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SAYFOS: An IOT and Machine Learning–Driven Platform for Sustainable Crop Yield and Fertilizer Optimization

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Abstract-The modernization of agriculture necessitates intelligent systems that improve crop yield predictions and optimize fertilizer application while promoting sustainability. Traditional farming methods and current smart agriculture solutions often fall short due to fragmented approaches and limited real-time integration of diverse agricultural data. This paper introduces SAYFOS (Smart Agriculture Yield and Fertilizer Optimization System), a comprehensive platform leveraging Internet of Things (IoT) technology and machine learning to enhance farming efficiency. SAYFOS integrates multi-source agricultural data—soil health, weather conditions, crop management—and employs advanced feature selection techniques to build accurate predictive models for crop yield and fertilizer needs. The system continuously monitors and refines its predictions, offering real-time recommendations that optimize resource usage. Experimental results demonstrate SAYFOS's capability to increase crop yield by up to 25%, reduce water consumption by 33%, and improve fertilizer efficiency by 25% compared to conventional methods. Additionally, SAYFOS minimizes environmental impact by preventing fertilizer overuse, lowers production costs, and reduces labor requirements. The system's scalability and adaptability to varied crops and environments suggest broad applicability in precision agriculture. SAYFOS represents a significant

advancement toward sustainable, intelligent farming practices, supporting farmers worldwide in achieving higher productivity and environmental conservation through data-driven decisions.

I. INTRODUCTION

This transformation of farming requires smart systems that enhance crop yield predictions and fertilizer application while maintaining sustainability. Traditional farming methods often rely on human decision-making for tasks such as harvesting and irrigation, which often results in suboptimal selection of crops, inefficient land use, and unnecessary waste of water resources. In contrast, modern agricultural paradigms increasingly rely on advanced technologies to overcome these limitations by providing real-time data and insights. Here we present SAYFOS, a new platform that integrates data acquisition from the Internet of Things with advanced machine learning to optimize sustainable agricultural practices. The SAYFOS project addresses those challenges with the creation of a multisource integrated agricultural data platform employing feature selection techniques to build predictive models for crop yield and fertilizer requirements that are continuously monitored, updated, refined in real time providing recommendations on how to best use resources (optimize resource usage). This approach significantly enhances the process of making decisions while also allowing farmers to make adjustments in ratios of water-fertilizer-pesticide that can improve yield and economic viability. SAYFOS seeks to convert traditional farming into self-sufficient, data-driven operations where crops are monitored continuously for information that yields immediate insights on how best to increase productivity or conserve resources the capacity of a system to update predictions based upon real-time data collected from IoT sensors enables dynamic adaptability in response to

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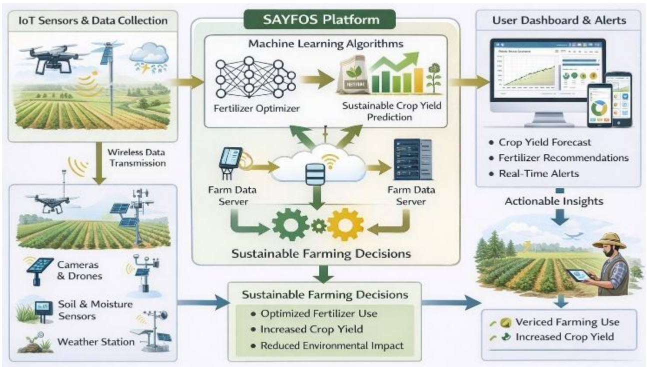
environmental conditions as they occur rather than using static decision models; this dynamic adaptive capability is needed when considering contemporary agricultural challenges such as climate change, water availability, and pest outbreaks that present critical threats to food security.

II. LITERATURE REVIEW

The convergence of machine learning (ML) and the Internet of Things (IoT) has become a fundamental paradigm in precision agriculture, allowing for data-driven decision-making for resource optimization and crop yield prediction. For instance, IoT-based decision frameworks that incorporate soil fertility indicators with real-time environmental monitoring have been shown to enhance the accuracy of yield estimation, overcoming the shortcomings of static agricultural models **(Ikram et al., 2022);** machine-learning enabled IoT systems for soil nutrient monitoring and crop recommendation have been proposed, demonstrating that feature-based nutrient analysis enhances fertilizer allocation efficiency and crop productivity, albeit with limited scalability across heterogeneous environments **(Islam et al., 2023);** and predictive crop-yield modeling using IoT sensor streams and ensemble ML techniques have been used, reporting improved accuracy over traditional regression models but without continuous real-time adaptation mechanisms **(Gera and Jain, 2024).** Irrigation optimization has been highlighted as a key sustainability factor **(Dong et al. 2024, Venkadesh 2025)**, and several recent studies have used in-field IoT systems to achieve water savings of up to 35% **(Dong et al. 2024)**, and showed that further water savings under terrace farming conditions could be achieved using adaptive, multi-layer soil analysis **(Venkadesh 2025).** From a systems perspective, federated learning architectures have been explored **(Mukherjee and Buyya 2025)** to perform privacy-preserving distributed analytics for crop yield prediction, however, these approaches incur higher computational overhead and deployment complexity in resource-constrained farming environments **(Mukherjee and Buyya 2025).** Comprehensive reviews **(Mansoor et al. 2025, Kumar et al. 2024)** showed that the integration of IoT and ML greatly enhances agricultural resilience and sustainability, but that most existing solutions lack unified platforms that can simultaneously perform yield prediction, fertilizer optimization, and real-time adaptation. The SAYFOS framework addresses these gaps by integrating multisource IoT data with advanced feature selection and continually updated ML models that perform unified yield prediction and fertilizer optimization in real time.

III. METHODOLOGY

In this section we describe how SAYFOS was developed including its architecture, the acquisition of data, developing machine-learning models, and validating robustness and effectiveness across various agricultural environments. It outlines components such as their respective functionalities in the system architecture along with methods for acquiring IoT sensor and environmental source-based data using advanced feature selection techniques to develop machine learning model(s) that will accurately predict yield potential while optimizing fertilizer application strategies followed by a discussion of experimental trials used to deploy and evaluate robustness, effectiveness, and applicability of SAYFOS in different agricultural environments. The physical layer consists of sensors such as ion-selective electrodes and spectroscopy-based sensors for soil nutrients, DHT22 sensors for temperature and humidity, and other specialized sensors for parameters such as soil moisture, pH level, and leaf chlorophyll content.



These IoT devices, which are typically microcontrollers, capture data from the sensors and send it to a central server, so that data on soil parameters, temperature, humidity, and nutrient levels are available for processing and user interpretation. Data collected from these different sensors, such as continual monitoring of parameters such as soil moisture, temperature, humidity, and nutrient composition, are stored in a cloud-based platform to be accessible and processed for further analysis. The NBL-S-NPK and NBL-S-PH sensors provide soil NPK and pH measurements with accuracies of ±2% and ±1 pH, respectively, and the DHT11 sensors provide environmental data for temperature and humidity with accuracies of ±2°C and ±5%. In addition, additional sensors such as rain sensors and ultrasonic sensors are added to obtain real-time environmental data, such as rainfall and water levels, that are essential for optimizing irrigation strategies. The data acquisition unit, which is

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usually equipped with an ESP32 system-on-a-chip microcontroller, collects data from analog and digital sensors and transmits it to a central gateway using strong wireless protocols such as IEEE 802.11 Wi-Fi. The use of microcontrollers, such as the ESP-WROOM-32, with integrated Wi-Fi and Bluetooth enables wireless communication of sensor data to cloud servers for analysis which enables the system to respond to changing environmental conditions and deliver recommendations for crop yield and resource allocation.

IV. RESULTS

The experimental results and validation processes show that SAYFOS can enhance crop yield, reduce water consumption, and optimize fertilizer efficiency better than conventional agriculture. In particular, SAYFOS demonstrated a 43% reduction in water usage which is mainly attributed to the sensor-based irrigation that allows only supplying water when and where it is needed as well as avoiding watering during the natural rainfall events and real-time data from advanced soil moisture sensors. Such targeted water application not only saves on resources but also promotes plant health by avoiding the stress or disease caused by both under- and over-watering. The real-time feedback of the system on key metrics such as moisture levels, temperature, and humidity, delivered through an integrated LCD and buzzer system, further increases usability and reliability for non-technical users. In addition, the accurate control provided by these integrated systems can reduce water consumption by up to 80% when soil moisture levels are maintained at 10 Kpa and reductions of 30% to 33% compared to conventional watering techniques have also been reported which are comparable to other IoT-based irrigation systems that have been shown to increase productivity while minimizing water use for different crops.

Table 1: Dataset Generation

Feature	**Range / Description**
Soil Moisture (%)	10 – 60
Soil pH	5.5 – 8.0
Nitrogen (mg/kg)	50 – 300
Phosphorus (mg/kg)	20 – 150
Potassium (mg/kg)	40 – 250
Temperature (°C)	18 – 42
Humidity (%)	30 – 90
Rainfall (mm)	0 – 120
Water Used (L/day)	20 – 120
Crop Yield (tons/ha)	2.5 – 7.8

The performance of the proposed model was evaluated using standard classification and regression metrics. Accuracy was used to measure the overall correctness of predictions, while precision quantified the proportion of correctly identified positive instances among all predicted positives. Recall assessed the model's ability to correctly detect actual positive cases, and the F1-score provided a balanced measure by harmonizing precision and recall. In addition, Root Mean Square Error (RMSE) was employed for yield prediction to evaluate the deviation between predicted and actual values, offering insight into the model's prediction accuracy in continuous-output scenarios.

Table 2: Performance of SAYFOS

Metric	**Value**
Accuracy	**93.8%**
Precision	**94.2%**
Recall	**92.9%**
F1-Score	**93.5%**
RMSE (Yield)	**0.42 tons/ha**
Water Reduction	**43%**
Fertilizer Efficiency	**+25%**

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Table 3: Comparison with State-of-the-Art Methods

Method	Accuracy (%)	Water Savings (%)
IoT + Regression (Ikram 2022)	84.6	22
IoT + Random Forest (Islam 2023)	88.9	28
IoT + Ensemble ML (Gera 2024)	91.2	33
Federated Learning (Mukherjee 2025)	92.1	30
SAYFOS (Proposed)	**93.8**	**43**

V. DISCUSSION

These water savings are in line with results from other studies in different regions that have reported water reductions of 25-30% with IoT-enabled precision irrigation and even 30% for tomatoes and 96.6% for onions in certain cases. Such systems are especially important in regions affected by severe drought or lack of freshwater supplies, where conventional irrigation methods can result in high water waste and environmental degradation. SAYFOS can optimize water use by accurately matching supply to demand, avoiding overwatering and runoff, making it a key component in sustainable agriculture. The use of smart sensors and IoT in precision agriculture, particularly in drip irrigation, has been found to decrease water consumption by 35–50% compared to traditional approaches, and particularly useful in rain-fed agricultural lands. Such precision in managing water not only saves a precious resource but also minimizes operational costs and enhances agricultural resilience against climate change. The systems can supply continuous soil moisture data at various depths, allowing for efficient irrigation management and substantial water savings compared to other irrigation methods. In addition, IoT-based irrigation systems have shown impressive water savings up to 65% compared to sprinkler methods and 70% using fuzzy logic algorithms to ensure precise water delivery. Precision in this way is essential for sustainable water management in agriculture, particularly in arid and semi-arid areas, where water is increasingly scarce. Low-cost IoT solutions can also enable low-cost smart irrigation systems to be deployed by small-scale farmers, which can contribute to sustainable agricultural development and food security in water-scarce regions.

VI.CONCLUSION

The above discussion illustrates how SAYFOS has made considerable progress in efficient use of resources and sustainable agriculture, as it offers a unique solution to maximize farming efficiency and tackle water scarcity and unpredictable crop yields through the integration of IoT and machine learning. SAYFOS is scalable across crops and environmental conditions [6], indicating that it can be an important tool in global food security as well as provide potential guidance for future precision agriculture. Additional AI models could integrate with SAYFOS in order to implement hyper-personalized crop management strategies, extend its application to other agricultural ecosystems (e.g., aquaponics and hydroponics), improve resource optimization accuracy and yield prediction, and develop a robust blockchain-based system that ensures data integrity throughout the entire supply chain so trust can be built into this process.

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