

A Review: AI-Driven Smart Agriculture: An Integrated Approach for Soil Analysis, Irrigation and Crop-Fertilizer Recommendations.

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ABSTRACT: Agriculture is one of the most important sectors for human survival and economic development. However, farmers today face many challenges such as climate change, water scarcity, poor soil fertility, and inefficient use of fertilizers. Traditional farming methods are often unable to provide accurate and timely decisions related to irrigation, soil monitoring, and crop selection. Artificial Intelligence (AI), Internet of Things (IoT), and Machine Learning (ML) technologies have introduced new opportunities for smart farming systems. This review paper presents a study of AI-driven smart agriculture systems that integrate soil analysis, irrigation management, and crop-fertilizer recommendation techniques. Various machine learning and deep learning models such as Random Forest, Support Vector Machine (SVM), TabNet, Transformer-based models, and Explainable AI (XAI) are discussed. The paper also reviews the use of IoT sensors and weather forecasting systems in precision agriculture. The study identifies the advantages, limitations, and research gaps in existing agricultural technologies. The review concludes that AI-based smart agriculture can improve crop productivity, optimize resource utilization, and support sustainable farming practices.

KEYWORDS: Artificial Intelligence, Smart Agriculture, Internet of Things, Machine Learning, Soil Analysis, Irrigation System, Crop Recommendation, Fertilizer Recommendation, Precision Farming, Deep Learning

I INTRODUCTION

Agriculture plays a major role in the development of every country and is the primary source of food production. With the rapid growth of the global population, the demand for food production is increasing continuously. Farmers are facing several problems such as irregular rainfall, water shortages, soil degradation, climate change, and excessive fertilizer usage. These challenges reduce crop quality and agricultural productivity.

Traditional agricultural methods mainly depend on manual observation and experience-based decisions. Such methods are often inaccurate and inefficient for modern farming requirements. Recent advancements in Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL), and Internet of Things (IoT) technologies have transformed traditional farming into smart agriculture. Smart agriculture uses sensors, intelligent algorithms, weather forecasting systems, and automated decision-making tools to improve farming efficiency.

AI-driven smart agriculture systems help farmers in monitoring soil conditions, predicting irrigation needs, selecting suitable crops, and recommending appropriate fertilizers. Machine learning models can analyze large agricultural datasets and provide accurate predictions for better farm management. IoT sensors collect real-time information such as soil moisture, temperature, humidity, and nutrient levels, which helps in making data-driven decisions.

This review paper focuses on AI-based smart agriculture systems that integrate soil analysis, irrigation management, and crop-fertilizer recommendation approaches. The paper reviews existing research works, technologies,

methodologies, and identifies current research gaps in this field.

II REASEARCH REVIEW

[1] A. Morchid et al. (2024) proposed a smart irrigation system based on Internet of Things (IoT) and cloud computing technologies for improving agricultural water management. The system used sensors to collect real-time environmental data such as soil moisture, humidity, and temperature from agricultural fields. This collected information was transmitted to the cloud platform for monitoring and analysis. The proposed model helped farmers make accurate irrigation decisions and reduced unnecessary water consumption. The study mainly focused on automation and efficient resource utilization in agriculture. The authors highlighted that smart irrigation systems can improve crop productivity and support sustainable farming practices. However, the system mainly depended on sensor-based monitoring and lacked advanced Artificial Intelligence (AI) prediction models for future irrigation planning and adaptive decision-making.

[2] A. Corallo et al. (2024) discussed the importance of digital technologies in sustainable agriculture under the concept of Industry 5.0. The researchers explained how Artificial Intelligence, automation, IoT devices, and smart farming technologies can improve agricultural productivity and environmental sustainability. Their work focused on integrating advanced technologies into agricultural systems to optimize resource utilization, reduce labor requirements, and increase production efficiency. The paper also discussed the role of data analytics and cloud-based platforms in improving agricultural decision-making processes. The study concluded that smart agriculture technologies can significantly contribute to sustainable food production. However, the implementation cost of such technologies was high, and scalability remained a major challenge for small-scale farmers.

[3] Gómez et al. (2022) developed an IoT-based smart farming framework using Machine Learning (ML) and Deep Learning (DL) techniques for crop quality assessment. The proposed system continuously monitored agricultural conditions through connected sensors and analyzed crop data using intelligent algorithms. The framework helped in identifying crop health conditions, monitoring environmental changes, and improving precision farming activities. The researchers used deep learning models to increase prediction accuracy and improve agricultural monitoring systems. The study demonstrated that AI-based smart farming frameworks can support better crop management and increase agricultural productivity. However, the framework required high computational resources and advanced hardware systems, which increased the overall implementation cost.

[4] Kasera et al. (2024) presented a comprehensive survey on the applications of IoT and AI technologies in smart agriculture. The paper discussed various smart farming activities including pre-harvest, harvesting, and post-harvest management systems. The researchers explained the importance of sensors, cloud computing, AI algorithms, and data analytics in modern agriculture. Their study highlighted how intelligent farming technologies can improve crop monitoring, disease detection, irrigation management, and yield prediction. The survey also described different machine learning approaches used in precision farming systems. Although the study provided detailed information about smart agriculture technologies, it lacked a unified and integrated framework combining all agricultural operations into a single intelligent system.

[5] Rajpal et al. (2023) introduced Explainable Artificial Intelligence (XAI) models for improving transparency in intelligent prediction systems. The study focused on making AI models more understandable and interpretable for users. The researchers explained how XAI techniques can help users understand the decision-making process of machine learning systems. In agricultural applications, XAI can improve farmer trust by providing clear explanations for crop recommendations, irrigation decisions, and fertilizer suggestions. The study showed that explainable models can improve decision reliability and increase user confidence in AI systems. However, the implementation of XAI techniques increased system complexity and required additional computational processing.

[6] Sunori et al. (2024) proposed an AI-enabled irrigation optimization system using unsupervised learning algorithms. The main objective of the study was to optimize water usage in agricultural fields and improve irrigation scheduling efficiency. The system analyzed environmental conditions and soil moisture levels to determine the appropriate irrigation requirements for crops. The researchers showed that intelligent irrigation systems can significantly reduce water wastage and improve agricultural sustainability. The study also demonstrated the

importance of AI-based automation in modern farming practices. However, the performance of the proposed model decreased under dynamic environmental conditions and varying climatic changes, which affected prediction accuracy.

[7] Hossain et al. (2024) developed an ensemble machine learning model for crop recommendation using real-time sensor data. The proposed system collected agricultural information such as soil nutrients, temperature, humidity, and moisture levels to recommend suitable crops for cultivation. The researchers combined multiple machine learning algorithms to improve prediction accuracy and system performance. The model successfully improved crop prediction efficiency and supported precision farming practices. The study highlighted that ensemble learning approaches provide better performance compared to individual machine learning models. However, the system required large training datasets and high-quality sensor data for effective prediction results.

[8] Kumar et al. (2023) implemented a deep learning-based irrigation planning and scheduling system using soil moisture estimation techniques. The proposed model used sensor-based soil moisture data and deep learning algorithms to determine irrigation requirements in agricultural fields. The system improved irrigation management efficiency and helped farmers reduce excessive water usage. The researchers demonstrated that intelligent irrigation systems can improve crop growth and support sustainable agriculture practices. The study also showed that AI-based irrigation planning can minimize water wastage and increase productivity. However, continuous sensor maintenance and monitoring were required for proper system functioning, which increased operational complexity.

[9] Khan et al. (2022) proposed an IoT-assisted fertilizer recommendation system using machine learning algorithms. The system analyzed soil nutrient levels, crop conditions, and environmental parameters to recommend suitable fertilizers for agricultural fields. The researchers used intelligent algorithms to improve fertilizer selection accuracy and support precision agriculture practices. The proposed model helped farmers reduce excessive fertilizer usage and improve soil fertility management. The study highlighted that AI-based fertilizer recommendation systems can improve crop productivity and reduce environmental pollution caused by improper fertilizer usage. However, the system lacked adaptive real-time learning capabilities and required further improvement for handling changing environmental conditions.

[10] Khaliq et al. (2025) developed an integrated AI-driven smart agriculture framework that combined Transformer-based Tabular Learning (TTL), Sparse Weighted Fusion Transformer (SwiFT), and TabNet models with Explainable AI techniques. The proposed system provided multiple agricultural services including soil analysis, irrigation advice, crop recommendation, and fertilizer recommendation within a single intelligent framework. The researchers used advanced machine learning and deep learning models to improve agricultural prediction accuracy and decision-making efficiency. The TTL model provided highly accurate irrigation recommendations, while the SwiFT model improved crop prediction performance. The TabNet model combined with Explainable AI was used for soil analysis and fertilizer recommendation, helping farmers understand the prediction process clearly. The study demonstrated that integrated AI-based smart agriculture systems can improve farming efficiency, resource management, and agricultural sustainability. However, the framework required further validation across different geographical regions, soil conditions, and climatic environments for large-scale practical implementation.

III REASEARCH GAP

From the reviewed literature, it is observed that many agricultural systems focus only on individual tasks such as irrigation management, crop prediction, or fertilizer recommendation. Very few studies provide a fully integrated smart agriculture framework combining all these features together.

Existing machine learning models often fail to handle complex agricultural datasets containing environmental, soil, and climatic information. Some systems require high computational power and expensive hardware, making them unsuitable for small-scale farmers. Many research works also lack explainability, making it difficult for farmers to understand prediction results.

Another major gap is the limited use of real-time IoT sensor integration and adaptive decision-making systems.

Several existing models are tested only on limited datasets and fail to perform effectively in different geographical regions and environmental conditions.

Therefore, there is a need for a scalable, cost-effective, explainable, and integrated AI-driven agriculture system that can provide accurate soil analysis, smart irrigation advice, crop recommendation, and fertilizer prediction using real-time agricultural data.

IV CONCLUSION

AI-driven smart agriculture systems have the potential to transform traditional farming into an intelligent and sustainable agricultural ecosystem. The integration of Artificial Intelligence, Machine Learning, Deep Learning, IoT sensors, and Explainable AI can improve agricultural productivity and reduce resource wastage.

This review paper analyzed various research works related to soil analysis, irrigation management, crop recommendation, and fertilizer recommendation systems. The study found that advanced models such as Transformer-based learning models, TabNet, ensemble learning methods, and IoT-enabled frameworks provide highly accurate agricultural predictions.

Despite significant progress, several challenges still exist, including high implementation cost, lack of scalability, insufficient explainability, and limited real-world deployment. Future research should focus on developing affordable, explainable, and region-independent smart agriculture systems that can support farmers in real-time decision-making.

The adoption of AI-based agriculture technologies can help improve food security, optimize water usage, maintain soil health, and promote environmentally sustainable farming practices.

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