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IoT Data and Random Forest Algorithm for Optimized Crop Rotation Planning for Sustainable Agriculture

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***Abstract*—Modern farming has prioritized developing sustainable agricultural practices to combat food insecurity and environmental damage. A reliable strategy for maintaining healthy soil and increasing yields is crop rotation. This study proposes a novel method that integrates Internet of Things (IoT) data with the Random Forest algorithm to optimize crop rotation plans. IoT sensors are real-time monitoring of the soil's moisture, temperature, and nutrient content using IoT, and a comprehensive overview is presented by combining this data with historical records and predictions. This dataset is analyzed using the Random Forest technique, which considers various characteristics, including crop compatibility, soil conditions, and climatic trends. The program uses machine learning to create optimal crop rotation plans for productivity, pest and disease control, and the promotion of sustainable agriculture. Our findings show that this strategy enhances crop rotation planning, increasing agricultural output while decreasing its ecological footprint. It helps in the development of sustainable farming methods and the expansion of precision agriculture via the use of IoT and machine learning.**

Keywords— IoT, Random Forest, Crop Rotation, Sustainable Agriculture, Optimized Planning

I. Introduction

Organic gardening needs energy to thrive and enhance productivity. Grown crops require fertilizers. Instead, we applied fertilizers, which might cause runoffs or farmer input [1]. This analysis proposes crop rotation based on geography and time to overcome this reliance. Agriculture involves managing land and increasing production. It only benefits modern civilization and future generations. Productivity from landscape structure and crop management is essential.

The crop rotation problem (CRP) and how it relates to the use of PA in farming [2]. This research introduces a novel mathematical solution based on nutrient balance and crop needs to make the CRP more sustainable. The CRP optimization process was incorporated into a genetic algorithm. The findings seem promising for both short-term and long-term crop planning.

Agriculture shapes India's economy. Population growth raises food consumption daily. Thus, agricultural output must be increased more efficiently [3]. Now, with IoT and machine learning, we can obtain better results. In real-time, the system is suggested to gather soil data, including NPK content, pH level, and temperature from IoT sensors, and send it to the cloud using MQTT and Node MCU firmware. We used the k-nearest neighbor algorithm model in the cloud architecture to get the optimal crop rotation recommendation. KNN predicts nearby comparable entities using supervised machine learning. Farmers may see their fields' real-time soil composition on the dashboard.

The growing population and diminishing arable land require smarter and more efficient agricultural production methods. Everyone needs to know about sustainable agriculture and food security [4]. Many agricultural technologies, including the IoT, make agriculture smarter and more successful in addressing future needs. Industry issues and potential guide scholarship and engineering. Thus, integrating sustainable IoT-based sensors and communication technology to manage every inch of the field improves agricultural output.

Potential uses of digital agricultural platforms for customized crop rotation farming have been investigated. Experiments conducted using fiber flax and annual ryegrasses on a digitized field with cutting-edge machinery are detailed [5]. The peculiarities of the information-analytical crop management system modules for fiber flax-specific crop rotations' operations with algorithms are exposed under actual field settings.

Rotating crops improves soil quality, helps prevent plant diseases, and boosts crop production. Since crop data from a single time point needs to adequately capture the dynamics of a system, mapping crop rotation is challenging [6].

Attempts at mapping crop rotation have been made by integrating crop maps sequentially. However, this resulted in a significant number of nonsensical crop sequences, making it difficult to evaluate the effects of crop rotation on a regional basis. An original method for mapping crop rotation is proposed, incorporating temporal information into traditionally static crop maps.

Many agriculture, ecology, and land management fields may benefit from the information provided by a GIS data layer on the perimeter of crop fields. For large agricultural regions, a field survey to define crop fields' boundaries would require more time and money to be practical [7]. Being time-consuming and prone to mistakes, on-screen digitization of high-resolution satellite images could be more convenient. Image segmentation based on spectral properties has recently made significant progress, which bodes well for identifying farmland boundaries. However, high-performance calculation systems were often needed to process enormous volumes of multi-band satellite imagery.

Depending on soil quality, nutrients, and composition, farmers must know which crop to grow. A machine learning program will measure Urea, potassium, magnesium, pH, and nitrogen to assist farmers in assessing soil quality [8]. Various farms in cities provide soil samples for testing. This system compares models and information to forecast the best crop for cultivation and crop rotation, improving annual yields. Based on soil nutrients, the result suggests a crop for each trimester to optimize crop rotation.

Smart agricultural solutions for new and crop-rotating farms employing drones and IoT sensors are discussed in [9]. The plan comprises drone seeding, pesticide/fertilizer spraying, monitoring of agricultural conditions, and sampling. Our approach provides Zigbee connectivity between ground sensors and drones and long-range connectivity for the gateway to broadcast and store farm data in the cloud for analysis and storage. From ground sensors the farmer has integrated into the farm, our drone captures agricultural data like pH and soil humidity.

Organization of this paper

Section 1 explains why efficient crop rotation is important for sustainable agriculture and how the IoT and the Random Forest algorithm may work together to achieve this goal. Section 2 summarized the current literature on crop rotation planning methodologies, IoT applications, and machine learning approaches in agriculture. Methodology, including data collecting, preprocessing, algorithm execution, and model assessment, is detailed in section 3. Discuss the system's efficacy, ramifications, and improvement opportunities highlighted in Section 4. It also presents the results of adopting the system. Section 5 summarizes the main points, advances the cause, and suggests the next steps for data-driven crop rotation planning to promote sustainable agriculture.

II. Related Works

The 4G-based crop rotation soil data monitoring system is an IoT that employs several devices and sensors to keep track of soil data [10]. This research uses the IoT and associated technologies to create a real-time system to monitor the soil conditions during crop rotation. It focuses mostly on the system's path, design, and implementation. Soil environment and weather data for agriculture may be automatically collected via the system's performance by combining several network modes.

Machine learning and statistical analysis of remotely sensed data enable us to assess crop rotation impacts in real life [11-16]. The statistically significant and economically important impacts consistent with agronomic parameters like crop water uptake and disease susceptibility are promising. Given this potential, high-quality training data is a critical public benefit, and encouraging and systematizing their gathering and dissemination would advance the worldwide analysis agenda.

Farmers plan crop rotation to improve soil quality, crop productivity, and pest/weed resistance, which entails choosing the kinds and temporal succession of plants on agricultural sites [17]. There is a need for purely data-driven techniques in crop rotation planning, and the available data sources and methods vary. Reinforcement learning is used in a novel approach to crop rotation planning. Compared to conventional techniques, ours offers several advantages for arranging crop rotations. It is adaptable, scalable, and data-driven. It can adapt to varied settings and cope with difficulties on a grand scale, and it considers the complexity and diversity of crop rotation systems.

Agriculture growth is affected by soil elements, including soil moisture, potassium, crop rotation, pH, surface temperature, nitrogen, phosphorus, and meteorological conditions like temperature and rainfall [18]. Technology boosts agricultural production and farm yields. This work provides smart agriculture by monitoring the agricultural land. Thus, farmers' production might grow significantly. It presents a website that uses Machine Learning algorithms and historical weather data to select the most lucrative crop for the current weather. This technique predicts agricultural yields using weather, soil, and previous yields. The suggested system combines data from different sources, data analytics, and forecast analysis to boost agricultural production productivity and farmer profitability.

Crop online monitoring detects weeds, water levels, pests, animal encroachment, crop growth, and agriculture. Farmers may connect to their farms anytime, anyplace, using IoT [19]. Wireless sensor networks monitor agricultural conditions, and microcontrollers automate farm procedures. Wireless cameras capture images and videos of situations remotely. A smartphone lets a farmer use IOT to monitor his farm's status anywhere globally. IOT technology may boost conventional agricultural production and lower costs.

The system's primary objective is to facilitate informed crop prediction by farmers. In addition to real-time readings, it gathers and preserves historical temperature and humidity readings from official government websites for greater precision. The outcome is more reliable when current and past data are combined. The accuracy of the system is improved by comparing various machine learning algorithms. Due to this method, farmers can do more with less effort, improving output and quality.

III. Proposed System

This innovative technique integrates IoT data with the Random Forest algorithm to create sustainable crop rotation plans. Contributing to the progress of data-driven and environmentally aware farming methods, the system uses real-time data and machine learning techniques to deliver personalized suggestions that optimize output while minimizing environmental effects. It also adapts to altering agricultural dynamics.

A. System Framework

The initial stage in this system's operation is gathering and combining various data sources. IoT sensors are strategically placed in farms to monitor soil variables in real time, including moisture, temperature, and nutrient content. These IoT sensors continuously monitor the ground and report their findings to a main server. Agricultural data from the past, such as crop rotations and harvest amounts, are also included. Incorporating weather predictions, which are essential for crop planning, provides the system with complete and current information.

The obtained data must first undergo a "preprocessing " procedure before it can be used for analysis [20]. To provide correctness and consistency, the data must be cleaned and formatted. In addition, missing values and outliers must be dealt with during data preparation to ensure optimal performance of machine learning algorithms. All of the data sources are in sync and adhere to the same standards for easy analysis. Cloud computing is included in the system to improve scalability and data accessibility.

Data collected by IoT devices is sent to the cloud, where it may be safely stored and analyzed. The cloud also allows farmers remote access to real-time field updates and optimal crop rotation plans, providing crucial information for environmentally friendly farming. After this process, the data will be prepared for the machine learning stage. The suggested method is built on the robust machine learning approach Random Forest, which is well-known for its flexibility and accuracy when dealing with complicated datasets.

To create a reliable and accurate model, an ensemble learning approach called Random Forest builds several decision trees and integrates their predictions. Random Forest is used in crop rotation planning to analyze a unified data set. The Random Forest model is trained using archival information such as crop cycles, yields, and soil and climate variables. The algorithm can learn and discover previously unseen connections and patterns by examining this information.

Throughout its training phase, the algorithm learns how distinct crops react to and interact with certain soil conditions and environmental variables. This information is vital for developing efficient crop rotation strategies. The system develops optimal crop rotation plans by combining information on crop compatibility, soil conditions, weather predictions, and pest control with insights from a Random Forest model.

The plans specify in great detail when and what kinds of crops should be planted on each plot of land. Sustainable farming methods that improve soil quality and minimize synthetic fertilizers and pesticides are advocated to increase crop yields. The system's user-friendly design caters to farmers by providing a straightforward interface. The technology allows farmers to enter their field data and preferences and outputs individualized crop rotation plans.

The interface continuously updates soil and weather data, so farmers may adjust as required. The suggested method is meant to aid farmers in making tough choices. It also explains why these plans are optimal for generating highly efficient crop rotation plans. Due to this openness, farmers can make informed decisions based on the system's recommendations. Using IoT sensors, it keeps track of the state of the fields and evaluates the results against the ideal planting schedule.

This feedback loop may improve the model's accuracy over time. The system can adjust and deliver updated advice to farmers in the event of unforeseen difficulties or changes in weather patterns. Several major advantages arise from the operation of the suggested system. It improves agricultural sustainability by making informed decisions on crop rotations in the present moment, using both current data and experience. The approach improves soil quality, lessens the need for synthetic fertilizers and pesticides, and reduces disease and insect problems.

Figure 1 block diagram shows the hardware works in tandem with the cloud. IoT sensors deployed in farms gather and send real-time information on the fields' soil and climate to a centralized data collection & transmission module. Next, the information is uploaded to the cloud, which will be stored and processed. The cloud-based data center unit does the heavy lifting to analyze and integrate the data. This information is stored in the cloud, where the Random Forest Algorithm may access it to devise planting schedules. The plans are accessible to farmers through a cloud-based user interface and may also get instantaneous changes.

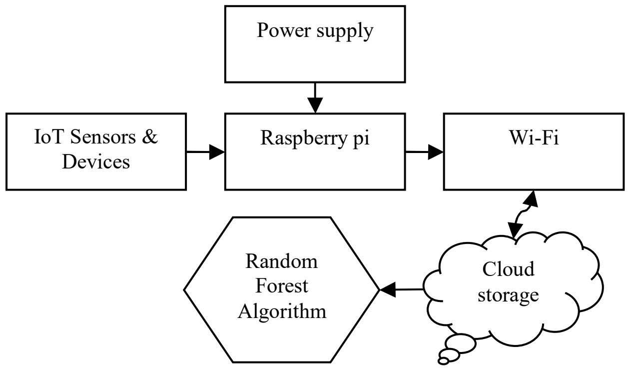

Fig. 1. Block diagram of Sustainable Agriculture with Cloud-Enhanced IoT and Random Forest

Microcontrollers, the "brains" of IoT devices, manage sensors, gather data, and make choices based on that information. Microcontrollers such as the Raspberry Pi are often used in this setup. Raspberry Pi has greater processing power and flexibility than Raspberry Pi boards.

Capacitive soil moisture sensors and the Decagon EC-5 are two sensors used to determine the soil's moisture level. This information is critical for gauging soil health and planning irrigation schedules. Temperature measurements from sensors such as the DS18B20 are crucial for understanding the field's thermal conditions, particularly as the seasons change.

Humidity sensors, such as the DHT22 and DHT11, are vital for determining the influence of air moisture on crops. The ESP8266 is a cheap microcontroller with Wi-Fi connectivity that enables remote data collection and uploads to the internet or local servers.

B. System Operates

The proposed algorithm optimizes crop rotation in sustainable agriculture by integrating data from the IoT with the Random Forest approach. IoT sensors in real time monitor soil temperature, moisture, and crop health. The Random Forest model forecasts the best crop rotations using preprocessed data. Achieving accurate models requires hyperparameter adjustment. Feedback loops enhance forecast accuracy by monitoringFeedback loops enhance forecast accuracy by monitoring how well the ideas users put into action are working. Using data-driven insights, this iterative strategy improves agricultural sustainability and production.

C. Step-by-step workflow of this system

1) **Data collection:** IoT sensors monitor soil and environmental conditions in real time.

2) **Data Integration:** Real-time and historical data are combined for analysis.

3) **Random Forest Analysis:** The algorithm optimizes crop rotation plans based on data on weather and pests.

4) **Plan Adjustment:** Plans are refined considering real-time data and risk factors.

5) **Cloud Storage:** Data and plans are securely stored in the cloud.

6) **User Interface:** Farmers access plans and updates via a user-friendly interface.

7) **Monitoring and Adaptation:** Continuous monitoring and feedback refine plans over time.

8) **Sustainable Farming:** The system supports sustainable agriculture practices.

IV. Result and Discussion

Sustainable agriculture has benefited greatly from this system's deployment. The Random Forest algorithm's crop rotation plans have repeatedly been demonstrated to improve crop yields and soil health. The exact monitoring and application of water and fertilizer made possible by IoT sensors has minimized waste and lessened the strain on natural resources. Farmers who have used this technique have seen improvements in their decision-making ability and a significant decrease in crop losses due to pests and diseases.

The capacity of this system to use IoT data and machine learning is a major factor in its success. Crop rotation plans that optimize plant compatibility and reduce soil depletion have been made possible by the Random Forest algorithm's ability to analyze complicated information. More resilient agricultural techniques have emerged due to the integration of weather predictions and past pest data. Farmers all over the globe may now have access to the system because of the cloud-based architecture that allows them to access data and suggestions remotely.

However, there are still challenges to overcome, especially regarding data reliability and sensor upkeep. It is essential to ensure the accuracy of IoT sensors' data and encourage their continued use in the field. Addressing the system's scalability and cost is important to achieve broad acceptance among small-scale farmers. Evaluating and validating the system via field experiments and case studies is required due to its potential influence on agricultural profitability, environmental sustainability, and productivity.

Optimized crop rotations provide many concrete advantages, including greater yield, decreased input costs, and better soil health. Stakeholders may evaluate these benefits, calculate the return on investment, and make educated choices about embracing and using technology. Further, it is essential to consider the social and economic effects of using crop rotation planning systems powered by the Internet of Things.

Concerns around fairness, access, and the distribution of information arise alongside the potential for technology-driven solutions to improve agricultural sustainability and production. For agricultural communities to embrace technology and fairly share its advantages, it is crucial to provide equal access, implement capacity-building programs, and encourage inclusive decision-making.

To train and evaluate the Random Forest algorithm, the dataset for crop rotation planning is presented in Table 1. Each row contains information on a single data sample, such as the percentage of wet soil, the temperature of the soil in degrees Celsius, and the nutrient content of the soil in parts per million (ppm). The actual crop rotation choice based on these factors is specified by the outcome variable "Crop Rotation Outcome." The dataset is split into two parts: one half is used to train the model, while the other half is used to test the models predicted accuracy. The Random Forest algorithm uses what it has learned from the training data to produce suggestions for crop rotation depending on the given inputs.

TABLE I. Random Forest Training and Testing Data for Crop Rotation Optimization

Sample ID	Soil Moisture (%)	Soil Temperature (°C)	Nutrient Content (ppm)	Crop Rotation Outcome
1	35	18	25	Wheat
2	32	17	26	Tomatoes
3	34	18	24	Corn
4	30	16	27	Barley
5	33	19	26	Soybeans
6	36	20	28	Wheat

Table 2 shows optimized four-year crop rotation patterns. The years in the columns and the fields in the rows indicate the fields and the years, respectively. The Random Forest algorithm considers various parameters, including soil conditions and crop compatibility, to provide planting recommendations each year that will most impact agricultural productivity and sustainability, as shown by the cell values.

TABLE II. Optimized Crop Rotation Plan Over a Four-Year Cycle

Field	Year 1	Year 2	Year 3	Year 4
Field 1	Wheat	Tomatoes	Corn	Barley
Field 2	Corn	Soybeans	Barley	Corn
Field 3	Barley	Wheat	Corn	Soybeans
Field 4	Soybeans	Corn	Wheat	Wheat

Figure 2 compares crop yields with predicted yields across many growing seasons. The data points on the x-axis show the number of seasons, while the y-axis shows crop production in tons per acre. Visually examining the model's success in predicting crop yields is an important part of making educated agricultural decisions, which creates this potential.

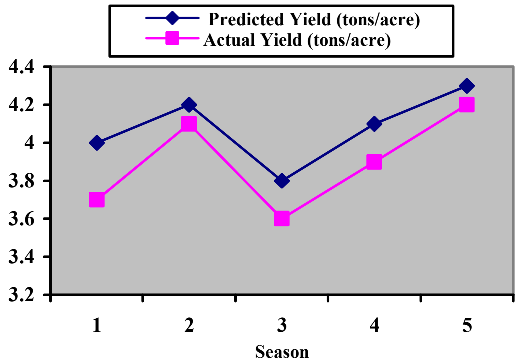

Fig. 2. Predicted vs. Actual Crop Yields

The results of using the Random Forest method to plan crop rotations over many years are shown graphically in Figure 3. On the y-axis, the user views the years, and along the x-axis, the user views how key performance indicators like accuracy, precision, recall, and F1 scores have changed over time. The algorithm's performance is shown against time. As the system learns from historical and real-time data, it improves over time and becomes more accurate and dependable in crop rotation recommendations. From the graph, users can learn much about how well the algorithm optimizes crop planning for sustainable agriculture.

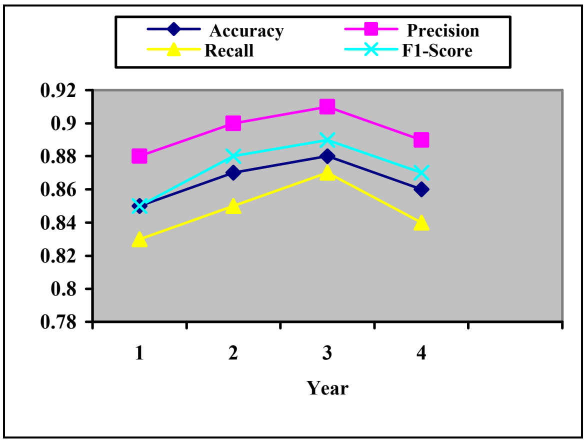

Fig. 3. Performance Trends of Random Forest Algorithm in Crop Rotation Planning Over Time

The advantages of using the system for sustainable agriculture have been substantial. Using data from IoT sensors and past trends, the Random Forest algorithm has advised increasing agricultural yields while decreasing vulnerability to pests and illnesses. The system's flexibility and robustness have been enhanced by incorporating real-time data, such as weather predictions and pest information. Farmers that have used the technique have reported a rise in output and a decrease in waste. The system is a promising first step toward data-driven, sustainable agriculture methods that emphasize environmental health and food production efficiency despite data accuracy and scalability challenges.

V. Conclusions

The system is a major step forward for contemporary farming. Modern technology and time-tested farming techniques create a more resilient and fruitful agricultural ecosystem. The core of this system is the Random Forest algorithm, which draws from a large database of IoT sensor data and previous agricultural knowledge. It develops crop rotation plans that optimize productivity while constantly monitoring and analyzing data and constantly monitoring and analyzing data and reducing exposure to damaging pests and diseases. The system's flexibility is enhanced by incorporating real-time data, such as weather predictions and pest information. The system's real-world benefits are enormous. Farmers have seen greater yields, less resource use, and reduced environmental effects. The approach ensures environmental and agricultural success by promoting data-driven decision-making to better match agricultural practices with sustainability objectives. Constant investigation and improvement are needed to address problems like data precision and scalability. The system's potential to increase farmer agency via information and targeted advice is, nevertheless, hard to deny. This leads to a future where agriculture and technology are in sync, leading to food security and ecological equilibrium. The system's ability to lead agriculture into a more sustainable and resilient future is a monument to the transformational power of innovation.

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