



AgriSense: IoT-Driven Precision Agriculture for National Food Sustainability and Development

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ABSTRACT

Precision agriculture integrates digital technologies to improve agricultural resource management, productivity, and sustainability, while the Internet of Things (IoT) enables real-time monitoring of soil and environmental conditions through connected sensors. In Nigeria, inefficient water and fertilizer use, declining soil health, climate variability, and limited access to timely agricultural information constrain sustainable food production. This study presents AgriSense, an IoT-driven precision agriculture platform designed to support data-informed farm management under Nigerian agricultural conditions. The study adopts a mixed-method research framework incorporating descriptive, experimental, and analytical approaches, with proposed data sources including IoT sensor measurements, farmer surveys and interviews, field observations, and relevant weather information. The AgriSense platform integrates soil-moisture, nitrogen-phosphorus-potassium (N-P-K), soil-pH, temperature, and humidity monitoring with farm and field management, sensor-status tracking, automated alerts, agronomic recommendations, and reporting functions. The demonstrated interface represents agricultural fields and crops across Asaba Demonstration Farm, Jos Highland Farm, and Sokoto Smart Farm. Its threshold-based alerts identify conditions associated with low soil moisture, low nitrogen, acidic soil, high temperature, and sensor connectivity faults, linking selected conditions to recommended management actions. The available demonstration establishes the platform's integrated monitoring and decision-support functionality. However, because the interface identifies its environment as a live simulation, the displayed information does not independently establish improvements in crop yield, input-use efficiency, soil health, or farmer income. The study provides a technological foundation for subsequent field validation of IoT-enabled precision agriculture and its potential contribution to sustainable food security in Nigeria.

1 Introduction

1.1 Background to the Study

Agriculture remains central to Nigeria's food security, employment generation, rural livelihoods and economic development. Recent evidence indicates that agriculture contributes substantially to national economic activity and supports a large proportion of the Nigerian labour force. However, the sector continues to face structural constraints, including limited irrigation, low technology adoption, land degradation, high production costs, weak input systems, and increasing climate-related risks. The vulnerability of Nigerian agriculture is particularly important because much of



smallholder production remains dependent on rainfall, and farmers have limited capacity to respond to increasingly variable climatic conditions. Recent studies associate climate variability, including irregular rainfall, drought and flooding, with declining agricultural productivity and increasing food-security risks in Nigeria.

Conventional agricultural management also frequently relies on generalized decisions about irrigation, fertilizer application, and crop management rather than field-specific information. Inefficient water management can result in unnecessary water consumption, while inappropriate fertilizer application can increase production costs, nutrient losses, and soil degradation. Climate variability further complicates decisions about when and how much water and fertilizer should be applied. Evidence from Nigerian farming systems suggests that climate-smart practices can improve agricultural productivity and household food-security outcomes, although adoption remains uneven.

The emergence of precision agriculture provides an opportunity to address these challenges through the systematic collection and analysis of field-level information. Internet of Things (IoT) technologies connect sensors, communication systems, and analytical platforms to generate real-time information about agricultural environments. In crop production, IoT-enabled sensors can monitor variables such as soil moisture, soil nutrients, pH, temperature, and humidity, thereby supporting more precise irrigation, fertilization, and crop-management decisions (Ndjuluwa et al., 2023). Recent reviews further demonstrate that smart sensors, IoT, artificial intelligence, and data analytics are increasingly being integrated to support resource optimization, crop monitoring, yield prediction, and automated decision support (He et al., 2024; Getahun et al., 2024).

For developing-country agricultural systems, the value of IoT extends beyond sensing. The conversion of sensor observations into understandable alerts, recommendations, and actionable information is critical to farmer decision-making. Predictive analytics can support farmers in estimating crop requirements and improving resource allocation, while digital agricultural applications can improve access to information and, under appropriate conditions, farm-level productivity (Ajayi et al., 2024; Kolapo & Didunyemi, 2024). However, connectivity, infrastructure, cost, digital literacy, technical capacity, and data security remain important barriers to the effective deployment of digital agriculture.

Against this background, the AgriSense project introduces an IoT-driven precision agriculture platform designed for Nigerian agricultural conditions. The platform integrates field sensors, real-time telemetry, a farm and field management interface, sensor monitoring, automated alerts, agronomic recommendations, and sensor-data reporting. Its monitoring functions cover parameters such as soil moisture, Nitrogen-Phosphorus and Potassium (N-P-K) nutrients, soil pH, temperature, and humidity, while its decision-support functions translate abnormal measurements into practical interventions. The research therefore moves beyond the conceptual application of IoT by examining an integrated platform for real-time agricultural intelligence and its potential contribution to resource efficiency, productivity, sustainability, and farmer decision-making.

1.2 Statement of the Problem

Nigeria's agricultural sector faces interconnected productivity, environmental, and socioeconomic challenges that constrain its contribution to sustainable national food security. Six major problems can be identified: inefficient resource utilization, climate-change impacts, declining soil health, limited access to agricultural technology and information, farmers' economic vulnerability, and barriers to adopting sustainable agricultural practices.

First, inefficient resource utilization remains a significant concern. Water and fertilizer are essential production inputs, yet decisions about their application are often made without sufficiently granular information about field conditions. IoT-based monitoring provides an opportunity to determine when soil moisture or nutrient conditions require intervention and thereby support more efficient resource allocation.

Second, climate variability and change increasingly expose agricultural production to drought, irregular rainfall, flooding, and temperature variations. Recent Nigerian studies show that climate-smart agricultural practices can improve resilience and food-security outcomes, but the effectiveness of such practices depends partly on farmers' capacity to access and respond to timely information.



Third, declining soil health caused by nutrient depletion, inappropriate input application, erosion, and unsustainable cultivation threatens the long-term productivity of agricultural land. IoT-based monitoring of soil moisture, pH, and nutrient conditions can provide field-level evidence for more informed soil and nutrient management (Ndjuluwa et al., 2023).

Fourth, limited access to real-time agricultural information constrains farmers' ability to make timely production decisions. Evidence from Nigeria indicates that farmers' use of digital agricultural tools is affected by exposure, knowledge, network availability, cost, and technical capacity.

Fifth, farmers' economic vulnerability limits their capacity to absorb production shocks and invest in modern technologies. Digital agricultural applications have demonstrated potential for improving technical efficiency and productivity, but benefits depend on farmers' access to appropriate technologies, skills, and supporting infrastructure. Finally, barriers to sustainable technology adoption remain substantial. Recent Nigerian evidence identifies education, training, internet access, smartphone ownership, awareness, cost, infrastructure, and institutional support as important determinants of farmers' willingness to adopt digital agricultural tools. Furthermore, IoT agricultural systems introduce cybersecurity and data-privacy concerns that must be addressed to protect the integrity and confidentiality of farm data (Adewusi et al., 2022).

The central research problem is therefore the absence of sufficiently integrated, locally relevant, and actionable agricultural intelligence systems capable of continuously converting field-level data into timely decisions for Nigerian farmers. AgriSense seeks to address this gap by integrating IoT sensing, real-time monitoring, data analytics, alerts, and agronomic recommendations within a unified precision-agriculture platform.

1.3 Aim and Objectives of the Study

The study aims to develop and evaluate an IoT-driven precision agriculture system that provides real-time agricultural intelligence to improve resource utilization, productivity, sustainability, and farmer decision-making in Nigeria.

The study seeks to address the following objectives:

1. Optimize water and fertilizer utilization through real-time monitoring of soil and environmental conditions.
2. Improve crop health and yield through data-driven agricultural decision-making.
3. Promote sustainable and environmentally responsible farming practices through precision management of agricultural inputs.
4. Empower farmers through access to real-time agricultural information, decision-support tools and relevant training.
5. Support smallholder farmers' economic opportunities through improved productivity, resource efficiency and access to actionable agricultural information.
6. Generate policy-relevant evidence to support wider adoption of IoT-enabled precision agriculture in Nigeria.

1.4 Research Questions

The study will answer the following questions:

1. How can IoT technologies optimize water and fertilizer utilization in Nigerian farming systems?
2. To what extent does access to real-time agricultural data improve crop health and yield?
3. How can IoT-enabled precision agriculture enhance sustainable farming and soil conservation?
4. In what ways can IoT-based agricultural intelligence strengthen farmers' resilience to climate variability?
5. How can access to real-time agricultural information and technology training empower smallholder farmers economically?
6. What policy and institutional frameworks are required to support the widespread adoption of IoT-driven precision agriculture in Nigeria?



1.5 Significance and Scope of the Study

Farmers: The study provides a basis for improving farm decisions through real-time information on soil moisture, nutrients, pH, and environmental conditions. The resulting alerts and recommendations can support more timely irrigation, fertilizer, and soil-management decisions.

Agricultural extension practitioners: AgriSense can complement conventional extension services by providing extension personnel with remotely accessible field information and evidence for targeted interventions. This is particularly relevant where limited extension resources make continuous physical monitoring difficult.

Policymakers: The study will provide empirical evidence concerning the feasibility, benefits, and adoption requirements of IoT-enabled precision agriculture. Such evidence can inform policies on digital agriculture, agricultural extension, rural connectivity, technology financing, data governance, and climate-smart agriculture.

Researchers and tertiary institutions: The project contributes an applied Nigerian case of integrating IoT sensing, agricultural analytics, and decision support. It can provide a platform for further research in agricultural informatics, artificial intelligence, sensor networks, climate-smart agriculture, and digital extension.

National food sustainability: By targeting more efficient use of water and fertilizers, improved soil management, climate resilience, and productivity, AgriSense addresses several factors that influence the sustainability and resilience of Nigeria's food-production system. Recent evidence indicates that climate-smart agricultural practices can contribute to improved food-security outcomes among Nigerian farming households.

1.6 Scope of the Study

The study focuses on the development and evaluation of the AgriSense IoT-driven precision agriculture platform and its application to selected agricultural farms and fields in Nigeria. The platform covers real-time monitoring of soil moisture, N-P-K nutrients, soil pH, temperature, and humidity, together with sensor-status monitoring, historical/trend visualization, alerts, agronomic recommendations, and data reporting.

The empirical component will examine selected farms and fields representing the agricultural environments included in the research design. The study combines field observations, IoT sensor measurements, farmer surveys/interviews, and relevant environmental or weather information, with comparisons between conventional and IoT-supported agricultural management where applicable.

The scope is therefore deliberately focused on real-time agricultural intelligence and decision support, rather than attempting to address every dimension of agricultural value-chain development. The expected contribution is an evidence-based assessment of whether an integrated IoT platform such as AgriSense can support more efficient, productive, sustainable, and climate-resilient agricultural management in Nigeria.

2 Literature Review and Conceptual Framework

2.1 Concept of Precision Agriculture

Precision agriculture (PA) refers to the use of spatially and temporally detailed information to manage agricultural production according to the specific conditions of fields, crops, and production zones. Unlike uniform farm management, PA enables inputs and interventions to be matched to observed variability in soil, crop, and environmental conditions. Recent literature identifies sensors, communication technologies, data analytics, and decision-support tools as the technological foundation of contemporary PA (Alahmad et al., 2023; Saini et al., 2025). A recent bibliometric review based on 24,337 publications retrieved from Scopus confirms the increasing convergence of IoT, artificial intelligence (AI), robotics, and data analytics in precision agriculture.

Real-time monitoring is particularly important because agricultural conditions change continuously. Soil moisture, nutrient availability, temperature, humidity, and crop stress can vary substantially across space and time. Sensor-based monitoring therefore provides higher-frequency information than periodic manual observations and can support timely



interventions. Alahmad et al. (2023) emphasize that site-specific data collection creates the basis for more precise interventions and advanced decision-support systems.

Consequently, PA increasingly represents a transition from experience-based or generalized farm management toward data-driven decision-making, in which measured conditions are transformed into management actions. This principle provides the conceptual foundation for AgriSense.

2.2 Internet of Things in Agriculture

The Internet of Things (IoT) provides the technological infrastructure through which physical agricultural objects and environments can be sensed, connected, and monitored. Agricultural IoT systems commonly comprise sensor nodes, communication networks, gateways, databases/cloud platforms, and user interfaces. Sensors collect field observations, communication technologies transmit them, and software platforms process and present the information to farmers or other agricultural stakeholders.

In crop production, IoT sensors can monitor soil moisture, temperature, humidity, pH, and nutrient conditions. Such measurements enable continuous data acquisition and facilitate field-specific management decisions (Ndjuluwa et al., 2023). Wireless sensor networks and contemporary communication technologies, including cellular networks, provide alternatives to conventional wired monitoring systems and facilitate remote agricultural monitoring (Alahmad et al., 2023).

The value of IoT, however, lies not merely in collecting data but in converting data into usable agricultural intelligence. Modern smart-farming systems therefore increasingly combine sensors with dashboards, analytics, alerts, and decision-support mechanisms. Recent reviews identify the integration of IoT and AI as an important direction for real-time crop monitoring, automated analysis, and precision management.

The AgriSense platform reflects this architecture by integrating sensor monitoring, real-time telemetry, trend visualization, alerts, agronomic recommendations, and downloadable sensor reports.

2.3 IoT Applications in Crop Production

IoT technologies have applications across major dimensions of crop production. Soil-moisture monitoring provides information for determining irrigation requirements and reducing unnecessary watering. Recent systematic evidence on IoT-based smart irrigation indicates that combining real-time sensing, wireless networks, and decision-support systems can improve water-use efficiency while maintaining crop productivity.

Nutrient monitoring provides field-level information about nutrient status and can support more targeted fertilizer application. N-P-K sensing and IoT-enabled soil analysis have been investigated for crop recommendation and precision nutrient management (Senapaty et al., 2023). Similarly, soil-pH monitoring can identify acidity or alkalinity conditions that affect nutrient availability and crop development.

Temperature and humidity monitoring provide information relevant to crop growth, irrigation scheduling, and environmental stress. When combined with other measurements, these variables can improve the identification of changing field conditions. Ndjuluwa et al. (2023) identify soil nutrients, moisture, humidity, and temperature among the principal environmental parameters monitored through agricultural IoT systems.

IoT also supports crop health, pest, and disease management. Integration with imaging, remote sensing, and AI enables automated detection and classification of crop diseases and other stress conditions. Contemporary reviews indicate that IoT provides the sensing, communication, and data infrastructure, while machine/deep-learning models can perform feature extraction, detection, and classification.

Thus, IoT applications extend from individual measurements to integrated crop-management systems in which multiple environmental and crop variables are combined to support timely interventions.

2.4 IoT, Climate-Smart and Sustainable Agriculture

IoT-enabled precision agriculture has considerable relevance to climate-smart and sustainable agriculture because it can improve the efficiency with which scarce agricultural resources are used. Real-time information can support irrigation



decisions, reduce unnecessary input application, and facilitate more targeted management of soil and crops. Alahmad et al. (2023) identify IoT and AI as technologies capable of reducing resource-use inefficiencies while supporting long-term agricultural productivity.

The environmental benefits of precision agriculture are also supported by recent life-cycle evidence. Bahmutsky et al. (2024) report that precision-agriculture practices can reduce several environmental impacts relative to conventional practices, particularly through improved nutrient management, although economic and environmental outcomes vary according to technology and production context.

For climate-risk management, continuous monitoring can provide early information about moisture deficits and environmental conditions that may indicate crop stress. Recent work on IoT-driven crop monitoring and precision irrigation emphasizes real-time sensing, sensor networks, and AI as mechanisms for proactive intervention under changing field conditions.

Accordingly, IoT can contribute to sustainable intensification by seeking simultaneous improvements in productivity, input-use efficiency, and environmental performance rather than simply increasing agricultural output.

2.5 Data Analytics and Predictive Agriculture

The increasing volume and frequency of sensor observations make data analytics essential to precision agriculture. Descriptive and statistical analysis can identify trends and relationships among soil, weather, and crop variables, while predictive models can estimate future conditions and support proactive farm management.

AI and machine learning have consequently become important components of precision agriculture. Reviews show applications in yield prediction, soil analysis, crop-stress detection, disease identification, and resource management (Alahmad et al., 2023; Sharma & Shivandu, 2024).

Predictive irrigation is one particularly important application. A 2024 systematic review of 55 studies found that machine-learning approaches demonstrate considerable potential for smart irrigation, although generalizability and wider empirical validation remain challenges. Predictive models can similarly estimate yield and crop requirements using historical and real-time observations. For AgriSense, data analytics therefore serves as the bridge between raw sensor measurements and actionable recommendations. The system's potential value depends not simply on the accuracy of individual sensors but on its capacity to interpret multiple measurements and convert them into meaningful agricultural decisions.

2.6 Farmer Adoption, Training and Socioeconomic Benefits

Technological effectiveness does not automatically translate into agricultural impact. Adoption depends on farmers' awareness, perceived usefulness, ease of use, affordability, digital literacy, connectivity, and access to technical support. This is particularly important in developing-country contexts where rural connectivity and technology access can be uneven.

Evidence from Southwest Nigeria demonstrates the importance of technology exposure and farmer training. Kolapo and Didunyemi (2024), using data from 380 smallholder maize farmers, found that exposure to agricultural smartphone applications significantly increased adoption, while users recorded higher total-factor productivity and technical efficiency than non-users. The study consequently demonstrates that training and sensitization can be important mechanisms for converting technological availability into actual use.

Cost and infrastructure remain important constraints. Recent precision-agriculture literature identifies inadequate infrastructure, integration difficulties, technology cost, and limited technical capacity among continuing barriers to adoption. For smallholders, these constraints make affordable, user-friendly, and locally relevant systems particularly important. AgriSense therefore incorporates not only sensing and analytics but also farmer-oriented dashboards, alerts, recommendations, and training for farmer empowerment and capacity building.

2.7 Cybersecurity and Data Governance

The increasing connectivity of agricultural systems creates cybersecurity and data-governance requirements. IoT devices can be exposed to unauthorized access, data interception, manipulation, spoofing and denial-of-service attacks. Such threats are particularly significant in agriculture because compromised information or control systems can affect physical production processes.

A 2021 review of smart-farming security identified IoT devices as introducing new vulnerabilities alongside their productivity benefits, emphasizing the need for appropriate security awareness and countermeasures. Similarly, Amiri-Zarandi et al. (2022) demonstrate that agricultural data privacy must be considered throughout the data lifecycle, including data collection, transmission, storage, analysis, and sharing.

For an agricultural platform such as AgriSense, therefore, data integrity, authentication, access control, privacy, secure communication, and reliable storage should be treated as integral components rather than optional technical features.

2.8 Research Gap and Conceptual Framework

2.8.1. Device-Level Vulnerabilities

The literature establishes that IoT, AI, sensors, and data analytics can improve agricultural monitoring and resource management. Nevertheless, several gaps remain. First, much of the existing research focuses on individual technological components, such as irrigation sensors, disease detection, or predictive models, rather than integrated farmer-facing systems. Second, infrastructure, cost, interoperability, technical skills, and scalability continue to constrain implementation, particularly in developing-country agricultural environments. Third, many smart-farming architectures still fail to integrate cybersecurity and agricultural-data privacy.

The Nigerian context adds another dimension. Evidence shows that exposure, training, and access strongly influence agricultural technology adoption, while connectivity and other socioeconomic constraints can limit uptake. Consequently, there is a need for locally adapted, integrated, user-oriented precision-agriculture platforms that connect field sensing with analytics, alerts, recommendations, and farmer decision-making.

2.8.2. Conceptual Framework

The framework assumes that IoT sensors provide reliable field-level observations; data processing and analytics transform these observations into interpretable information; alerts and recommendations communicate conditions requiring intervention; and farmer decisions determine the resulting management actions. Effective implementation should ultimately contribute to improved productivity, more efficient use of water and fertilizers, improved soil management and greater agricultural sustainability.

The framework therefore positions AgriSense not simply as an IoT monitoring system but as an integrated agricultural decision-support platform linking sensing, analytics and human decision-making. Figure 1 presents the conceptual framework of AgriSense.

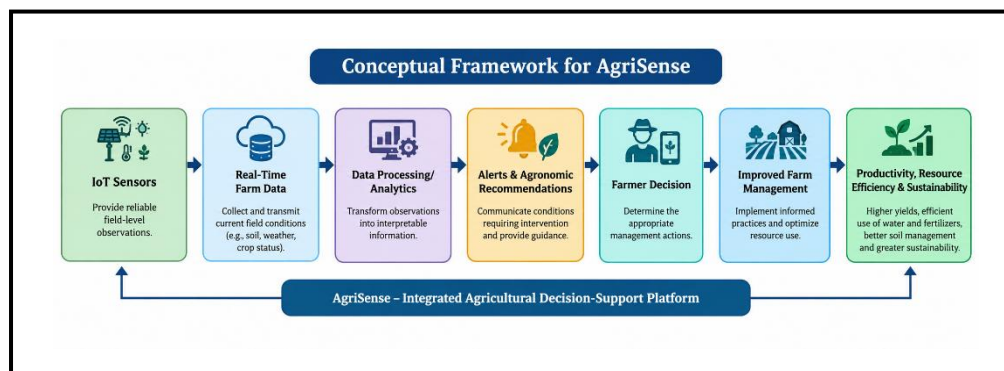


Figure 1: Conceptual Framework of AgriSense

3 Materials and Methods / AgriSense System Design

3.1. Research Design

The AgriSense research adopts a mixed-method research design incorporating descriptive, experimental and analytical components. The descriptive component examines agricultural conditions, farmer practices, and technology adoption challenges; the experimental component is intended to compare conventional farming with IoT-supported precision agriculture; while the analytical component uses sensor and farm data to support evidence-based agricultural decision-making. This design is consistent with the original project methodology, which proposes IoT sensing, farmer surveys and interviews, field observations, satellite and weather data integration, and quantitative, qualitative, and predictive analysis. For the present manuscript, the implemented AgriSense web platform is treated as the technological demonstration component of the study. The platform provides field-level monitoring, sensor status, alerts, recommendations, and reporting functions. The webpage identifies the system as a “Live simulation”; consequently, values displayed in the interface are interpreted as demonstration/simulation outputs unless corresponding raw field records are independently supplied by the research team. Figure 2 presents the research design.

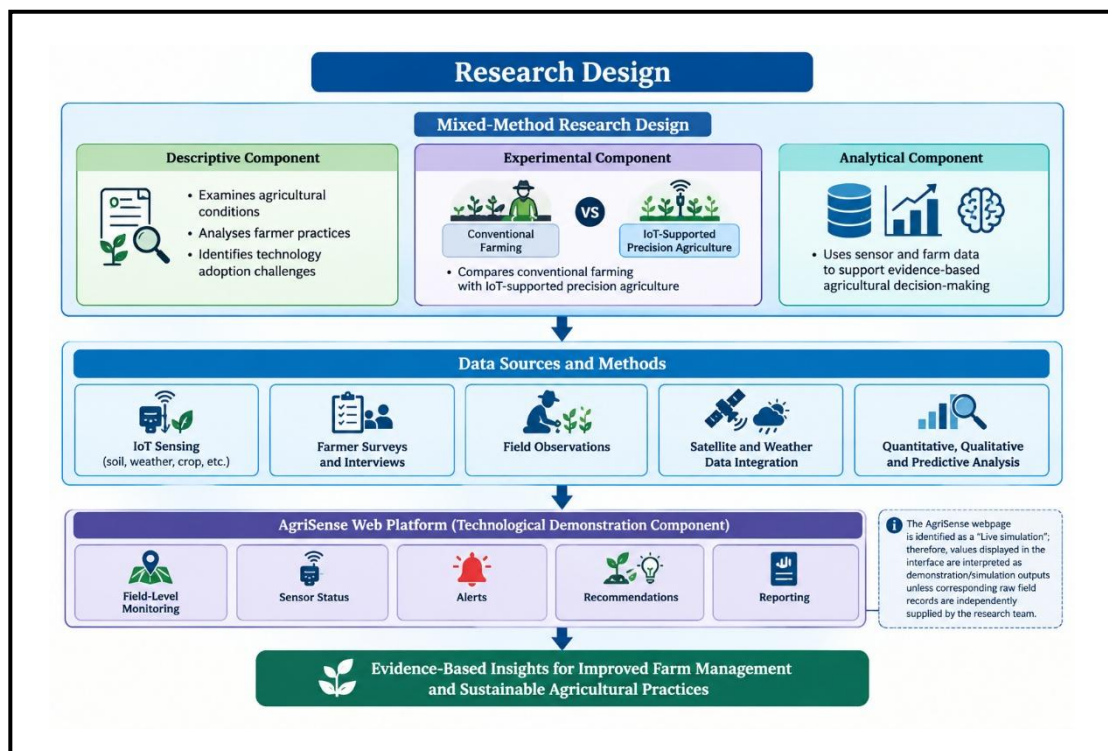


Figure 2: Research Design

3.2. Study Locations and Agricultural Fields

The AgriSense demonstration interface identifies three agricultural locations: Asaba Demonstration Farm, Jos Highland Farm, and Sokoto Smart Farm. These locations provide geographically differentiated examples of the intended Nigerian agricultural application of the platform.

The crops explicitly identified in the supplied interface are maize, cassava, rice, vegetables, and onion. The documented field-crop associations are presented in Table 1.

Table 1: Agricultural locations and crops represented in the AgriSense interface

Farm/location	Field	Crop identified
Asaba Demonstration Farm	Field A	Maize
Asaba Demonstration Farm	Field B	Cassava
Asaba Demonstration Farm	Field C	Rice
Asaba Demonstration Farm	Field D	Vegetables
Jos Highland Farm	Field B	Rice
Jos Highland Farm	Field C	Vegetables
Sokoto Smart Farm	Field C	Onion

Only crop-field combinations explicitly visible in the supplied interface are reported. No crop is assigned to fields for which the webpage extract does not provide sufficient information.

3.3. AgriSense IoT Architecture

AgriSense is organized around a field-sensing and decision-support architecture comprising four functional layers.

Sensing layer: The platform incorporates soil-moisture, N-P-K nutrient, soil-pH, and temperature/humidity sensing. These sensors provide the principal environmental and soil variables displayed by the application.

Data and communication layer: Sensor records are associated with unique identifiers, field locations, sensor status, last readings, and alert conditions. The interface provides continuous access to sensor information and identifies operational states such as Active, Inactive, and Fault.

Analytics and decision-support layer: The platform evaluates incoming measurements against configured agronomic thresholds and converts abnormal conditions into alerts and management recommendations. The supplied interface demonstrates rule-based detection of low soil moisture, low nitrogen, low soil pH, and high temperature.

Application layer: Processed information is presented through the Overview Dashboard, Farms & Fields, Sensors, Alerts, Recommendations, and Reports modules. These modules provide a farmer- and administrator-facing mechanism for monitoring farm conditions and responding to identified problems. The AgriSense IoT architecture is presented in Figure 3.

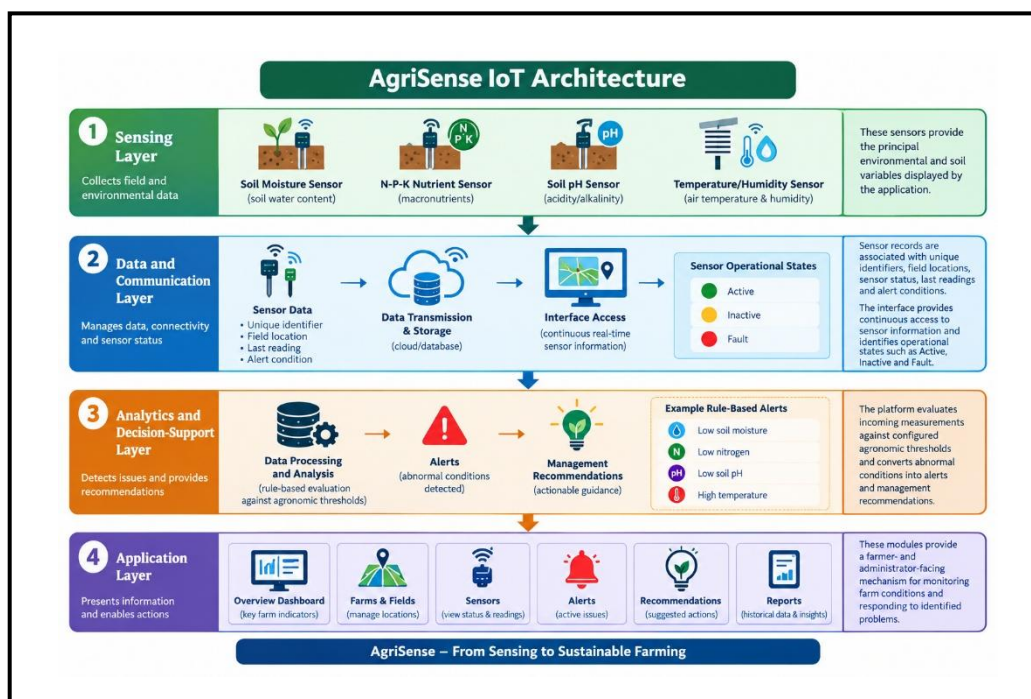


Figure 3: AgriSense IoT Architecture



3.4. Sensor Variables and Monitoring Parameters

The principal parameters represented in the AgriSense interface are as presented in Table 2.

Table 2: Sensor Variables and Monitoring Parameters

Sensor category	Parameters represented	Example displayed value
Soil moisture	Soil moisture (%)	29.2 at Field A–Maize
N-P-K nutrients	Nitrogen, phosphorus and potassium	36.2, 24.0 and 53.3, respectively, at Field A–Maize
Temperature & humidity	Temperature (°C), relative humidity (%)	25.2°C and 70.5% at Field A–Maize
Soil pH	Soil acidity/alkalinity	3.8 at Field B–Cassava

The interface also shows different sensor operational states. For example, AGS-0001 is displayed as an active soil-moisture sensor for Field A–Maize, whereas AGS-0009 is displayed as a temperature/humidity sensor for Field D–Vegetables with a **Fault** status. The interface also records intermittent connectivity faults for individual sensors. See Figure 7.

3.5. Data Collection and System Monitoring

The proposed research methodology includes data collection through IoT sensors, farmer surveys and interviews, field observations, and satellite/weather data integration. Within the AgriSense demonstration platform, sensor observations are associated with specific fields and locations and are displayed through the Sensors module. The platform records the sensor type, field/farm, operational status, last reading, last-seen information, and associated alerts. See Figure 5.

3.6. Alert and Recommendation Mechanism

AgriSense implements threshold-based monitoring that translates sensor conditions into actionable agricultural alerts. See Figure 8. The supplied interface demonstrates four principal conditions as shown in Table 3.

Table 3: AgriSense Parameters for Actionable Alerts

Parameter	Demonstrated threshold	System response
Soil moisture	Below 20%	Irrigation recommended
Nitrogen	Below 15 ppm	Fertilizer top-up advised
Soil pH	Below 5.5	Acidity outside optimal band
Temperature	Above 36°C	Heat-stress risk warning

For example, the interface reports soil moisture of 15.1% and 15.3% at Field A–Maize and associates these conditions with irrigation recommendations. It also reports nitrogen values of 11.5, 13.1, 12.4, 11.9, and 14.8 ppm at Field C–Rice, generating fertilizer top-up warnings. Soil-pH readings of 5.3 and 5.4 at Field D–Vegetables generate acidity alerts, while a temperature reading of 36.4°C at Field A–Maize generates a heat-stress warning. These observations demonstrate the operation of the platform's alert logic but do not constitute statistical evidence of agronomic effectiveness.

3.7. Data Management and Ethical Considerations

The project methodology specifies informed consent, secure and anonymized data storage, protection of farmer information, and consideration of environmental impacts. For the operational platform, sensor identifiers and field identifiers are used to associate measurements with agricultural locations.

4 AgriSense Web Application Interface

The AgriSense web application provides the user-facing interface through which the IoT precision-agriculture platform presents farm information, sensor observations, alerts, recommendations, and reports. The interface integrates these functions into a unified environment intended to support agricultural monitoring and decision-making.

4.1. AgriSense Overview Dashboard

Figure 5 presents the AgriSense overview dashboard. The dashboard provides a consolidated view of the agricultural monitoring environment and serves as the principal entry point to the application. It provides access to the major functional modules, including Overview, Farms & Fields, Sensors, Alerts, Recommendations, and Reports.

The dashboard demonstrates the integration of the principal components of the platform within a single web-based environment. This integration is important because precision agriculture requires the transformation of distributed sensor observations into information that can be readily interpreted by farmers, agricultural officers, and other authorised users. Figure 5 presents the AgriSense dashboard.

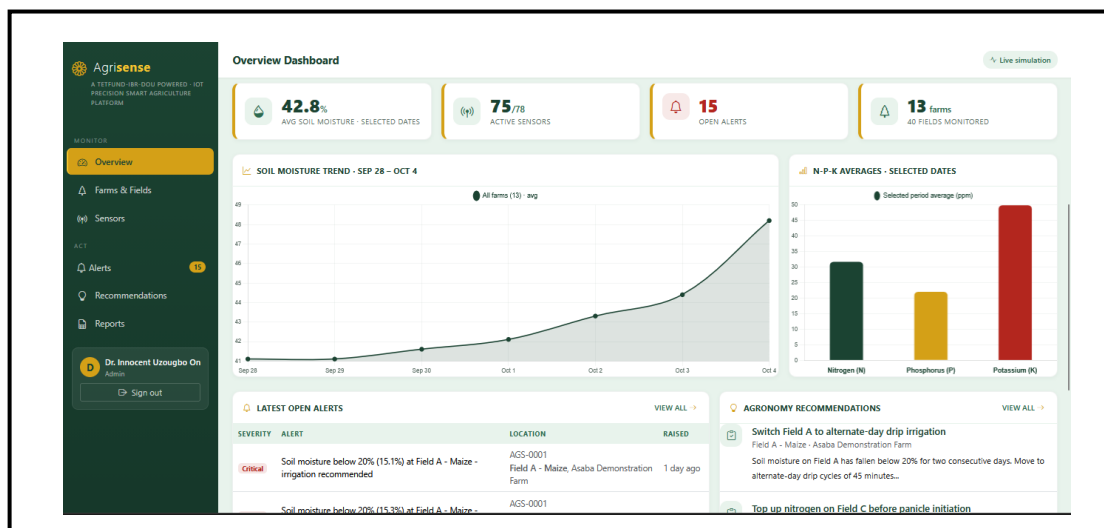


Figure 4: AgriSense overview dashboard showing the integrated agricultural monitoring and decision-support interface

4.2. Farms and Fields Interface

The Farms & Fields interface provides the spatial and agricultural context for the sensor information displayed by the platform. The demonstration includes Asaba Demonstration Farm, Jos Highland Farm and Sokoto Smart Farm, with different fields associated with crops such as maize, cassava, rice, vegetables and onion.

The association of sensor information with specific farms, fields and crops is an important feature of the platform because agricultural decisions are location- and crop-dependent. A moisture condition requiring irrigation in a maize field, for example, may require a different management response from a nutrient condition detected in a rice field. Figure 6 presents the AgriSense farms and fields interface showing farm, field, and crop associations.

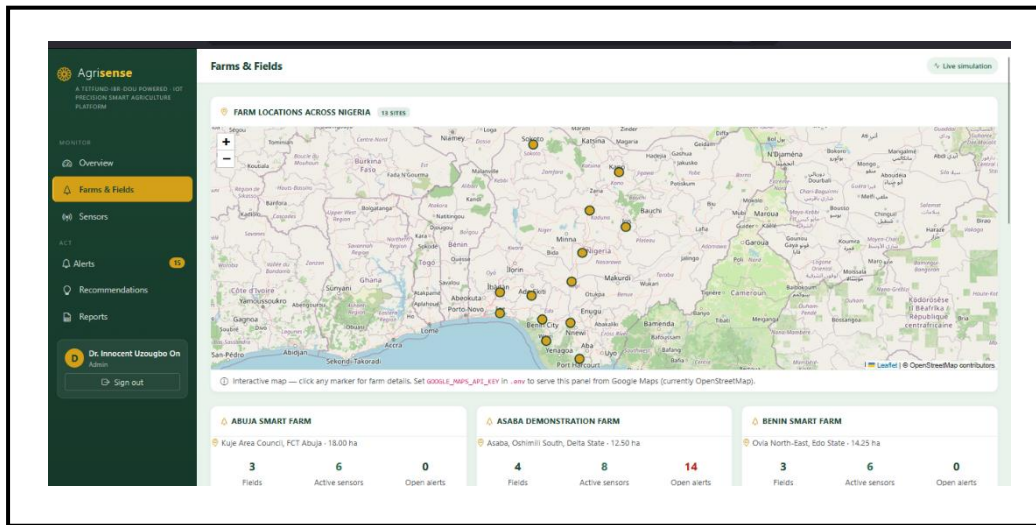


Figure 5: AgriSense Farms & Fields interface showing farm, field, and crop associations

4.3. Sensor Monitoring Interface

Figure 7 presents the Sensors interface. The displayed sensor categories include soil moisture, N-P-K nutrients, temperature and humidity, and soil pH. Individual sensor identifiers are associated with particular fields and locations, allowing sensor observations to be interpreted within their agricultural context. The interface also displays sensor operational states, including Active, Inactive, and Fault. This functionality is significant because an IoT agricultural monitoring platform must account not only for agricultural measurements but also for the operational condition of the devices producing those measurements. Examples displayed by the application include AGS-0001 for soil moisture at Field A–Maize, Asaba Demonstration Farm; AGS-0002 for N-P-K at the same field; and AGS-0003 for temperature and humidity. Other sensors are associated with cassava, rice, and vegetable fields. Figure 7 presents the Sensor monitoring interface for AgriSense.

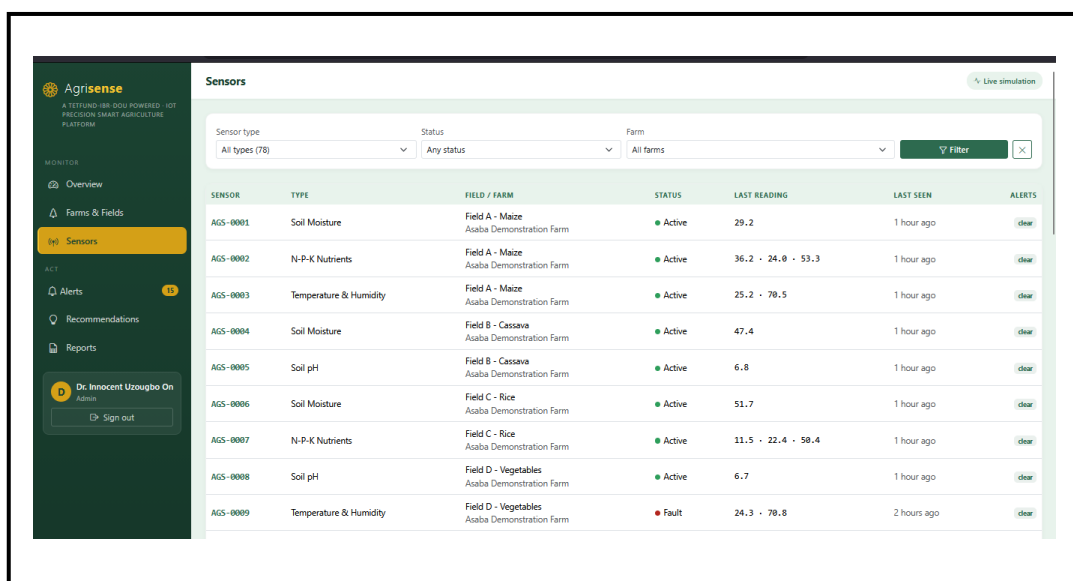


Figure 6: AgriSense Sensors interface showing sensor identifiers, agricultural variables, field associations and operational status

4.4. Alerts Interface

The Alerts interface provides an important decision-support function by converting selected sensor conditions into understandable warnings and recommendations. The demonstration includes alerts for low soil moisture, low nitrogen, low soil pH, high temperature, and sensor connectivity problems. For example, in Figure 8, the application displays low soil-moisture conditions for Field A–Maize and associates these conditions with irrigation recommendations. Similarly, low nitrogen readings for Field C–Rice generate fertilizer top-up recommendations, while low soil-pH conditions for Field D–Vegetables generate acidity warnings. The interface also categorises events according to severity, thereby helping users distinguish critical conditions from warnings and informational system events. See Figure 8.

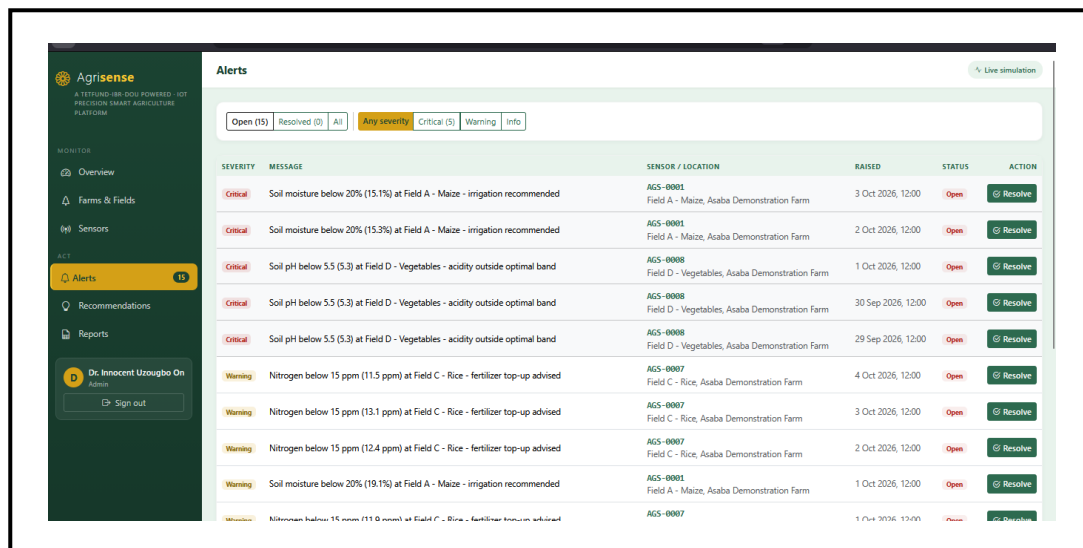


Figure 7: AgriSense Alerts interface showing agricultural threshold violations, severity levels and recommended responses

4.5. Recommendations Interface

The Recommendations module represents the decision-support component of the AgriSense application. Rather than merely presenting raw sensor values, the platform associates selected conditions with suggested management actions. The demonstrated recommendations include irrigation for low soil moisture, fertilizer top-up for low nitrogen, and maintenance attention for sensor connectivity problems. This functionality illustrates the transformation of sensor data into actionable agricultural information. See Figure 9.

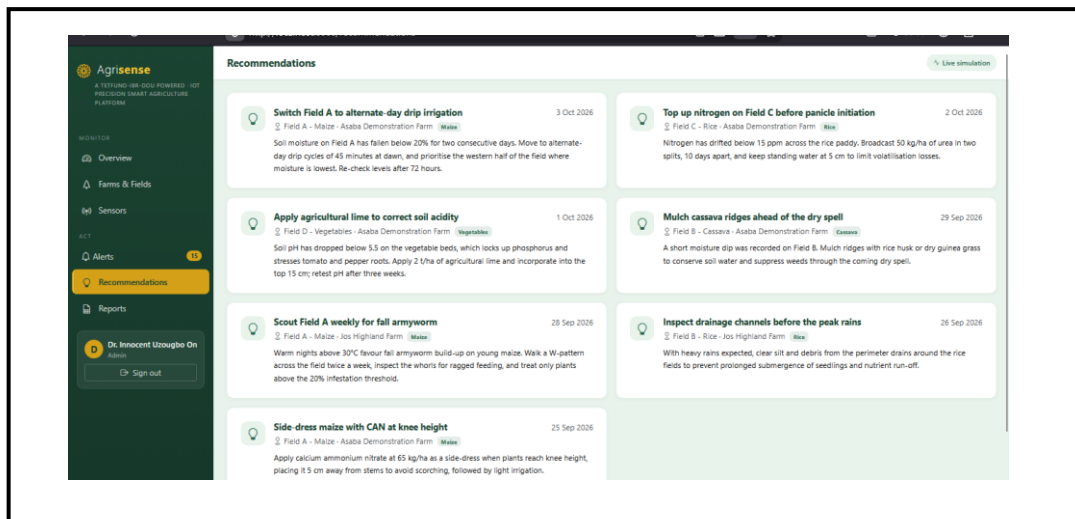


Figure 8: AgriSense Recommendations interface showing management actions generated from monitored agricultural conditions

4.6. Reports Interface

The Reports module provides a mechanism for presenting and reviewing information generated by the platform. In an operational deployment, such reporting functionality can support monitoring, record-keeping, management review, and communication between farmers, extension personnel, researchers, and agricultural administrators. The report interface is therefore an important component of the overall decision-support architecture because it can provide a structured representation of information generated through the monitoring process. See Figure 10.

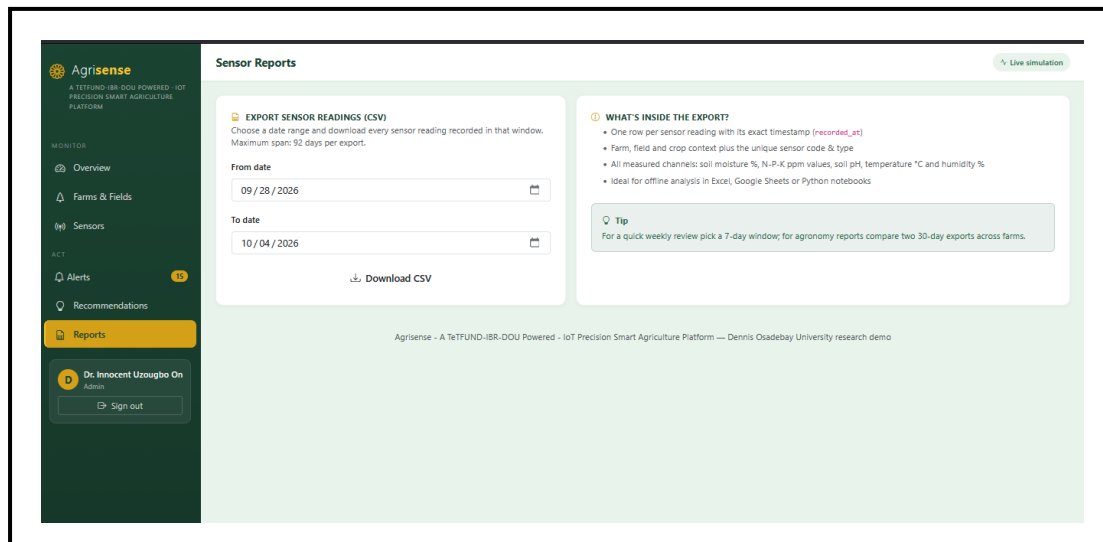


Figure 9: AgriSense Reports interface for reviewing information generated by the agricultural monitoring platform

4.7. Integrated Application Workflow

Taken together, the screenshots demonstrate that AgriSense integrates sensing, data presentation, threshold evaluation, alert generation, and decision support within one web application. The demonstrated workflow can be represented as:

Sensor Data → Field Association → Data Monitoring → Threshold Evaluation → Alert Generation → Recommendation → Management Action

This workflow corresponds to the conceptual architecture presented earlier in the study and demonstrates how the platform is intended to support data-driven agricultural management. It is important, however, to distinguish between interface functionality and empirical agricultural performance. The screenshots establish that the corresponding application modules and decision-support functions are represented in the demonstrated system. They do not, by themselves, establish improvements in crop yield, water-use efficiency, fertilizer efficiency, soil health, farmer income, or other agricultural outcomes.

Consequently, the screenshots serve primarily as implementation evidence supporting the technical description and demonstrated functionality of AgriSense. Quantitative claims concerning agricultural performance should be based on independently collected and validated field data.

4.8. Summary of Interface Evidence

The application screenshots collectively demonstrate the following major capabilities of AgriSense:



- i. Web-based presentation of the precision-agriculture platform.
- ii. Organisation of agricultural information by farm, field, and crop.
- iii. Monitoring of soil moisture, N-P-K nutrients, temperature/humidity, and soil pH.
- iv. Identification and monitoring of individual sensor records.
- v. Display of sensor operational states.
- vi. Automated presentation of threshold-based alerts.
- vii. Generation of field-specific agricultural recommendations.
- viii. Presentation of agricultural monitoring information through reports.
- ix. Integration of sensing and decision-support functions within a single interface.

The screenshots therefore provide visual corroboration of the platform functionality described in Sections 3 and 4. Because the application is explicitly identified as a live simulation, the figures should be interpreted as documentation of the demonstrated AgriSense system rather than as photographic evidence of validated field experimentation.

5 Results and Discussion

5.1. Overview of AgriSense Demonstration Results

The AgriSense platform demonstrates an integrated IoT-based agricultural monitoring and decision-support environment. The interface provides access to farm and field information, sensor readings, sensor status, alerts, recommendations, and reports. The demonstration environment represents agricultural fields at Asaba Demonstration Farm, Jos Highland Farm, and Sokoto Smart Farm. The crops explicitly represented include maize, cassava, rice, vegetables, and onion. These examples demonstrate the applicability of the platform to different crop and environmental contexts.

5.2. Sensor Monitoring Results

The Sensors module demonstrates the capacity of AgriSense to associate individual sensors with particular fields and agricultural locations. The displayed sensor categories include soil moisture, N-P-K nutrients, temperature/humidity, and soil pH.

Examples from the interface include:

- i. AGS-0001: soil-moisture sensor associated with Field A–Maize, Asaba Demonstration Farm.
- ii. AGS-0002: N-P-K nutrient sensor associated with Field A–Maize.
- iii. AGS-0003: temperature/humidity sensor associated with Field A–Maize.
- iv. AGS-0004: soil-moisture sensor associated with Field B–Cassava.
- v. AGS-0005: soil-pH sensor associated with Field B–Cassava.
- vi. AGS-0006: soil-moisture sensor associated with Field C–Rice.
- vii. AGS-0007: N-P-K sensor associated with Field C–Rice.
- viii. AGS-0008: soil-pH sensor associated with Field D–Vegetables.
- ix. AGS-0009: temperature/humidity sensor associated with Field D–Vegetables.

The displayed values illustrate the multidimensional nature of the monitoring system. For example, Field A–Maize is shown with soil moisture of 29.2, N-P-K readings of 36.2, 24.0, and 53.3, and temperature/humidity readings of 25.2°C and 70.5%, respectively.

The platform also demonstrates operational monitoring. AGS-0009 is shown with a Fault status, while other sensors are identified as Active or Inactive. This indicates that the system is designed not only to capture agronomic variables but also to monitor sensor availability and connectivity.

5.3. Automated Alert Results

The Alerts module demonstrates automated detection of predefined threshold violations. The system assigns severity levels and associates each event with the relevant sensor and agricultural field.

Table 4: Examples of alerts demonstrated by the AgriSense platform

Condition	Example value	Field/crop	System response
Low soil moisture	15.1%	Field A–Maize	Irrigation recommended
Low soil moisture	15.3%	Field A–Maize	Irrigation recommended
Low nitrogen	11.5 ppm	Field C–Rice	Fertilizer top-up advised
Low nitrogen	13.1 ppm	Field C–Rice	Fertilizer top-up advised
Low soil pH	5.3	Field D–Vegetables	Acidity warning
Low soil pH	5.4	Field D–Vegetables	Acidity warning
High temperature	36.4°C	Field A–Maize	Heat-stress warning
Connectivity fault	—	Field D–Vegetables	Maintenance check advised
Connectivity fault	—	Field C–Onion, Sokoto Smart Farm	Maintenance check advised

The interface therefore demonstrates a direct relationship between sensor observations and management actions. Low moisture generates an irrigation recommendation, low nitrogen generates a fertilizer recommendation, low pH generates an acidity warning, and high temperature generates a heat-stress warning.

The repeated alerts visible in the interface also demonstrate that the system can maintain an alert history rather than displaying only the most recent sensor condition.

5.4. Field-Specific Decision Support

The demonstrated alert logic provides field-specific decision support rather than presenting identical recommendations to all farms.

For **Field A–Maize**, low soil-moisture events generate irrigation recommendations, while the temperature reading of 36.4°C generates a heat-stress warning. This illustrates the potential for combining water-status and thermal information in crop management.

For **Field C–Rice**, low nitrogen readings trigger fertilizer top-up recommendations. The repeated nitrogen alerts indicate the system's ability to identify a continuing nutrient-related condition.

For **Field D–Vegetables**, low soil-pH readings trigger acidity warnings. The system therefore provides an indication that corrective soil-management measures may be required.

The interface also demonstrates sensor-maintenance decision support. Connectivity faults associated with AGS-0009 and AGS-0036 generate maintenance recommendations, indicating that system reliability is treated as part of the monitoring process.

5.5. Demonstrated Contribution to Precision Farm Management

The principal demonstrated contribution of AgriSense is the integration of sensing, monitoring, and decision support within a single farmer-facing platform. Instead of requiring farmers or administrators to interpret isolated sensor readings independently, the platform converts selected abnormal readings into understandable alerts and recommended actions.



The workflow demonstrated by the platform can therefore be represented as:

Sensor Measurement → Threshold Evaluation → Alert Generation → Agronomic Recommendation → Farmer/Administrator Action

This is consistent with the broader project objective of using real-time agricultural information to support water management, nutrient management, crop health and sustainable agricultural practices. The project's expected outputs include improved resource efficiency, soil-health monitoring, farmer empowerment, and scalable IoT-supported agriculture.

5.6. System Reliability and Operational Issues

The demonstration data also reveal that IoT agricultural systems must account for sensor and communication reliability. The presence of sensors marked Fault or associated with intermittent connectivity demonstrates a practical challenge in deploying connected agricultural technologies. This observation is important because precision agriculture depends on the availability and quality of sensor data. An incorrect, delayed, or missing reading could result in an inappropriate management recommendation. Consequently, future field implementation should incorporate sensor calibration, data-quality checks, missing-data handling, and maintenance procedures.

5.7. Discussion

The AgriSense demonstration supports the feasibility of integrating multiple agricultural sensing variables into a unified IoT precision-agriculture platform. The combination of soil moisture, N-P-K, pH, and temperature/humidity measurements provides complementary information for irrigation, nutrient, and soil-condition monitoring.

The approach is consistent with recent precision-agriculture research, which identifies IoT sensors as important tools for real-time monitoring and data-driven farm management. Recent literature also emphasizes the importance of integrating sensor data with analytics and decision-support mechanisms rather than merely collecting measurements. The demonstrated threshold-based alert mechanism is particularly relevant for an agricultural context in which farmers may benefit from simple, interpretable recommendations.

5.8. Implications for Agricultural Practice

The demonstrated system has potential practical value for precision agricultural management because it provides location-specific information rather than relying solely on generalized farming recommendations. A farmer managing maize at Asaba, for example, can receive a moisture-related irrigation alert, while a rice field can receive a nitrogen-related warning. Such field-specific monitoring can potentially support more timely intervention and reduce unnecessary application of agricultural inputs. The results therefore support AgriSense as a decision-support platform.

6. Conclusion, Recommendations and Implications

6.1. Summary of Findings

The study developed and demonstrated AgriSense, an IoT-enabled precision-agriculture platform designed to support real-time monitoring and decision-making in crop production. The platform integrates soil-moisture, N-P-K nutrient, soil-pH, and temperature/humidity sensing with a farmer-facing interface comprising monitoring, alerts, recommendations, and reporting functions. The demonstration interface represents agricultural fields at Asaba Demonstration Farm, Jos Highland Farm, and Sokoto Smart Farm, explicitly showing maize, cassava, rice, vegetables, and onion. The platform demonstrates field-specific monitoring and automated alerts for low soil moisture, low nitrogen, low soil pH, and high temperature. It also identifies sensor faults and connectivity problems, thereby demonstrating the importance of both agronomic and technical monitoring. The principal finding, supported by the available evidence, is that AgriSense provides an integrated mechanism for converting sensor observations into understandable agricultural alerts and recommended actions. The original research proposal similarly identifies



improved resource efficiency, soil-health monitoring, farmer empowerment, and scalable IoT-supported agriculture as intended project outcomes.

6.2. Conclusion

AgriSense demonstrates the feasibility of integrating IoT-based agricultural sensing, real-time monitoring, threshold-based alerts, and agronomic decision support within a single platform. Its representation of maize, cassava, rice, vegetables, and onion across Asaba, Jos, and Sokoto provides a practical demonstration of how precision-agriculture technologies can be configured for different crop and farm contexts. The system's ability to identify low soil moisture, nitrogen deficiency, acidic soil conditions, and high temperature illustrates its potential to support timely farm-management decisions. Its sensor-status and connectivity monitoring further demonstrate that operational reliability is an important component of an agricultural IoT system. Thus, AgriSense provides a promising technological foundation for data-driven and potentially more sustainable agricultural management in Nigeria, but its agronomic and socioeconomic effectiveness requires further empirical validation.

6.3. Recommendations

6.3.1. Farmers

Farmers participating in future AgriSense field trials should use sensor-generated alerts as decision-support information alongside field observation and established agronomic practices. Particular attention should be given to irrigation alerts, nutrient warnings, soil-pH conditions, and temperature-related crop stress. Farmers should also report system faults and unusual readings to facilitate sensor maintenance and data-quality control.

6.3.2. Extension Agencies

Agricultural extension agencies should support farmer training in interpreting sensor readings and responding appropriately to alerts. Training should emphasize that technology-generated recommendations are decision-support tools and should be considered together with crop stage, weather conditions, field observations and professional agronomic advice.

6.3.3. Tertiary Institutions and Research Organisations

Universities and research institutions should conduct longer-term field experiments using AgriSense or comparable platforms. Future studies should document the exact study locations, participating farms, crop areas, sample sizes, sensor specifications, calibration procedures, measurement intervals, study duration, experimental allocation, and analytical methods to ensure full reproducibility.

The original project specifically envisages knowledge sharing through training and workshops and scalable IoT solutions for wider agricultural application.

6.3.4. Government and Policymakers

Government agricultural programmes should consider precision-agriculture technologies as part of broader digital-agriculture and food-security strategies. Support should include research funding, agricultural extension, digital infrastructure, farmer training and appropriate standards for agricultural IoT systems.

Policy interventions should also address the barriers identified in the research proposal, including cost, technical capacity, cybersecurity and the need for supportive legislation.

6.3.5. Technology Developers

Future versions of AgriSense should incorporate robust sensor calibration, automated data-quality checks, missing-data detection, sensor-health monitoring and clear audit trails. The platform should also document the algorithms used for predictive functions and provide appropriate validation metrics where AI models are introduced.

User-interface design should remain simple enough for farmers and extension personnel while retaining sufficient technical detail for researchers and administrators.



6.3.6. Telecommunications and Infrastructure Providers

Reliable connectivity is essential for real-time agricultural monitoring. Infrastructure providers should support affordable and dependable connectivity in rural farming environments. Alternative communication mechanisms and local data buffering should also be considered where network availability is intermittent.

The occurrence of connectivity-related sensor alerts in the AgriSense demonstration reinforces the importance of this issue.

6.4. Policy and Development Implications

The AgriSense project has several potential implications for agricultural development in Nigeria.

First, digital precision agriculture can be incorporated into agricultural development programmes as a mechanism for improving access to timely farm information. Rather than relying exclusively on periodic extension visits, connected sensors can provide continuous information about selected field conditions.

Second, the platform provides a possible foundation for resource-efficient agriculture. Monitoring soil moisture and nutrients can support more targeted decisions about irrigation and fertilizer application. However, the actual magnitude of water or fertilizer savings must be established through field experiments rather than assumed from the platform demonstration.

Third, the project supports climate-resilient agricultural management by providing mechanisms for detecting conditions associated with water stress and high temperature. This is potentially important in the context of changing agricultural conditions, but its effectiveness for climate adaptation requires longitudinal validation.

Fourth, the project highlights the need for agricultural data governance and cybersecurity. As agricultural systems increasingly depend on connected sensors and digital platforms, data protection, authentication, access control and system integrity should form part of agricultural technology policy.

Finally, the project can contribute to capacity building and digital inclusion by combining technology development with farmer training, extension support and institutional research. These elements are consistent with the project's stated objectives concerning farmer empowerment, policy development, and scalable IoT solutions.

6.5. Limitations and Future Research

The principal limitation of the present study is that the available AgriSense interface represents a live simulation/demo environment rather than a sufficiently documented longitudinal field dataset. Consequently, the study cannot presently establish statistical effects on crop yield, water consumption, fertilizer use, soil health, or farmer income.

Additional limitations include the absence, in the available documentation, of detailed sensor specifications, calibration procedures, exact sampling intervals, participating-farmer sample size, field areas, experimental allocation, statistical-test specifications, and identified AI algorithms.

Future research should therefore:

1. Conduct longitudinal field trials using validated sensor measurements.
2. Document the exact number and characteristics of participating farms and farmers.
3. Record crop area, crop variety, planting dates, and relevant agronomic practices.
4. Document sensor manufacturer, model, accuracy, calibration, and deployment configuration.
5. Establish and report the precise measurement interval and study duration.
6. Compare conventional and AgriSense-supported management using an explicitly defined experimental design.
7. Measure crop yield, irrigation volume, fertilizer application, soil properties, and relevant economic outcomes.
8. Specify and validate the statistical tests used for hypothesis testing.
9. Clearly identify any AI or machine-learning algorithms, training data, validation procedures, and performance metrics.
10. Evaluate the platform across additional Nigerian agroecological environments and cropping systems.
11. Assess long-term farmer adoption, usability, affordability, and maintenance requirements.
12. Investigate cybersecurity, data governance, and interoperability as the platform scales.



These steps would allow subsequent research to move from demonstrating technical feasibility to establishing empirical agricultural effectiveness.

6.6. Contribution to Knowledge

The principal contribution of the study is the development and demonstration of an integrated IoT precision-agriculture framework that links:

IoT Sensors → Real-Time Farm Data → Threshold-Based Analytics → Alerts → Agronomic Recommendations → Farmer Decision Support → Farm Management

Unlike a sensor-only monitoring system, AgriSense integrates sensing with an application interface through which agricultural conditions are presented as field-specific alerts and recommendations. The platform also incorporates sensor-status monitoring and reporting, extending the system beyond basic data acquisition.

The study further contributes a Nigeria-oriented demonstration involving maize, cassava, rice, vegetables, and onion across Asaba Demonstration Farm, Jos Highland Farm, and Sokoto Smart Farm. This provides a practical foundation for subsequent empirical research into the use of IoT technologies for Nigerian agricultural production.

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