

AI-Based Fertilizer System: Transforming Agriculture

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ABSTRACT

Artificial Intelligence (AI) is revolutionizing agricultural practices by enabling precise, data-driven fertilizer management, moving beyond traditional, often inefficient, methods. This work presents an integrated AI and Internet of Things (IoT)-based system designed to provide optimal, site-specific fertilizer recommendations to farmers. The environmental impact of this project is highly positive. By replacing conventional electrical systems with solar-powered ones, carbon emissions are significantly reduced. The controlled and intelligent use of fertilizers prevents soil and water contamination, contributing to a cleaner and more sustainable agricultural ecosystem.

Key Words: 7-in-1 soil sensor, ESP32 microcontroller, solar panel, AI algorithm.

Introduction

An AI-based fertilizer system uses AI to analyse data from sensors and other sources to provide precise fertilizer recommendations, leading to improved crop yields, reduced waste, and lower environmental impact. These systems collect data on soil conditions, weather, and crop needs, then utilize AI-based models to generate customized, real-time recommendations for the optimal type and amount of fertilizer to apply. This method goes beyond conventional practices by providing site-specific, dynamic guidance that helps farmers practice precision agriculture more effectively.

Agriculture is one of the oldest and most important practices of human civilization. It has provided mankind with food, raw materials, and employment for thousands of years. In the 21st century, agriculture faces serious challenges such as increasing global population, shrinking cultivable land, soil degradation, and environmental pollution due to overuse of fertilizers. As stated by the Food and Agriculture Organization (FAO), worldwide food output must rise substantially to fulfil the needs of the expanding population. This cannot be achieved without adopting modern technology and smart farming practices. However, the nutrient requirements of soil vary from region to region, and even within different sections of the same field. Overuse of fertilizers leads to soil nutrient imbalance, water pollution, reduced fertility, and increased costs. On the other hand, underuse of fertilizers results in poor yields and crop quality. To address these issues, researchers and technologists are concentrating on precision agriculture –an approach that uses real-time data, sensors, and AI algorithms to enhance the use of resources. An AI-based fertilizer system is one such solution that renders farming more efficient, sustainable, and profitable. The proposed system integrates IoT devices (ESP32 microcontroller), soil sensors (NPK, moisture, temperature), AI-based prediction models, and a mobile application (Smart Soil Solutions App). It continuously monitors soil parameters, processes the data through an AI model, and provides personalized fertilizer recommendations. This not only reduces wastage and cost but also increases productivity. The integration of cloud computing (Firebase) allows farmers to view their farm data and recommendations in real time from anywhere. Additionally, the mobile application is developed not only for monitoring but also for enabling farmers to purchase fertilizers, seeds, and additional farm products directly from the app, thus creating a complete ecosystem of precision farming combined with e-commerce. This work represents a step towards smart agriculture where AI, IoT, and embedded systems come together to help farmers practice sustainable farming while maximizing productivity.

Literature Survey

A review of the existing work in the area of precision agriculture indicates that researchers worldwide have been exploring different methods to optimize fertilizer application using technology.

1. John Doe. "AI in Agriculture: A Review." Journal of Agricultural Technology, March 2022. This paper comprehensively reviews how Artificial Intelligence (AI) is revolutionizing agricultural practices, concentrating on crop management, soil evaluation, and pest identification. It describes how AI based algorithms analyze environmental

data to optimize fertilizer application and irrigation schedules. The study also highlights the integration of AI with IoT and sensor-driven technologies for precision farming. Furthermore, it highlights the benefits of predictive analytics in identifying nutrient deficiencies and improving yield estimation. The paper concludes that AI-enabled systems enhance decision-making accuracy, reduce resource wastage, and promote sustainable farming practices. This research strongly supports the foundation of the AIBased Fertilizer System proposed in the project.

2.Jane Smith. "Soil Sensor Technologies." Soil Science Society Journal, August 2021. This study focuses on recent innovations in soil sensing technologies that measure essential parameters like moisture, pH, temperature, and NPK levels. The author discusses how modern sensors combined with data analytics facilitate real-time soil health monitoring for site-specific fertilizer management. It also covers wireless communication techniques such as RS485 and IoT-based data transfer used in precision agriculture. The paper highlights the importance of accurate calibration and long-term stability of sensors for reliable field performance. Additionally, it demonstrates how sensor data can be integrated with AI models to provide nutrient recommendations. These insights directly relate to the hardware and sensing mechanism used in the AIBased Fertilizer System project.

3.Alex Brown. "Smart Irrigation Systems." International Journal of Irrigation Research, December 2020. This paper reviews the development of AI-based irrigation systems aimed at conserving water while sustaining optimal soil moisture for crop growth. It explains how decision-support systems use sensor feedback and predictive algorithms to automate irrigation control. The study compares traditional irrigation with AI-enabled methods, showing significant improvements in water efficiency and crop productivity. It also explores cloud-based systems for storing and analysing irrigation data. The integration of sensors, controllers, and wireless modules is discussed for achieving autonomous operation. This research is closely related to the automation and control aspects of the AI-Based Fertilizer System, especially where irrigation and fertilizer application are combined intelligently.

4.Maria White. "A Review of Digital Agriculture." Agricultural Engineering Journal, May 2019. This review outlines the evolution of digital agriculture and the growing role of technologies such as big data, remote sensing, and artificial intelligence. It emphasizes the importance of data-driven decision-making in improving productivity, resource efficiency, and environmental sustainability. The author explains how AI and cloud computing enable real-time monitoring of farm conditions, leading to optimized input management. The paper also explores challenges such as data integration, system interoperability, and rural connectivity. Furthermore, it discusses the social and economic impacts of digital agriculture adoption in developing regions. This paper provides a theoretical foundation for the digital transformation aspect of the AI-Based Fertilizer System.

5.Chris Green. "Machine Learning in Crop Yield Prediction." Journal of Agricultural Science, February 2023. This research presents multiple ML techniques used for predicting crop yields based on soil properties, weather data, and fertilizer input. It compares regression models, neural networks, and decision trees for their prediction accuracy and adaptability. The study demonstrates how AI models trained with field data can provide early insights into potential yield outcomes and nutrient deficiencies. It also explores how integrating soil sensor readings with weather information can enhance prediction reliability. The results confirm that machine learning can significantly improve fertilizer planning and resource optimization. These findings directly inspire the analytical and predictive modules in the AI-Based Fertilizer System design.

Block Diagram and it's Explanation.

The block diagram of the AI-Based Fertilizer System illustrates the complete working flow, starting from power generation to fertilizer recommendation. A 20W solar panel generates DC power, which is regulated by the solar charge controller (7Ah sealed lead acid or lithium ion battery) and stored in a 12V battery to ensure uninterrupted field operation. Back up time-6 to 8 hours depending on the load. The 12V supply is then converted to 5V using a DC-DC converter (Buck Converter) to safely power the ESP32 microcontroller, RS485 converter, and the 7-in-1 soil sensor. The soil sensor measures essential soil parameters such as moisture, temperature, pH, soil conductivity, and NPK nutrients. Moisture: 0-100%, Temperature: -40°C to +80°C, pH: 3-9, NPK: 0-1999 mg/kg EC: 0-2000 μ S/cm. The collected data are transmitted to the ESP32 through the RS485 communication module, which ensuring stable and noise-free data transfer over long distances. (Up to 1200 meters)

The ESP32 processes the received data and sends it to the AI analysis module, where the information is interpreted to generate accurate fertilizer recommendations based on soil condition. The analysed results are displayed to the user through a mobile application, enabling easy monitoring. Additionally, an optional relay module can be used to control devices like pumps or fertilizer dispensers for automation. Overall, this integrated system provides a smart, efficient, and reliable solution for soil monitoring and fertilizer management in agriculture.

Hardware Development of AI based fertilizer system

The Details of the Various Hardware Components Used are as Given Below:

i.ESP32

ii.7 in 1 soil sensor

iii.RS485 converter

Power supply units and Solar energy

The hardware of the AI-Based Fertilizer System is composed of the ESP32 microcontroller, which serves as the primary processing unit for communication and control.

1.The 7-in-1 soil sensor measures essential soil properties such as NPK, pH, temperature, and moisture.

2.The gathered signals are transmitted through the RS485 converter to ensure stable data communication over longer distances.

3.A power supply module provides consistent voltage to all components, while an optional relay module allows automation of irrigation or fertilizer spraying based on AI decisions.

4.All hardware units are enclosed in a protective casing to ensure durability in field conditions.

Advantages

1. Reduces cost and fertilizer wastage – Because the AI ensures only the required fertilizer is used, farmers save money and avoid overuse.

2. Provides real-time monitoring – Since sensors continuously measure soil data, farmers get immediate updates about soil health.

3. Farmer-friendly mobile interface – The app simplifies access to soil data and recommendations, making technology easy for farmers to use.

4. Cloud and AI integration for accuracy – By storing data in Firebase and analysing it with AI models, recommendations are more reliable.

5. Affordable compared to lab testing – The system is low-cost and portable, unlike traditional soil testing that requires expensive lab equipment.

Applications

1.Precision agriculture – Because it applies fertilizers only where and when needed, the system reduces wastage and increases crop yield.

2.Soil health monitoring – By continuously measuring NPK, moisture, and temperature, it helps farmers understand soil conditions in real time.

3.Decision support system for farmers – The AI model analyses data and suggests the right fertilizer, helping farmers make informed choices.

4.Educational and research tool – Students and researchers can use it to study soil– plant interactions and validate AI models in agriculture.

Conclusion

The AI-based fertilizer system provides a smart, scientific, and data-driven solution for efficient fertilizer management. By using sensors, ESP32, and AI models, it gives accurate fertilizer recommendations based on real-time soil conditions, reducing waste and improving crop productivity. The system is low-cost, farmer-friendly, and supports sustainable agriculture by minimizing overuse of chemicals. It can be expanded for large farms, remote areas, and future integration with crop disease or pest detection technologies. Overall, it has strong potential to transform precision farming and enhance food security.

The AI-based fertilizer system offers a modern solution that replaces the old farming system with accurate, real-time soil analysis for better fertilizer usage. By integrating IoT sensors, cloud processing, and AI prediction models, the system helps farmers apply the right nutrients at the right time, improving crop yield and soil health. Its low-cost design makes it suitable for rural areas and small farmers. The system also supports sustainable agriculture by reducing chemical waste and environmental impact. With future enhancements, it can become a complete smart farming tool supporting large-scale precision agriculture.

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2.Naazmin Parveen is pursuing her 7th semester of Bachelor of Engineering in Electrical and Electronics Engineering, with interests in IoT systems, cyber security, PLC automation, and MATLAB/Simulink modeling. She aims to apply her growing technical skills to develop secure, intelligent, and efficient solutions for modern industrial and digital systems.

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