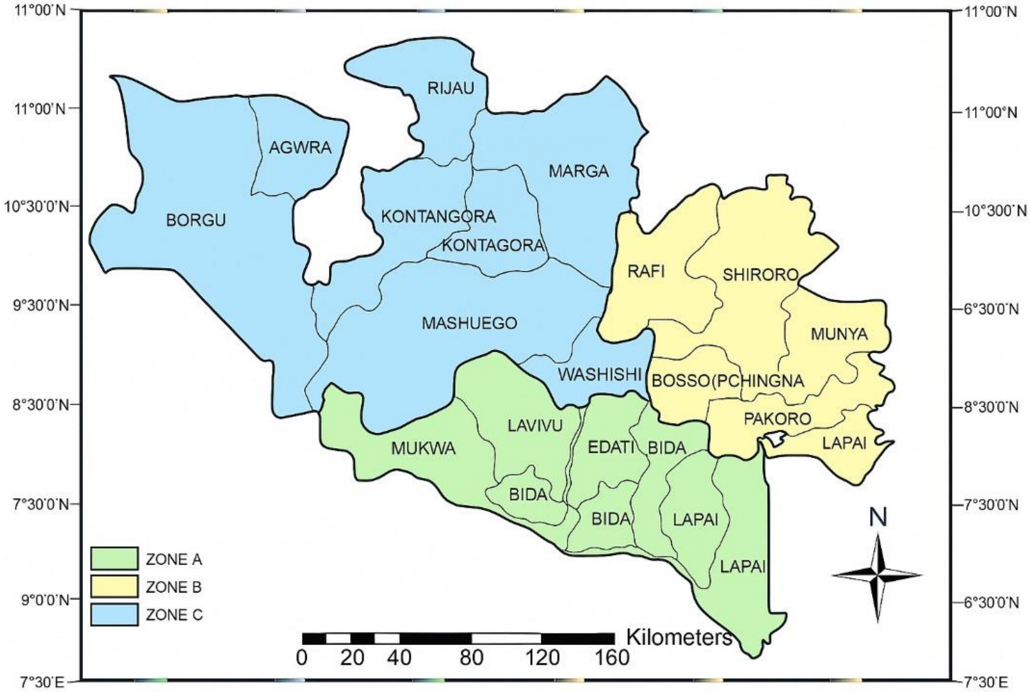

Figure 1: Map of Niger State highlighting senatorial zones relevant to rice farming and prior soil research.

These zones were selected to demonstrate how IoT-based monitoring systems can be adapted to varying agro-ecological conditions in Niger State. The selected areas are:

i. Zone A: Bida and Agaie
ii. Zone B: Rafi and Munya
iii. Zone C: Rijau and Borgu

Soil characteristics in these areas have been analyzed or referenced to simulate sensor calibration and contextualize system deployment to serve as benchmarks for real-time sensor readings. These zones were chosen based on rice cultivation density and regional importance in state-wide agricultural activities.

3.2 Data Collection and Soil Sampling

Initial baseline data collection involves physical sampling of soil from selected rice farms across the zones. The soil is tested in laboratories for parameters including nitrogen (N), phosphorus (P), potassium (K), moisture content, temperature, and pH. These lab results are then used to calibrate and validate the readings from the field-deployed sensors.

To support the calibration process and contextual soil profiling, the Table 1 presents selected rice varieties along with their preferred soil conditions, including pH, texture, fertility, and water requirements.

The research team also conducts structured interviews with farmers to understand existing soil management practices, levels of technological adoption, and knowledge gaps. This ensures that the proposed solution is tailored to the user environment.

Table 1: Rice Varieties and Suitable Soil Conditions

Rice Variety	Preferred Soil Texture	Soil pH	Soil Fertility	Water Conditions	Remarks
IR64	Loamy or clay loam	5.5 – 7.0	High organic matter	Flooded or well-irrigated	High-yielding, commonly grown in Asia
NERICA (1–10)	Sandy loam to clay	5.0 – 7.0	Moderately fertile	Upland, rainfed	Suitable for upland African fields, drought-tolerant
Swarna	Clay loam	5.5 – 7.5	High fertility, N-rich	Flooded during growing season	Widely used in India and Bangladesh
Basmati 370	Silty clay loam	6.0 – 7.5	Medium to high fertility	Flooded or controlled irrigation	Aromatic variety; prefers well-drained soils
Japonica (Calrose, etc.)	Silty loam or clay loam	5.8 – 7.5	Fertile, N and P rich	Paddy or controlled irrigation	Cold-tolerant, grown in temperate zones (e.g., California, Japan)
FARO 44 (Sipi)	Clay loam	5.0 – 6.5	Moderate to high fertility	Flooded or rainfed lowland	Popular in Nigeria; lowland adapted
Ofada Rice (Nigeria)	Clayey or silty loam	5.5 – 6.5	Organic-rich, well-drained	Lowland or rainfed	Indigenous Nigerian variety; often grown traditionally
Azucena (Philippines)	Loamy or clay loam	5.5 – 7.0	Medium fertility	Flooded or irrigated	Aromatic, tall traditional variety
WITA 4	Clayey or loamy	5.0 – 6.5	High organic content	Flooded or irrigated lowlands	Improved variety used in West Africa
Hybrid rice (various)	Loamy clay	5.8 – 7.0	High fertility with NPK	Irrigated or semi-irrigated	Higher yield, requires better management

3.3 System Architecture and Design

The proposed system model, as reviewed here, demonstrates the ability to analyze soil nutrients to enhance productivity in rice farming. The system will perform real-time analysis of soil nutrients. With the aid of sensors in the field, it is possible to measure the Nitrogen, Phosphorus and Potassium (NPK) levels of the soil right away, doing away with the requirement to transport the soil to a laboratory. A database of soil nutrients (NPK) for different species of rice, such as Faro 44, Faro 58, Faro 59, Faro 61 and Faro 65, is created. Computation of the amount of fertilizer needed to raise the soil's nutrient content to the appropriate levels for a higher crop yield for any of these varieties of rice. The system will offer a simple smartphone application for accessing and viewing soil data and suggested fertilizers. The methodology to be adopted is shown in Figure 2.

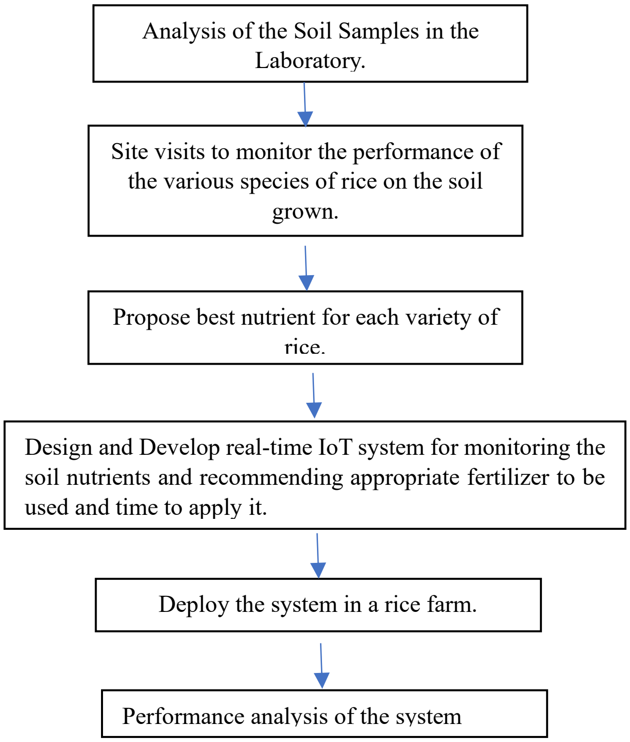

Figure 2: Conceptual schematic summarizing methodological frameworks for IoT-based soil nutrient monitoring in rice farming

3.3.1. Sensing Layer

This consists of integrated sensors for measuring:

i. Nitrogen (N), Phosphorus (P), Potassium (K) levels
ii. Soil pH
iii. Soil moisture
iv. Ambient temperature

These sensors will be interfaced with an Arduino Uno microcontroller that serves as the primary processing unit for on-site data collection.

3.3.2. Processing and Transmission Layer

The Arduino Uno will process the raw sensor data and sends it to a cloud-based platform via a Wi-Fi-enabled controller module (ESP8266). Data will be uploaded at fixed intervals to ensure real-time synchronization without data overload.

The cloud platform, built using open-source tools like ThingSpeak or Firebase, will host and process the data using predefined rules and machine learning models. These models compare current values against optimal thresholds for various rice varieties (FARO 44, 58, 59, 61, and 65).

3.3.3. Application Layer

The processed information will be sent to the farmer's mobile device through a custom mobile application. The app interface will display:

i. Real-time soil nutrient status
ii. Recommended rice variety for planting
iii. Type and quantity of fertilizer required
iv. Best time for fertilizer application
v. Forecasted yield trends

The app also includes a feedback feature for farmers to report crop performance, enabling continuous model improvement.

3.3.4 System Workflow

The workflow reviewed in this model illustrates how a typical IoT-based nutrient monitoring system functions in the context of rice farming. The system work flow is listed below:

i. **Sensor Measurement**: Soil parameters are directly measured on site.
ii. **Data Transmission**: Sensor data is sent via UART to the Arduino board.
iii. **Cloud Upload**: Arduino transmits data to the cloud over Wi-Fi.
iv. **Processing**: Cloud-based algorithms analyse the data.
v. **Decision Support**: The app displays results with actionable recommendations.

3.3.5 Pilot Deployment

The prototype system will be deployed on selected rice farms. Sensor readings will be compared with manual lab results over time to validate system accuracy and reliability. Performance metrics will include sensor accuracy, network reliability, user acceptance, and yield improvement.

Figure 3 illustrates the block diagram of the proposed IoT-based soil nutrient monitoring system tailored for rice farming applications, with potential for national-scale deployment. The system integrates multiple soil and environmental sensors, including pH, temperature, soil moisture, and nutrient sensors (N, P, K), which are interfaced with an Arduino Uno microcontroller. These sensors collect real-time data from the field, which is then transmitted through a Wi-Fi-enabled module to a cloud-based platform for processing and analysis. The processed data is visualized and interpreted via a mobile application, enabling farmers to make informed decisions regarding crop selection, fertilizer application, and irrigation scheduling. This architecture supports the core objective of delivering precision agriculture tools to small- and medium-scale rice farmers in Nigeria, using Niger State as a contextual example.

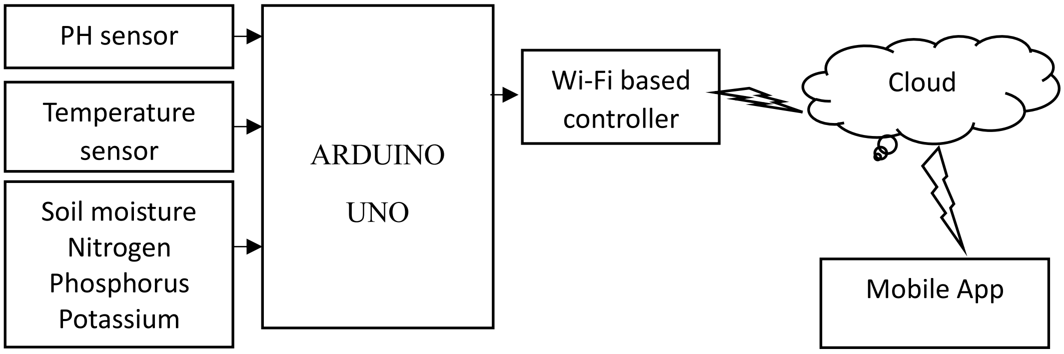

Figure 3: Soil Nutrient Monitoring System for varieties of Rice Species using Sensor Technology

This system architecture represents a typical application of IoT technologies adapted to the needs of smallholder rice farmers in Niger State, and is used here to illustrate how existing technologies can be contextualized for local use.

4.0 Expected Results and Outcomes from Reviewed Model

On deployment of the developed model, the following outcomes are anticipated based on its design, related studies and simulation tests.

4.1 Real-Time Soil Monitoring

Findings from reviewed models suggest that IoT-based systems are capable of providing rice farmers with up-to-date data on soil health parameters such as nutrient composition (N, P, K), pH, temperature, and moisture. By removing the delays associated with laboratory testing, this system empowers farmers to take immediate and informed actions.

4.2 Improved Fertilizer Application

Review of related systems indicates that data-driven approaches enable more accurate fertilizer application rates and schedules tailored to each soil condition and rice variety. This reduces both under- and over- application, minimizing costs and environmental impact.

4.3 Enhanced Yield and Productivity

As shown in studies and the system under review, matching soil conditions with appropriate rice varieties will significantly improve the alignment between soil conditions and appropriate rice varieties, such as FARO 44, FARO 58, and FARO 61. By analyzing real-time data on nutrient composition, pH, moisture, and temperature, the system can intelligently recommend rice types that are most compatible with the specific characteristics of each farm plot. This reduces reliance on guesswork or trial-and-error methods and increases the likelihood of achieving higher yields. Matching soil profiles with suitable rice genetics not only improves productivity but also enhances fertilizer-use efficiency and resource management. As more data is collected, the system's recommendations will become increasingly accurate, contributing to more informed, sustainable, and site-specific agricultural practices in Niger State. Table 2 highlights selected rice varieties commonly used in Nigeria and beyond, along with their optimal soil conditions. This alignment is critical for improving productivity and resource efficiency in precision rice farming.

4.4 Cost Reduction and Resource Efficiency

Optimized fertilizer usage and improved irrigation guidance help farmers minimize waste and conserve valuable resources. As a result, farming becomes more sustainable and economically viable, particularly for small and medium-sized enterprises (SMEs).

Table 2: Rice Varieties and Their Matching Soil Conditions for Optimized Yield

Rice Variety	Preferred Soil Texture	Optimal Soil pH	Soil Fertility	Water Requirements	Remarks
FARO 44 (Sipi)	Clay loam	5.0 – 6.5	Moderate to high	Flooded or rainfed lowland	Popular in Nigeria; adaptable to lowland areas
FARO 58	Clay loam	5.5 – 7.0	High NPK requirement	Irrigated or rainfed	Improved yield; widely adopted
FARO 61	Loamy clay	5.5 – 6.5	Rich in organic matter	Flooded or semi-irrigated	Heat tolerant; suitable for northern Nigeria
NERICA (1–10)	Sandy loam to clay	5.0 – 7.0	Moderately fertile	Upland, rainfed	Drought-resistant; upland suitability
Ofada Rice	Silty loam or clayey	5.5 – 6.5	Organic-rich	Rainfed or lowland	Indigenous Nigerian variety; traditional farming
Swarna	Clay loam	5.5 – 7.5	High, nitrogen-rich	Flooded	High-yielding; used in Asia
WITA 4	Clayey or loamy	5.0 – 6.5	High organic content	Flooded or irrigated lowlands	Used in West Africa; stable yields

4.5 Data Repository and Knowledge Transfer

All gathered data will be stored in the cloud, enabling continuous model learning and trend analysis over multiple farming cycles. The system also serves as a training tool for agricultural extension workers and researchers.

These anticipated outcomes align with findings from existing literature on IoT-enabled precision agriculture systems and further reinforce the potential impact of such technologies when adapted to local farming contexts.

5.0 Discussion

The IoT-based intelligent system reviewed in this paper directly responds to critical challenges encountered by small- and medium-scale enterprise (SME) rice farmers in Niger State, particularly those related to poor access to timely and affordable soil testing facilities, limited digital literacy, and inefficient use of agricultural inputs. Currently, many farmers in the region rely on traditional or manual methods of assessing soil fertility, which are not only labour intensive and time-consuming but also lack precision. The absence of accessible diagnostic tools often results in guesswork when it comes to fertilizer application, leading to nutrient imbalances, low productivity, and unnecessary input costs.

By enabling real-time monitoring of essential soil parameters, such as nitrogen, phosphorus, potassium (NPK), pH, moisture, and temperature the system offers an innovative alternative to laboratory-based analysis. As demonstrated in reviewed models, the use of low-cost sensors integrated with cloud-based decision support platforms allows farmers to access relevant, location-specific information. directly through a mobile application. This functionality equips farmers with the tools to make more informed and timely decisions regarding fertilizer type, quantity, and timing, thereby reducing wastage and improving yield outcomes.

Moreover, systems of this nature, as discussed in related works, have the potential to mitigate limitations posed by digital illiteracy. The mobile application is designed with a simple, user-friendly interface that can be adapted to local languages and symbols, allowing even farmers with minimal formal education to interact with and benefit from the technology. Such user-friendly design principles enhance the potential for scaling the system across diverse Nigerian rice-growing regions. Training and capacity-building programs facilitated by extension officers will further support farmers in understanding and using the system effectively.

As a result, the IoT-based solution is expected to not only improve the agronomic efficiency of rice production but also to enhance farmers' confidence in adopting data-driven farming practices. This transformation, as seen in comparable implementations, could mark a significant step toward the digital inclusion of rural agricultural communities, ultimately contributing to food security, economic development, and climate-smart agriculture across Nigeria

5.1. Scalability and Replicability

The reviewed system is designed using modular and low-cost components (Arduino, off-the-shelf sensors), making it replicable and scalable across other regions and crop types. The mobile app interface will be localized into language to suit Nigerian farmers.

5.2. Limitations

Despite the potential benefits observed in reviewed IoT-enabled soil nutrient monitoring systems for rice farming in Niger State, the following limitations must be considered, particularly in the context of practical deployment, data reliability, and system sustainability.

5.2.1 Connectivity Challenges in Remote Areas

One of the key challenges anticipated is the limited availability and reliability of internet connectivity in rural and remote farming communities. Since the system relies on continuous data transmission from field-deployed sensors to cloud-based platforms for real-time analysis and recommendations, poor network infrastructure can cause delays or interruptions in data upload and processing. This not only hinders real-time decision-making but also undermines the reliability and responsiveness of the system. Offline data buffering or local storage solutions may be required as a contingency, but these add layers of complexity to system design and maintenance.

5.2.2 Inconsistent Power Supply for Field Devices

Powering IoT devices such as sensors, microcontrollers, and communication modules is essential for uninterrupted operation. However, many rural rice farms in Niger State are not connected to the national power grid, and frequent outages are common in areas that are. Although the use of solar-powered modules is proposed, such systems may face limitations due to seasonal variations in sunlight availability, initial costs of setup, and maintenance issues such as battery degradation or panel vandalism. An unreliable power supply could result in intermittent system functionality, affecting data continuity and system dependability.

5.2.3 Calibration Discrepancies Between Sensors and Laboratory Data

Low-cost sensors often exhibit variations in accuracy due to environmental conditions, manufacturing differences, and wear over time. These sensors are susceptible to calibration drift, particularly in highly variable soil conditions. Discrepancies between real-time sensor readings and standard laboratory soil analyses could lead to inaccurate recommendations on fertilizer application or crop selection. Maintaining consistency across multiple sensors deployed in various locations requires regular calibration and possibly, manual verification—a task that may not be feasible or affordable for many smallholder farmers. This challenge, also noted in existing studies, underscores the need for incorporating adaptive calibration algorithms or semi-automated validation processes into the system architecture.

5.3. Policy and Adoption Considerations

To enhance adoption of the IoT-based system reviewed in this paper, partnerships with agricultural extension agencies and relevant state government programs will be essential. These institutional actors serve as vital intermediaries between researchers and the farming communities, providing technical support, localized knowledge, and trusted communication channels. Their involvement from the early stages of implementation will not only strengthen the credibility of the system but also facilitate its integration into existing agricultural advisory frameworks. Extension officers can play a critical role in interpreting system-generated recommendations for farmers, particularly those with limited digital literacy or formal education, thereby translating technological innovations into actionable farming decisions.

Furthermore, the financial cost of deploying the system, although minimized through low-cost hardware and open-source platforms, may still pose a significant barrier for smallholder farmers. To encourage wider use and avoid deepening existing inequalities in access to technology, it is crucial that initial deployment be subsidized, especially through strategic clustering of users. Organizing farmers into cooperatives or community groups can help distribute costs, promote shared ownership, and foster peer learning. This model not only improves affordability but also enhances sustainability by building collective responsibility for maintenance and local troubleshooting.

Subsidized deployment, combined with institutional backing, can serve as a foundation for broader scalability and policy integration. Government and donor support for pilot schemes will demonstrate the practical utility of the system and provide data to inform future investments. Over time, embedding the system into national or state-level agricultural policy frameworks, particularly those targeting food security, smart agriculture, and digital innovation, will be key to ensuring long-term adoption and transformative impact. These considerations reflect insights from previous deployments of similar technologies in agricultural settings.

6.0. Conclusion and Future Work

This paper reviewed an IoT-based intelligent system for real-time soil nutrient monitoring and decision support specifically tailored for rice farming in Niger State. By integrating advanced sensor technologies with embedded microcontrollers, the system continuously collects accurate data on essential soil parameters such as nitrogen, phosphorus, and potassium levels. This real-time monitoring enables timely insights into soil health, allowing farmers to make informed decisions about fertilizer application. The incorporation of cloud computing facilitates data storage, analysis, and remote access, providing an interactive platform for farmers to receive tailored recommendations based on current soil conditions. This integration of hardware and software components ensures a low-cost, scalable, and user-friendly solution that is accessible even to small and medium-scale farmers.

The reviewed system's decision support capabilities are intended to optimize fertilizer usage by minimizing waste and preventing over-application, thereby promoting sustainable agricultural practices and reducing environmental impacts. By enabling precise nutrient management, the system is designed to improve rice crop yield and quality, contributing to food security in the region. The accessibility of the platform supports farmers with varying levels of digital literacy, offering an intuitive interface that simplifies complex agronomic data into actionable advice. Overall, the proposed IoT-based intelligent system represents a significant step toward modernizing rice farming across Nigeria through technology-driven, data-informed agricultural practices. Its modularity and adaptability make it relevant for broader adoption in varied agroecological zones within the country.

These findings and projections are consistent with trends observed in similar IoT-based systems for precision agriculture. Future exploration based on the reviewed system and related studies may involve:

i. Full-scale pilot testing in all six zones
ii. Integration with weather forecasting data
iii. AI-based predictive modelling for yield forecasting
iv. Expansion to other crops beyond rice

The implementation of this system has the potential to contribute significantly to Nigeria's agricultural transformation, enhance food security, and promote climate-smart agricultural practices.

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