Smart System to Optimize Organic Crop Rotation Using Precision Agriculture Data

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2023 7th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT) | 979-8-3503-4215-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/ISMSIT58785.2023.10304948

***Abstract*—Optimizing organic crop rotation and effectively managing pests and diseases remain a significant challenge for farmers. In this research, we propose a Smart System to Optimize Organic Crop Rotation using Precision Agriculture Data. The system leverages Internet of Things (IoT) technology, machine learning (ML) algorithms, and cloud computing to enhance decision-making and improve productivity in organic farming. The proposed system integrates multiple components to provide farmers with informed decisions for optimized crop rotation. Soil sensors collect data on soil health, which is then analyzed using a multi-objective optimization technique to determine the best crop for a given soil sample. Real-time weather data is incorporated to enable climate-resilient farming practices and help farmers make educated choices in selecting crops and implementing rotation plans. Additionally, a cloud computing-based model is developed for pest and disease identification, providing farmers with effective solutions to combat these challenges in organic methodologies. By leveraging IoT, ML, and cloud computing, our system proposes farmers a more efficient and effective approach to managing their crops. The system provides real-time data-driven recommendations on fertilizer selection and crop rotation, leading to improved crop growth, increased yields, and reduced environmental impact. Moreover, by adopting organic farming practices, the system contributes to the sustainable development of the agricultural sector.**

Keywords—Smart system, organic farming, crop rotation, precision agriculture, IoT, machine learning, cloud computing, pest management, climate-resilient farming, sustainable agriculture.

I. INTRODUCTION

To pursuit of sustainable agriculture, this research aims to develop an integrated smart agricultural system that encompasses crucial functionalities to enhance organic farming practices. The primary focus lies on optimized crop rotation, precision agriculture data integration, smart pest and disease management, and climate-aware decision support. The core functionality of the system revolves around optimized crop rotation and soil analytics. [1] By utilizing real-time data from IoT sensors, the system will assess soil parameters and crop growth patterns to generate personalized crop rotation plans and most optimized crops for a particular soil in real time.This approach maximizes crop yields, fosters sustainable practices, and reduces reliance on synthetic fertilizers. Another vital aspect of our research is the integration of precision agriculture data. By analyzing weather patterns, crop health, and soil variability, farmers will gain valuable insights into resource-efficient crop management. This data-driven approach optimizes agricultural practices and minimizes environmental impacts. To combat challenges posed by pests and diseases, we propose a web-based platform with image recognition and augmented reality (AR) capabilities. This smart system empowers farmers to swiftly identify and manage pests and diseases using non-chemical solutions, promoting organic farming sustainability. [2] Additionally, this research envisions a climate-aware decision support system. Analyzing local weather conditions, including temperature, precipitation, humidity, wind patterns, and extreme events, farmers will receive climate-specific recommendations for crop selection and cultivation strategies. This approach bolsters crop resilience against climate change and optimizes yields under varying weather conditions. By unifying these diverse functionalities, this integrated smart agricultural system seeks to empower farmers with an all-encompassing solution. The fusion of technology, data-driven insights, and sustainable practices will pave the way for a more resilient, productive, and environmentally conscious organic farming sector, contributing to the broader goals of global food security and sustainable agriculture.

II. BACKGROUND STUDY

Agriculture is an essential area of the global economy, providing food, fiber, and raw materials to various industries. However, conventional farming practices would engender negative environmental impacts such as soil degradation, water pollution, and biodiversity loss. As a result, there is an increasing demand for sustainable agricultural practices that prioritize social fairness, economic viability, and environmental protection.

Organic farming has emerged as a promising alternative that focuses on natural inputs and the preservation of soil health. Key components of organic farming include crop rotation and soil analytics. Crop rotation involves alternating different crops in a single field, improving soil fertility, reducing erosion, and controlling pests and diseases. Soil analytics, on the other hand, utilizes advanced technologies to monitor soil properties such as moisture, temperature, and nutrient levels, enabling farmers to make informed decisions about crop selection and management.

The use of external nitrogen, phosphorus, and potassium (NPK) fertilizers in conventional agriculture has been a common practice to provide additional nutrients necessary for plant growth and development. However, the use of external fertilizers has been associated with several negative effects on soil health and the environment. Nitrogen fertilizers, for instance, can lead to groundwater pollution by adding nitrates and can harm aquatic ecosystems. Phosphorus fertilizers can contribute to soil degradation and potassium fertilizers can lead to soil salinization. Frequent use of external fertilizers can make it harder for plants to absorb nutrients and water, resulting in reduced growth and yield [2].

Careful management of external NPK fertilizers is essential to avoid these negative impacts on soil health and the environment. Crop rotation, as an alternative to external fertilizers, offers several benefits to agricultural and soil systems. It reduces weed, insect, and plant disease occurrence, improves soil physical, chemical, and biological characteristics, and enhances water retention capacity and aggregate stability. Additionally, crop rotation reduces greenhouse gas emissions by reducing the need for nitrogen fertilizer and promotes nitrogen fixation by rhizobacteria in leguminous crops.

The importance of organic farming and crop rotation in sustainable agriculture is further emphasized in various research papers. IoT-based soil nutrient analysis and monitoring systems have been developed to address the challenges faced by farmers, enabling real-time data collection on soil conditions, and optimizing agricultural practices [5]. Climate-resilient organic farming techniques, incorporating precision agriculture technologies and weather monitoring, have been proposed to adapt to changing weather patterns and enhance crop productivity while minimizing environmental impacts [6] [7]. ML algorithms, and image processing have been utilized for insect identification and disease recognition in crops [8] [9].

III. Methodology

A. Crop Rotation Creation with Precision Agriculture Data

Our research aims to provide farmers with a tool to facilitate organic crop rotation based on precise data gathered through IoT devices, focusing primarily on the Nuwara Eliya district in Sri Lanka. This research is twofold, interlinking agricultural considerations (50%) and technological applications (50%).

1) Platform and User Interface :The system comprises a mobile application, allowing farmers to input parameters, including soil's NPK level, area temperature, prior crops' data, pest attack history, desired crop rotation duration, and crop family choices. This data is transmitted to a cloud-hosted API, integrated with a rule engine, which processes this information using expert-defined rules to generate a personalized crop rotation plan returned to the user. An accompanying web-based rule editor (Drools Workbench) enables agricultural experts to continuously refine the rule-base, reflecting evolving agricultural insights *[3]*.

2) Implementation: The core of the system is a rule-based engine developed using the Drools framework, deployed on a KIE server. Drools was selected due to its capability to handle complex decision logic and the flexibility to modify rules without changing the core application *[4]*.

3) *Rule Definition:*For the targeted region (Nuwaraeliya),

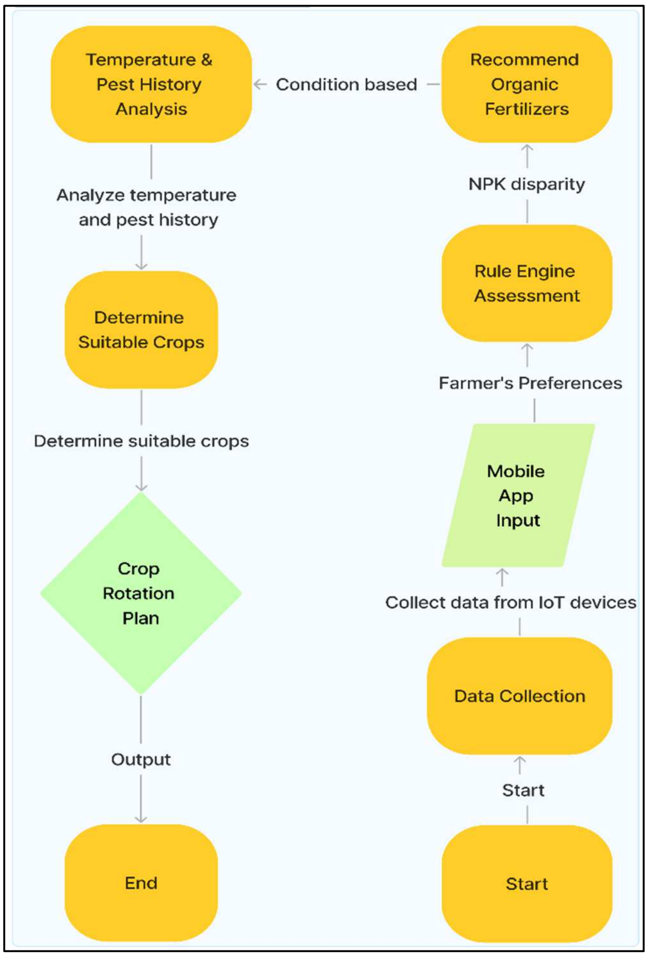

Fig. 1. Data collection to crop rotation recommendation.

we identified viable crop *[5]*families (Vegetables and Root Crops) based on climatic and soil characteristics. For vegetables, optimal soil composition should be Nitrogen (N): 0.1-0.2%, Phosphorus (P): 0.05-0.1%, and Potassium (K): 0.2-0.3% *[5]*. For root crops, it's Nitrogen (N): 0.75-1%, Phosphorus (P): 0.375-0.5%, and Potassium (K): 1.25-1.5% .

4) The rule engine operates sequentially :

a) Validates the compatibility of the NPK values against crop family choices.

b) Assesses the feasibility of cultivating selected crops based on soil health.

c) Evaluates past pest attacks and suggests alternative crops if necessary.

d) Factors in area-specific temperature, suggesting crops that thrive in those conditions.

e) Constructs a crop rotation schedule based on the farmer's desired timeframe, with each crop's unique cultivation period considered.

B. Soil based crop recommendation

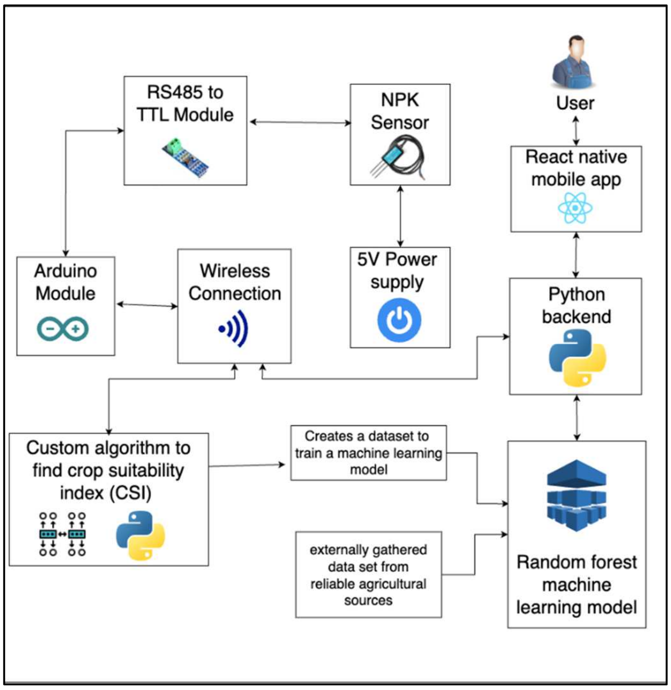

Fig. 2. Overview diagram of soil-based crop recommendation

Soil-Based Crop Recommendation Component aims to recommend the most suitable crops for a given agricultural field based on soil nutrient levels. In fig.2. it shows an overview diagram of the soil-based crop recommendation component. To achieve this, an IoT NPK (Nitrogen, Phosphorus, and Potassium) sensor (JXBS-3001-NPK-RS) was deployed in the target field to measure the soil nutrient concentrations. [6] . When configuring the NPK sensor with the Arduino module NodeMCU ESP8266 was used because of its ability for wireless WIFI communication.

Those gathered data from the NPK sensor is then used with an algorithm to find the Crop Suitability Index (CSI) and generated a dataset with relevant N P K levels and most suitable crop. The CSI represents the compatibility of each crop with specific NPK levels in the soil, enabling effective crop recommendations. Additionally, an external dataset was acquired from reputable agricultural sources, containing information about ideal soil compositions and crops that thrive under specific NPK level ranges. Then both data sets are used to train a machine learning model to ensure the effectiveness of the component. The datasets underwent pre-processing to remove outliers and handle missing values, ensuring data quality and consistency.

Three ML models were considered for crop recommendation: Regression Model, Decision Tree Model, and Random Forest Model. The external dataset was divided into training and testing sets. Each model was trained on the training set and evaluated using its accuracy. [7]Among the evaluated models, the Random Forest Model showed the highest accuracy in predicting the optimal crop for a particular soil sample. The trained Random Forest model was continuously fed real-time NPK data from the sensor and processed it to recommend the most suitable crop based on the current soil conditions. [8] [9].

The Mobile application was developed and configured with a python back end where NPK sensor data is taken in and returns the most optimized crops for a particular soil sample in real time which resulting in high yields with low fertilizers. The integration of the Soil-Based Crop Recommendation Component with the Smart System enabled seamless communication and data exchange between components. The combined outputs from each component were fused using data binding techniques, and the decision-making process utilized the combined information to determine the best-suited crop rotation plan for the agricultural field.

C. Crop suggesion using real time weather data

Therefore, predicting the weather for a given time is part of the weather recommendation component. The information we gather, such as the temperature and humidity, is used in this process. We can collect this weather-related data with the aid of our unique apparatus, which combines a DHT 11 sensor and an Arduino Uno board. The device performs as a weather sleuth, constantly keeping an eye on the temperature and humidity levels outside. So might discover what the weather typically does by looking at the data our equipment collects. We can learn when it will be sunny, wet, or humid, for instance. Farmers should be aware crops that support different kind of weather patterns [10]. According to the weather patterns, farmers are advised on which crops are most likely to thrive on their farms at certain times of year.

Furthermore, it predicts the weather in the future based on empirical data. This system foretells the future by analyzing what has already occurred. This aids farmers in anticipating the weather and preparing for it. The system provides recommendations on when to sow and produce crops based on the collected data and projections. Crops that thrive in certain conditions can be recommended when indications suggest a warm and rainy environment. From this, a tool has been developed that provides farmers with weather information and planting advice. The unique tool analyzes the weather, determines its implications, and then offers guidance to farmers. It's akin to having a weather and farming-savvy companion constantly available for advice. This is how research advances and educates farming.

D. Object detection using yolov5 and augmented reality

Through the flexible Three.js platform, this research aims to establish a novel and ground-breaking methodology that strategically converges the exceptional accuracy of the YOLOv5 object detection model with the immersive and interactive potentials of AR. The main goal of the research is to offer a highly sophisticated solution that is both novel and well-suited for the complex and multifaceted problem of precise pest identification in the ever-changing and convoluted agricultural landscape.

1) YOLOv5 Model for Precise Pest Detection : The thorough collection of an enormous and extraordinarily varied dataset, which includes a broad range of crops and possible pest species, forms the core of this study[19]. Every pest instance in this dataset has been painstakingly vetted and prepped, and bounding boxes have been placed precisely to annotate each case of the pest. The YOLOv5 model goes through a tough training routine after this painstaking annotation procedure, which is strengthened further by the judicious insertion of innovative data augmentation techniques[16]. A battery of tests using well-known metrics including precision, recall, and F1-score are used to assess the model's accuracy and effectiveness rigorously and thoroughly in the field of pest detection. This thorough evaluation approach makes sure that the model is perfectly tailored to function well in real-world scenarios of pest

2) *Enhanced Augmented Reality with Three.js:*A sophisticated virtual world that painstakingly replicates the subtleties of real agricultural landscapes is painstakingly built using the potent powers built into Three.js[20]. The augmented reality experience thrives in this dynamic virtual environment that was meticulously created. Precision camera calibration and a precise and smooth spatial alignment are made possible by the expert tracking and integration of AR markers[17]. Pests are automatically detected and seamlessly placed onto the real-time augmented reality picture, giving users an immersive and dynamic experience that allows them to seamlessly combine the virtual and real worlds[18]. Users are given the opportunity to explore the augmented world thanks to this potent capability, which also makes it possible for them to acquire contextual information in a thorough and interesting way.

3) Integration, Rigorous Testing, and Expert Insights: An integrated system that demonstrates incredible potential is the result of the seamless integration of YOLOv5's detailed and excellent object detection precision and Three.js' immersive AR capabilities. In order to confirm the system's robustness and inherent adaptability across the spectrum of varying conditions encountered in real-world pest management scenarios, this integrated system goes through extensive and meticulous testing across a variety of diverse and complex scenarios. Additionally, seasoned agricultural professionals' unique ideas and criticism are extremely helpful in guiding iterative refinements, ensuring that the integrated system remains attuned to the subtle and intricate nuances of real-world pest management dynamics.

In conclusion, this research is not merely an exploration of technological prowess; it is a testament to the transformative potential of symbiotic innovation. The seamless harmony between the precision-driven object detection capabilities of YOLOv5 and the immersive AR potentials of Three.js signifies a remarkable advancement in the realm of pest management within agriculture [21]. The implications are profound, promising a reimagined landscape of decision-making that is bolstered by enhanced productivity, sustainability, and resilience within the critical domain of pest management.

IV. RESULTS AND DISCUSSIONS

A. Evaluation of the Organic Crop Rotation System Using Precision Agriculture Data

Upon deploying the Smart System for Organic Crop Rotation in the Nuwara Eliya district, several notable outcomes and implications emerged.

1) *System's Recommendations Validity:*Upon evaluation, the recommendations provided by the system largely aligned with the expert advice and traditional knowledge of the region. This validation strengthens the system's credibility and emphasizes the importance of precision data in modern agriculture.

*2) NPK Discrepancies:*In instances where farmers' soil NPK levels deviated from the ideal, the system's recommendations for organic fertilizers and interventions were consistent with best practices. This highlighted the system's ability to provide actionable insights based on precision data. As depicted in table 01 when standard levels for N,P,K differs then metnioned organic fetilizers will propse by system.

TABLE I. FERTILIZER RECOMENDATION

Nutrient	Standard Level	Organic Fertilizers
Nitrogen (N)	0.1-0.2%	Compost, fish meal
Phosphorus (P)	0.05-0.1%	rock phosphate
Potassium (K)	0.1-0.2%	Wood ash

3) *Scalability Considerations:*Given the success in Nuwara Eliya, discussions around expanding the system's rule base to include more districts have been initiated. This will necessitate additional collaborations with local agricultural experts from those districts.

The integration of precision agricultural data into the decision-making process of organic crop rotation showcases promising potential. The system, with further refinements, could serve as a benchmark for other districts in Sri Lanka and potentially for similar agricultural settings worldwide.

B. Crop Recommendation using real time soil data

The Soil-Based Crop Recommendation Component yielded valuable insights, showcasing its potential for precision agriculture. This adaptability to changing soil conditions emphasizes the system's practicality. The algorithm accurately calculated the Crop Suitability Index (CSI) using real-time NPK sensor data and generated a dataset. Three machine learning models were considered for crop recommendation, Regression Model, Decision Tree Model, and Random Forest Model. Noticeably Random Forest Model demonstrated high accuracy in predicting optimal crops based on real-time NPK levels as shown in Fig.3.

The Regression Model operates by establishing

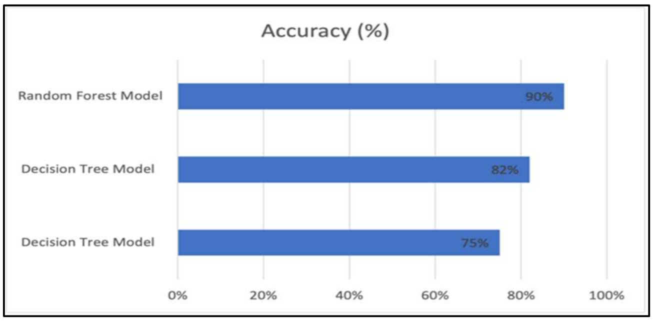

Fig. 3. Accuracy of the machine learning models used.

relationships between the NPK levels and historical crop data. It generates a mathematical equation that captures the correlations between these variables. When presented with current NPK data, the Regression Model uses this equation to predict the most suitable crop based on its understanding of past associations. While this model provides a straightforward prediction, its accuracy is limited by its linear nature and the assumption of a constant relationship between NPK levels. The Decision Tree Model, on the other hand, takes a more intricate approach. It constructs a decision tree which is a branching structure where each node represents a condition based on NPK levels, and each leaf node corresponds to a recommended crop. This model evaluates the NPK data by traversing the decision tree from the root node to a leaf node. At each branching point, it makes decisions based on the NPK values, ultimately arriving at a specific crop recommendation. The Random Forest Model enhances the recommendation process by aggregating the predictions of multiple decision trees. It creates an ensemble of decision trees, each trained on a different subset of the data. When new NPK data is presented, each individual tree in the ensemble provides its own recommendation. The Random Forest Model then combines these recommendations to arrive at a final crop recommendation. This ensemble approach improves prediction accuracy and robustness. Hence configuring the Crop Recommendation Component to the Smart System for Better Organic Crop Rotation, it highlighted how different parts of the system work together. Techniques that combine data made our decisions about crop rotation stronger. This whole Smart System, which uses real-time NPK data and machine learning, helps farmers make better decisions that take care of the environment.

C. Crop suggession using real time weather data

After collecting and analyzing the weather data using smart devices, we discovered some important things. We noticed that during hot and dry times, certain crops like tomatoes and peppers tend to do well. On the other hand, when it's rainy and a bit cooler, crops like lettuce and spinach seem to thrive. Additionally, it turned out that the weather forecasts were a good match for what transpired. As a result, farmers may find our smart device to be a beneficial planning tool [11]. For instance, if our device alerts them that the upcoming week will be bright, they might choose to grow crops that benefit from sunlight.

TABLE II. WEATHER BASED CROP RECOMENDATION

Weather Conditions	Average Temperature (°C)	Average Humidity (%)	Recommended Crops
Hot and Dry	30°C	40%	Tomatoes, Peppers
Rainy and Cooler	22°C	65%	Lettuces, Spinach
Consistent Rainfall	25°C	80%	Rice, Corn
Warm and Dry	28°C	35%	Melons, Sunflowers

The average temperature, humidity, and recommended crops are all included in table 02 along with the weather data. Farmers can choose the best crop rotation practices by carefully weighing these elements in tandem. Even though our smart system recommendations typically come true, farmers should be adaptable because the weather might occasionally change unexpectedly.

The unique aspect is that our technology does more than just provide weather information; it also makes agricultural planting recommendations [12] as shown in the fig.4. Farmers now have an easier time deciding what to cultivate and when. It's like having a helpful friend who is an expert on weather and farming. The forecasts we made

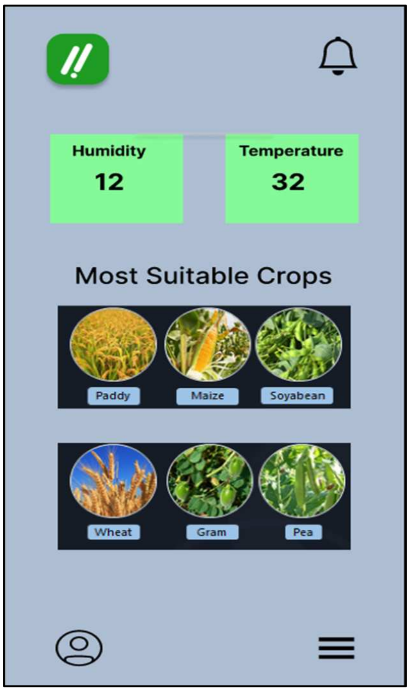

Fig. 4. Weather based crop recommendation UI output.

weren't always accurate, though, as we discovered. Guessing the weather can be challenging, especially when it changes unexpectedly [13]. Because of this, even though our device is useful, it's still a good idea for farmers to keep an eye on the skies in case something happens.

D. Pest detection with yolov5 and augmented reality

The comprehensive assessment metrics covering recall, accuracy, precision, and F1 score like shown in the fig. 5, provide a quantified look at the effectiveness of the React Native-YOLO augmented reality solution for pest overlay in real situations.

The actual application highlights the smooth combination of YOLO's sophisticated pest detection skills, React Native's dynamic user interface, and augmented reality's immersive possibilities. This synthesis appears as a powerful tool to seamlessly incorporate digital pest markers into physical environments, enhancing in-the-moment interaction.

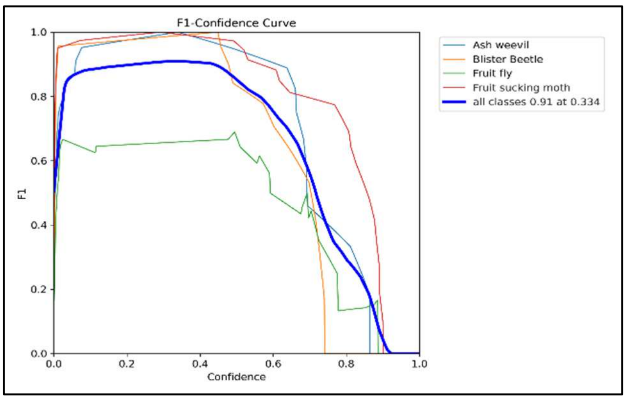

Fig. 5. F1-Confidence curve

Fig. 6. Pest Detection of the model

Beyond numerical quantities, the discussion's core issues are involved. According to figure5, digital pest indicators are integrated with the physical environment to create an augmented reality that adds richness to user experiences. The interactive aspect is highlighted; users actively interact with virtual overlays in their current context in addition to identifying them. This combination opens the door for a wide range of uses, from agricultural analyses to public health interventions. Additionally, the combination of these technologies resonates with a wider range of immersive and computer vision domains. The future is brighter with improved real-time detection, increased engagement, and a wider range of applications.

V. CONCLUSION

This research successfully introduced a Smart System for Optimized Organic Crop Rotation, harnessing the capabilities of the IoT, ML, and cloud computing to address prevalent challenges in organic farming. Through real-time soil health analytics and climate-sensitive data processing, would instrumental for farmers to make decisions about the exact time period of crop rotations in turns, save from pest attacks, and suggest remedies for diseases. Notably, the cloud computing-based model for pest and disease identification emerged as a pivotal tool, bridging traditional farming methodologies with modern technological solutions. By integrating these technological advancements with traditional agricultural practices, we believe our system not only optimizes organic farming but also propels the agricultural sector closer to its sustainability goals.

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