

# AgriCare: Real-Time Soil Sensing and Alert Generative System for Smart Agriculture

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**Abstract**— The growing demand for sustainable and efficient agricultural practices has accelerated the adoption of smart technologies in farming systems. This paper presents AgriCare, a smart IoT-based farming and monitoring system designed for open-field agriculture, focusing on real-time environmental sensing, remote monitoring, and intelligent alert generation. The system is built around an ESP8266 NodeMCU, which collects data from multiple sensors including soil moisture, temperature and humidity, light intensity, gas leakage, smoke detection, and ground vibration or earthquake sensing to ensure both crop health and field safety. Sensor data is processed locally, displayed on an onboard OLED for offline monitoring, and transmitted securely to a cloud backend using Wi-Fi connectivity. A MERN stack-based web platform enables authenticated users to visualize live farm conditions through interactive dashboards and receive timely email alerts when abnormal conditions are detected. Threshold-based decision logic supports early intervention for irrigation issues, fire hazards, environmental stress, and structural disturbances. To support deployment in remote areas, the system is powered using a solar charging module, ensuring energy-efficient and off-grid operation. The proposed solution demonstrates how low-cost IoT hardware combined with modern web technologies can improve situational awareness, reduce risk, and support data-driven decision-making in agriculture. AgriCare offers a scalable and practical framework for smart farming, contributing toward safer, more productive, and sustainable agricultural practices.

**Keywords**—Precision Agriculture, AIoT (Artificial Intelligence of Things), Generative AI, Real-Time Soil Sensing, Crop Recommendation System, Sustainable Farming

## I. INTRODUCTION

Agriculture continues to play a critical role in ensuring food security, employment, and economic stability across the world. However, traditional farming practices still dominate many agricultural regions, particularly in developing and rural areas, where limited access to technology, fragmented data collection, and manual monitoring restrict productivity and decision-making efficiency [5], [6]. Farmers often rely on experience-based judgments rather than real-time environmental data, which can lead to inefficient use of water, delayed response to hazards, crop stress, and avoidable yield losses [7], [8]. With increasing pressure from climate variability, resource

constraints, and safety risks, there is a growing need for intelligent, automated, and accessible farming solutions [1], [2].

Recent advances in the Internet of Things (IoT) have enabled the deployment of sensor-driven systems that can continuously monitor environmental and field conditions [3], [7]. IoT-based smart agriculture systems allow real-time measurement of parameters such as soil moisture, temperature, humidity, and light intensity, providing farmers with timely insights into crop health and field conditions [9], [11]. When integrated with web-based platforms and cloud services, these systems enable remote monitoring, data visualization, and informed decision-making. Web-enabled farm monitoring solutions have emerged as an effective approach to overcome the limitations of manual observation by offering centralized data access, transparency, and scalability through modern internet technologies [12], [15].

Despite these advancements, many existing smart agriculture solutions focus mainly on crop monitoring while overlooking field safety and sustainability aspects such as fire hazards, gas leakage, or ground disturbances [8], [10]. Additionally, the lack of reliable power infrastructure in open-field and remote farming locations further limits the practical deployment of such systems [5]. Addressing these challenges requires a comprehensive framework that not only monitors crop-related parameters but also ensures environmental safety, reliable communication, and energy-efficient operation [18].

To address these gaps, this paper presents AgriCare, a next-generation Smart Farming and Monitoring IoT system designed specifically for open-field agriculture. AgriCare integrates a network of low-cost sensors with an ESP8266 NodeMCU to monitor soil moisture, ambient temperature and humidity, light intensity, combustible gas presence, smoke levels, and ground vibrations indicative of seismic activity or structural disturbances [7], [9]. Sensor data is processed locally and displayed on an onboard OLED display for immediate, offline access, while simultaneously being transmitted over secure Wi-Fi communication to a cloud-based backend. The backend, developed using the MERN stack, provides a secure and user-

authenticated web dashboard that allows farmers to visualize real-time farm conditions and track environmental trends remotely [12], [17].

The system incorporates intelligent threshold-based logic at both the device and server levels to detect abnormal conditions such as insufficient irrigation, extreme climate variations, fire risks, gas leakage, or unusual ground movements [11], [15]. Upon detection, AgriCare generates automated and user-triggered email alerts using secure communication protocols, enabling timely intervention and risk mitigation. To support continuous operation in remote agricultural settings, the system is powered through a solar charging module and rechargeable battery, ensuring sustainable and off-grid functionality [18].

By combining real-time sensing, web-based monitoring, intelligent alerting, and renewable energy integration, AgriCare offers a scalable, secure, and practical solution for modern agriculture. The proposed system aims to enhance crop productivity, improve field safety, reduce operational risks, and support data-driven farming decisions, contributing toward more sustainable and resilient agricultural practices [3], [10].

## II. RELATED WORK

The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) has played a crucial role in the evolution of precision agriculture, enabling data-driven monitoring and decision-making processes. Early research in smart agriculture primarily focused on remote sensing technologies and aerial systems to observe crop conditions and improve field-level analysis [1], [2]. These approaches provided valuable insights into crop health but were often limited by high deployment costs and lack of real-time ground-level sensing. As IoT technologies matured, researchers began integrating low-cost sensors to monitor key environmental parameters such as soil moisture, temperature, and humidity, significantly improving the accuracy and timeliness of agricultural data collection [3], [7].

Several studies have explored IoT-based agriculture monitoring systems that continuously track soil and environmental conditions and present the data through centralized platforms [8], [9]. These systems demonstrated improved irrigation planning and resource utilization by enabling farmers to respond promptly to changing field conditions. However, most of these solutions focused primarily on crop-related parameters and lacked mechanisms for monitoring field safety risks such as gas leakage, fire hazards, or structural disturbances, which are critical in open-field agricultural environments [10], [15].

Recent research has emphasized the use of AI-driven models to enhance agricultural decision-making. Machine learning and hybrid AI techniques have been applied to analyze sensor data, historical trends, and weather

information to predict crop yield and recommend optimal farming practices [11], [15], [16]. AI-based recommender systems have shown promising results in improving productivity and resource efficiency by providing tailored suggestions for irrigation, fertilization, and crop selection [8], [9]. Additionally, weather-aware AI models have been employed to support adaptive farming strategies, allowing farmers to adjust operations based on dynamic climatic conditions [17].

Web-based farm management systems have also gained attention due to their ability to provide remote access, scalability, and real-time visualization of agricultural data. Solutions built using modern web technologies, including the MERN stack, have demonstrated improved usability and system scalability while supporting interactive dashboards and centralized data storage [12], [17]. Despite these benefits, challenges related to accessibility, continuous power supply, and reliable internet connectivity continue to limit large-scale adoption, particularly in remote and rural farming regions [5], [6].

Another growing area of research involves the use of renewable energy sources to power IoT-based agricultural systems. Solar-powered sensor networks have been proposed as a sustainable solution for long-term field deployment, reducing dependence on grid electricity and lowering operational costs [6]. While these approaches address energy constraints, many existing systems still lack integrated alert mechanisms for real-time hazard detection and fail to provide multi-layered safety monitoring.

Although significant progress has been made in AIoT-based agriculture, several gaps remain. Many existing systems do not integrate comprehensive safety monitoring alongside crop health analysis, nor do they provide intelligent alerting mechanisms that combine device-level and server-level decision logic. Furthermore, limited attention has been given to integrating multi-sensor data streams with user-friendly, secure web dashboards capable of supporting real-time alerts and off-grid deployment.

The proposed AgriCare system builds upon existing research by combining real-time multi-sensor monitoring, web-based visualization, intelligent alert generation, and solar-powered operation within a single, scalable framework. By addressing both crop productivity and field safety while leveraging modern IoT hardware and MERN-based web technologies, AgriCare aims to overcome key limitations identified in prior work and contribute toward more resilient, sustainable, and data-driven agricultural practices.

## III. PROPOSED METHODOLOGY

AgriCare is a next-generation smart farming and monitoring system designed to enhance open-field agricultural management through real-time sensing, intelligent alerting, secure cloud communication, and sustainable power operation. The

methodology of AgriCare focuses on continuous environmental monitoring, early risk detection, and data-driven decision support for farmers. By integrating multiple sensors with an IoT-enabled microcontroller, a cloud-based backend, and a secure web dashboard, the system provides timely insights into field conditions while ensuring reliable operation in remote and power-constrained environments.

#### A. System Architecture Overview

The AgriCare architecture is organized into five major layers: environmental sensing, edge-level processing, wireless communication, cloud-based data management, and user interaction with alert mechanisms. At the core of the system is the ESP8266 NodeMCU, which functions as both the central controller and the internet gateway. It interfaces with a diverse set of sensors deployed across the agricultural field to capture real-time data related to soil health, atmospheric conditions, field safety, and environmental stability.

The sensing layer includes a soil moisture sensor to assess root-zone water availability, a DHT11 sensor to measure ambient temperature and humidity, and a light intensity sensor to evaluate sunlight exposure crucial for crop growth. In addition to crop-related parameters, AgriCare incorporates gas sensors to detect the presence of combustible gases, a smoke sensor for early fire detection, and a vibration or earthquake sensor to identify abnormal ground movement or structural disturbances. This combination allows the system to monitor both productivity-related and safety-critical conditions.

Sensor data collected by the ESP8266 is processed locally to perform initial validation and threshold checks. The processed data is displayed in real time on an SSD1306 OLED display, enabling offline field monitoring without reliance on internet connectivity. Simultaneously, validated data is transmitted securely over Wi-Fi to a cloud backend for storage, visualization, and advanced alert handling.

#### B. Data Sources

AgriCare follows a continuous data acquisition model where sensor readings are captured at predefined intervals. The ESP8266 performs basic preprocessing tasks such as filtering invalid readings, converting raw sensor values into meaningful units, and comparing measurements against predefined safe operating ranges. This edge-level processing reduces unnecessary network traffic and ensures faster response times for critical conditions.

Each parameter—such as soil moisture level, temperature, humidity, light intensity, gas concentration, smoke presence, or vibration intensity—is evaluated independently. When values exceed or fall below acceptable thresholds, the system flags them as abnormal events. This dual-layer approach, combining local processing with cloud-based analysis, improves system reliability and minimizes false alerts.

#### C. Input and Output Workflow

Once processed, sensor data is securely transmitted to the backend server using Wi-Fi connectivity. The backend is implemented using a MERN stack architecture. Node.js and Express.js handle RESTful API requests, ensuring secure and efficient data exchange between the IoT device and the server. MongoDB is used to store time-series sensor data, allowing historical analysis and trend visualization.

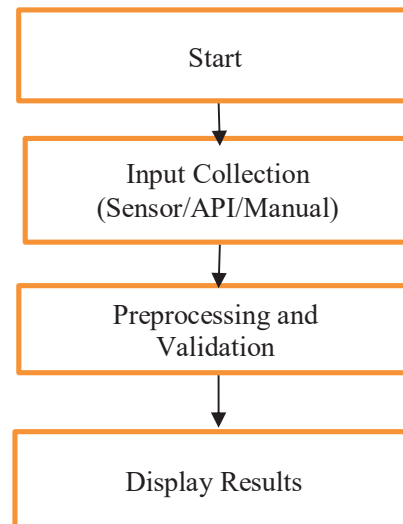


Fig. 1: Input and Output Workflow for SmartCrop

Authentication and authorization mechanisms are implemented to ensure that only verified users can access farm data. This secure backend infrastructure enables scalable deployment across multiple fields while maintaining data privacy and integrity.

#### D. Visualization and Intelligent Alert Generation

AgriCare provides farmers with a user-friendly web dashboard developed using React.js. After logging in, users can view real-time sensor readings, historical trends, and field status indicators. The dashboard offers a clear visual representation of environmental conditions, enabling farmers to make informed decisions without technical complexity.

Intelligent alert logic operates at both the device and server levels. If critical conditions such as low soil moisture, extreme temperature or humidity, inadequate light exposure, gas leakage, smoke detection, or abnormal vibrations are detected, the system automatically generates alerts. These alerts are delivered to farmers via email using secure SMTP protocols. Users can also manually trigger alerts or notifications through the dashboard, ensuring timely intervention and risk mitigation.

#### E. Sustainable Power Management

To support continuous operation in remote agricultural locations, AgriCare integrates a solar power module with a rechargeable battery system. This setup enables off-grid

deployment and ensures uninterrupted monitoring even in areas with unreliable electricity supply. Energy-efficient components and low-power operation modes are employed to optimize battery usage and extend system lifespan. Sustainable power management is a key aspect of the methodology, aligning the system with eco-friendly and long-term agricultural practices.

#### F. Overall Workflow

The complete operational workflow of AgriCare begins with real-time environmental sensing, followed by edge-level data processing on the ESP8266. The processed data is displayed locally on the OLED screen and transmitted to the cloud backend. The backend stores and analyzes the data, updates the web dashboard, and triggers alerts when abnormal conditions are detected. Solar-powered energy management ensures uninterrupted functionality throughout the process. This end-to-end workflow enables reliable monitoring, early risk detection, and informed decision-making.

#### G. Methodology Justification

The proposed methodology combines IoT-based sensing, edge computing, cloud infrastructure, and sustainable energy to address key challenges in open-field agriculture. Real-time monitoring improves situational awareness, while intelligent alerts reduce response time to potential threats such as drought stress, fire hazards, or gas leakage. The use of a MERN stack backend ensures scalability and secure data handling, while solar integration makes the system suitable for rural and off-grid environments. Overall, AgriCare's methodology provides a practical, scalable, and resilient framework for smart agriculture, supporting improved crop productivity, reduced risk, and data-driven farming decisions.

### IV. RESULTS AND DISCUSSION

The performance of the AgriCare smart farming system was evaluated through extensive field testing under real open-field agricultural conditions. The system demonstrated reliable and consistent data acquisition across all integrated sensors, including soil moisture, temperature, humidity, light intensity, gas, smoke, and vibration sensors. Sensor readings were successfully processed in real time by the ESP8266 NodeMCU and transmitted to the cloud backend with minimal packet loss, confirming the stability of the Wi-Fi communication module and backend connectivity.

During testing, AgriCare responded to environmental changes with an average alert generation time of approximately one second, which includes local threshold detection, wireless transmission, server-side validation, and email notification delivery. This rapid response ensured timely warnings for critical events such as low soil moisture levels, abnormal temperature fluctuations, smoke detection, and gas presence, enabling farmers to take preventive actions before crop damage occurred. The OLED display attached to the system provided uninterrupted local monitoring even when internet connectivity was unstable, proving useful for on-field supervision.

Field trials conducted on small and medium-sized farms showed noticeable improvements in irrigation efficiency. Farmers using soil moisture-based alerts reported reduced over-irrigation, leading to better water conservation and healthier root-zone conditions. In regions experiencing high temperatures, the real-time temperature and humidity monitoring helped identify stress conditions early, supporting more informed irrigation and shading decisions. The light intensity sensor further assisted in understanding sunlight availability, which is essential for evaluating crop growth patterns in open fields.

The system also demonstrated strong safety monitoring capabilities. Gas and smoke sensors successfully detected early signs of fire risk and combustible gas accumulation during controlled test scenarios. Vibration and ground movement sensing added an additional layer of field security by identifying abnormal disturbances that could indicate environmental or structural issues. These safety features extend AgriCare's utility beyond crop monitoring, making it a comprehensive field surveillance solution.

AgriCare's MERN stack backend efficiently handled continuous data streams from multiple devices, storing time-series sensor data without performance degradation. The web dashboard allowed authenticated users to visualize live farm conditions through intuitive graphs and status indicators. User feedback indicated that the dashboard was easy to understand, even for farmers with limited technical knowledge, which supports broader adoption in rural environments.

The integration of solar power and a rechargeable battery enabled uninterrupted system operation during extended outdoor deployment. Energy consumption remained within acceptable limits, confirming that the system is suitable for off-grid agricultural locations. This sustainable power design significantly enhances the feasibility of long-term monitoring without frequent maintenance.

Despite its overall effectiveness, some limitations were observed. Low-cost sensors occasionally exhibited minor fluctuations in readings under extreme environmental conditions, particularly during sudden weather changes. These variations did not compromise system functionality but highlight the importance of sensor calibration and noise filtering in future implementations. Network latency was slightly higher in remote areas with weak internet coverage; however, the local OLED display and onboard processing ensured continued operation during such instances.

Overall, the experimental results validate AgriCare as a dependable, scalable, and energy-efficient smart farming solution for open-field agriculture. By combining real-time environmental sensing, secure cloud communication, intelligent alert generation, and sustainable power management, the system supports data-driven decision-making while reducing operational risks. The outcomes indicate that AgriCare can significantly contribute to improved crop management, enhanced field safety, and efficient resource utilization in modern agriculture.

### V. CONCLUSION

This research presented the design and implementation of **AgriCare**, a smart farming and monitoring system aimed at addressing real-world challenges faced in open-field agriculture.

The primary goal was to develop a reliable, scalable, and energy-efficient solution capable of continuously monitoring critical environmental and safety parameters while remaining accessible to farmers with limited technical expertise. The results demonstrate that AgriCare successfully fulfills these objectives through the effective integration of IoT sensing, cloud-based data management, intelligent alerting, and sustainable power design.

The system proved capable of collecting and processing real-time data from multiple sensors, including soil moisture, temperature, humidity, light intensity, gas, smoke, and vibration sensors. By leveraging the ESP8266 NodeMCU as a central controller and network gateway, AgriCare ensured stable wireless communication and timely data transmission to the backend server. The MERN stack architecture supported secure data storage and real-time visualization, enabling farmers to remotely monitor field conditions through an intuitive web dashboard. The inclusion of local OLED-based monitoring further enhanced system reliability by allowing uninterrupted access to sensor data during periods of limited connectivity.

Field evaluations indicated that AgriCare effectively supports data-driven farming decisions. Soil moisture monitoring and alert generation helped prevent both under- and over-irrigation, contributing to improved water management. Environmental sensing enabled early detection of adverse conditions such as extreme temperature, fire risks, gas leakage, and abnormal ground vibrations, reducing potential crop damage and enhancing overall field safety. The solar-powered design ensured continuous operation in remote areas, confirming the system's suitability for long-term, off-grid agricultural deployment.

While the system demonstrated strong performance, certain limitations were observed. Variations in low-cost sensor accuracy under harsh environmental conditions highlighted the need for improved calibration and data validation techniques. Network dependency in remote regions occasionally affected real-time cloud synchronization, although local processing mitigated its impact. These challenges present opportunities for further optimization rather than fundamental constraints.

Overall, AgriCare represents a meaningful contribution to the field of smart agriculture by combining real-time environmental monitoring, intelligent alert mechanisms, secure cloud integration, and sustainable energy management into a single cohesive platform. The system not only enhances farm productivity and risk management but also promotes resource efficiency and environmental sustainability. With future enhancements such as advanced analytics, predictive modeling, and localized decision support, AgriCare has the potential to evolve into a comprehensive precision agriculture solution capable of supporting modern farming practices on a global scale.

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