AI based model to characterize soil and suggest suitable organic fertilization techniques

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BACHELOR OF TECHNOLOGY
In
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DECLARATION

I/We declare that the project work contained in this report is original and it has been done by me under the guidance of my project guide.

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Chapter 1: Introduction

1.1 Overview of the problem statement

The agricultural landscape is undergoing a significant transformation, driven by the need for sustainable and efficient farming practices. Artificial intelligence (AI) has emerged as a powerful tool in this domain, offering innovative solutions to various challenges. One such application lies in characterizing soil and suggesting suitable organic fertilization techniques .The project aims to develop an AI-based model that characterizes soil properties and recommends suitable organic fertilization techniques tailored to the specific needs of the Bengaluru Rural area. By leveraging machine learning algorithms, the system will analyze various soil parameters such as pH, moisture content, nutrient levels, and organic matter. The data for these parameters will be collected using an embedded system equipped with sensors for real-time soil monitoring. The embedded system will process the sensor data and transmit it to a central processing unit, where machine learning models will analyze the data to predict soil health and recommend optimal organic fertilization strategies.

1.2 Objectives and goals

- Soil Characterization: Develop a machine learning model to get an accurate characterization of soil with respect to physical, chemical, and biological properties from data obtained on soil samples.
- Fertilization Recommendation: Design an AI-driven recommendation system that proposes suitable organic fertilizers in view of the characteristics of the soil, crop requirements, and environmental factors.
- Data Integration: Integrate a number of datasets, including test results on soils, nutrient requirements of crops, and composting of organic fertilizers, into one comprehensive database for use in training and validating models.
- Model Interpretability : Use explainable AI techniques so that predictions and recommendations by the model are transparent and easily understandable for agricultural experts and farmers.

Main Goals:

- Improved Agricultural Productivity - Crop yield and soil health through proper, datadriven organic fertilization.
- Sustainability- Support sustainable agriculture by reducing the consumption of chemical fertilizers.

- User-Friendly Application- Develop a user-friendly interface for collecting soil data from the farmer for fertilization recommendations.

Additional Goals:

Validation and Testing - Validate the model concerning accuracy on various types of soils and crops . Knowledge Transfer - How to share knowledge and tools among the agricultural community so that there will be widespread adoption.

Chapter 2 : Literature Review

Introduction to Soil Composition and Importance in Agriculture

1. Composition of Soils

Soil is a complex, dynamic, and vital natural resource. It plays a crucial role in plant growth, regulation of water, and maintaining the balance of the environment. The composition of soil differs considerably with respect to location, climatic conditions, and land use. Some of the main constituents of soils are as follows:

Mineral Particles: They are inorganic constituents resulting from the weathering of rocks. They are classified into sand, silt, and clay based on size. Their relative amounts determine the texture of a soil. Texture refers to the water-holding capacity, aeration, and availability of food for plants.

Organic Matter: Composed of decomposed plant material and animal matter, organic matter is required to hold the fertility of the soil. It improves the structure of the soil, enhances water and nutrient retention, and allows good growth of useful microorganisms.

Water: Water in the soil, also called soil moisture, is essential for plants since it is what nutritionally dissolves and makes it available for plants to absorb. How much water it can hold for a given soil depends on its texture and organic matter content.

Air: Soil air refers to that which is occupied in the pore spaces between soil particles. This is very essential for root respiration and also the activity of micro-organisms in the soil.

Soil Nutrients: These are basic elements, for example, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Nutrients in soil are quite vital for plant growth and development.

pH Level: This refers to the measure of acidity or alkalinity of the soil and affects the availability of the nutrients and activity of the microbes. Most crops prefer a slightly acidic to neutral pH, around 6-7.

Ref No	Title of the paper	Year	Authors	Key Findings	Research Gaps
1.	A Review on Applications of Artificial Intelligence For Identifying soil Nutrients	2023	Shagun Jain(B) and Divyashikha Sethia	1.For the crops, everything means the nutrients in the soil, and AI can accomplish this job much quicker and inexpensively than other ways of monitoring.	1.The paper notes that it is difficult to achieve AI models that can perform well across regions, considering that there are

				2.Those can locate nutrient issues via AI technologies like Machine Learning to further grow crops. 3.Great potential is promised, while the developer still needs to work on the various soil types and algorithmic complications.	variations in soils. 2.There was noticed the need to increase the effectiveness of algorithms against the background of data complexity when using AI for soil analysis. 3.It is also noted in the reviews that, so far, AI is not very widely spread for soil nutrient prediction, and more research is required in terms of environmental impact.
2.	Explainable AI for Soil Fertility Prediction	2023	HARSHIV CHANDRA , PRANAV M. PAWAR,E LAKKIYA R., TAMIZHA RASAN P S , RAJA MUTHALA GU ,AND ALAVIKUN HU	1.Very Accurate: The model is correct in predicting soil fertility with an accuracy of 97% of the time. 2.Uses Huge Data: It leverages a large, rich dataset with detailed information on soil from all over Europe. 3.Easy Explanations: It helps farmers understand their soil and make better	1.Model Transparency: The need for models to provide understandable predictions to the users and not purely be a black box like the current ones. 2.Global Applicability: The model should be tested

			PANTHAKKAN	decisions by providing comprehensible graphs	for effectiveness in diverse regions and conditions other than the EU. 3.Long-term Impact: There is a need for research into the long-term impact of the model's recommendations on soil health.
3.	IoT-enabled Crop Recommendation in Smart Agriculture using Machine Learning	2023	Gregory Davrazos, Theodor Panagiotakopoulo, Sotiris Kotsiantis, Achilles Kameas	1.Random Forest is the best model for the recommendation of crops with IoT data. 2.Locally, main factors for crop yield prediction involve geographical data and soil properties. 3.Thus, by using IoT with machine learning, the farmer can choose the most suitable cropone with increased sustainability.	1.Applying Advanced Models: The study used basic models; therefore, future workers could test more advanced ones. 2.Normalize Data: There must be a standardized form of preparation since different methods of preparation may be needed.
4.	Adapting Crop Recommendations to Local Climate Variability Through	2000	Thirumala Akash K, Mohammed Usman F, Nitesh Kumar T, and	1.Very Accurate: Machine learning can predict what crops need with 99.7% accuracy. 2.Adapts to Changes: It works good in	1.Data Collection Issues: Small farmers find it difficult to collect all the data. 2.Complex Tools: The systems are highly

	Machine Learning		Mohammed Riyaz Ahmed	various weather and situations.	complicated and require easier interfaces.
5.	PRODUCTION AND UTILIZATION STRATEGIES OF ORGANIC FERTILIZERS FOR ORGANIC FARMING: AN ECOFRIENDLY APPROACH	2013	MD.SADIQUE SHAIKH1 AND MADHURI A. PATIL	1.Ecological Advantages: Organic fertilizers preserve the soil and develop healthier plants. 2.Slow Nutrient Release: They slowly release nutrients and, therefore, are less harmful to the environment. 3.Nutrient Balance and Rules: Proper nutrient balance is important, and fertilizers must meet organic farming standards.	1.Long-Term Impact: Study how organic fertilizers affect soil and crops over time, and compare them with chemical fertilizers. 2.Soil Health: Explore how organic fertilizers work with soil microbes and improve nutrient management. 3.Regulations: Improve rules and methods to prevent fraud and ensure organic fertilizers are genuine.

Chapter 3 : Strategic Analysis and Problem Definition

3.1 SWOT Analysis

Strengths

S1. High precision and efficiency

S2. Customizable recommendations

S3. Promotes sustainability

Weaknesses

W1. Depends on data quality

W2. Complex to implement

W3. High initial costs

W4. Needs frequent updates

Opportunities

O1. Advancements in technology

O2. Expansion to new Markets

O3. Integration with other Tools

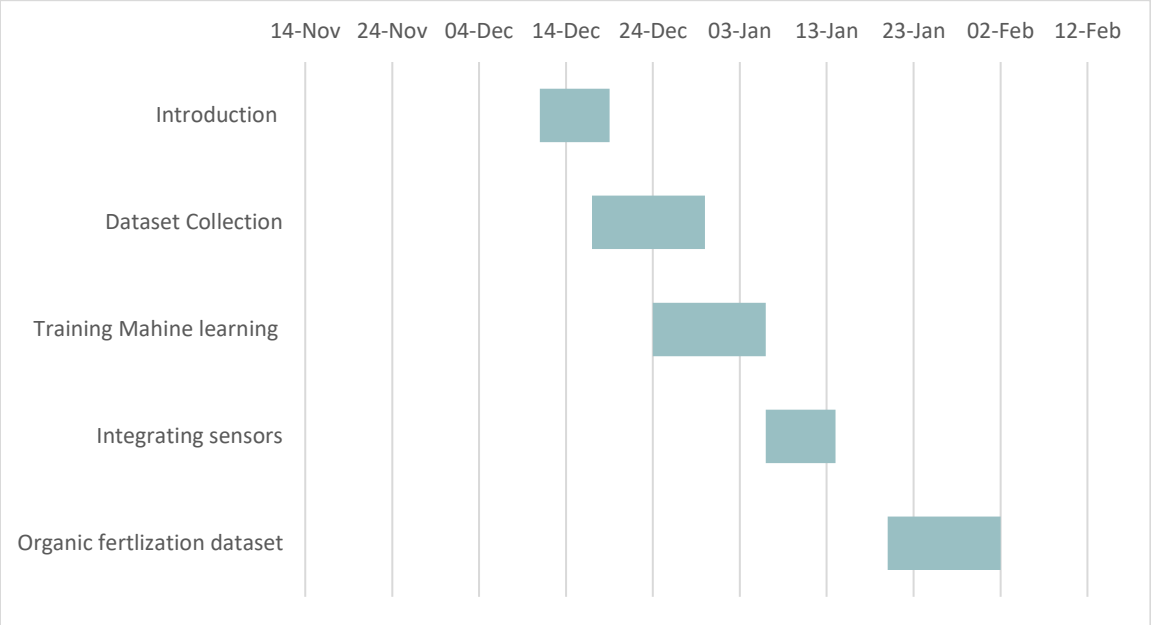
O4. Educational potential

Threats

T1.Resistance to change

T2.Environmental variability

3.2 Project Plan - GANTT Chart



3.3 Refinement of problem statement

The purpose is to develop an AI-informed model which identifies the soil property and provides a suitable method of organic fertilization at a specific point in space for high crop yield. Therefore, for soil parameters, including pH values, nutrient profiles, moisture content, and texture, this model will be making recommendations at the individual level based on data to organic fertilizers. It encourages sustainable agricultural practices and minimizes the use of chemical fertilizers while maximizing crop yield and soil health.

Key objectives:
Soil analysis: Adopt AI for the combination of data from different sources, including sensors, satellite-related data, and laboratory results, in the determination of key characteristics impacting crop yields.
The model will be based on the analyzed soil data and crop requirements, providing organic fertilization methods that improve soil fertility and facilitate safer, more eco-friendly farming practices.

Adaptability: The model will be adaptable to different soil types, climatic conditions, and crop varieties, ensuring accurate recommendations across a wide range of farming conditions.

Sustainability Focus Organic fertilization solution with respect to sustainable improvement in soil health that supports environment-friendly activities and biodiversity promotion.

These are the key considerations:

Data Quality and Quantity: Good quality and representative soil data should be available to be able to train the AI model effectively.

Model Selection: The nature of the data, the problem complexity, and its suitable ML algorithms such as random forest, support vector machines, or neural networks should be chosen.

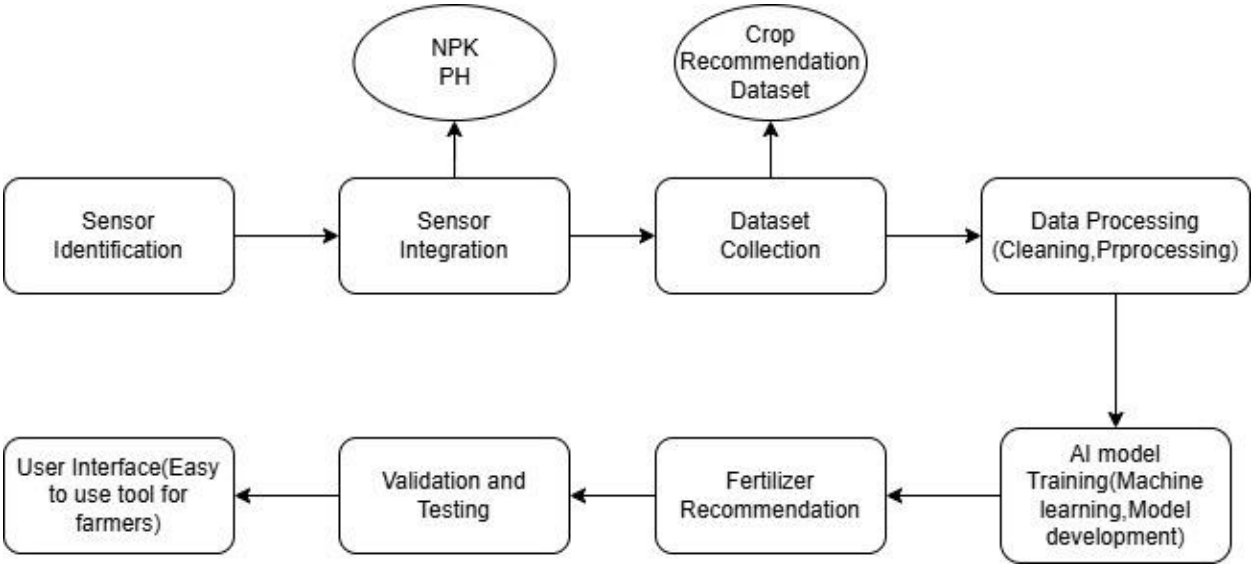
User Interface: Develop an intuitive and user-friendly interface through which farmers input soil data and receive personalized recommendations.

Scalability: Design a system that handles huge datasets and diverse agricultural scenarios.

Ethical Considerations: Take all necessary steps that are required to have responses to concerns with regard to privacy and the responsible usage of AI in agriculture.

Chapter 4 : Methodology

4.1 Description of the approach



4.2 Tools and techniques utilized

1.Data Collecting Devices :

Accurate and trustworthy data collection is essential for AI-based soil characterization and organic fertilizer recommendations. Real-time soil data is collected by a variety of sensors and Internet of Things devices, and it is subsequently preprocessed for additional analysis using AI algorithms.

Sensors for Soil :

Specialized tools called soil sensors are used to measure important aspects of soil. The following are the main categories of sensors utilized in agriculture:

NPK Sensors

Goal: Determine the soil's levels of potassium (K), phosphorus (P), and nitrogen (N).

Working Principle: To identify nutrient levels, these sensors usually employ optical spectroscopy or ion-selective electrodes.

Applications: NPK sensors help recommend appropriate organic fertilizers by offering insightful information about soil fertility.

CropX NPK sensors and Hanna Instruments are two examples.

pH Sensors

Goal: Find the pH of the soil to determine how acidic or alkaline it is.
Working Principle: The amount of hydrogen ions in the soil solution is measured by a glass electrode.
Applications: Plant health and nutrient availability depend on maintaining ideal pH levels. It may be suggested to add organic amendments such as sulfur for alkaline soil or lime for acidic soil. For instance, HORIBA pH meters and Bluelab soil pH pens.

2.Algorithms :

Machine Learning:

a. Models of Soil Classification

Decision Trees: It is a tree-based classification algorithm. They employ this decision trees for the classification of different types of soil depending on pH level, nutrient content, and texture.
Random Forest: This is another method which based on ensemble to predict from the multiple decision trees to get an increased accuracy.
Support Vector Machines (SVM): A classifier that, given a number of soil types, tries to find the best decision boundary between them
KNN Algorithm: This predicts the class of a data point based on the classes of its k-nearest neighbors in the feature space.

b. Models for fertilizer recommendation

Rule-based Expert Systems: Applied predefined rules as created by agricultural experts ("If soil nitrogen is low, recommend compost or manure").
Reinforcement Learning: Feedback loops enable the AI to act to optimize fertilizer recommendations by observing crop performance over some time.
Collaborative Filtering: This technique would predict which organic fertilizers similar types of soil and crops used by other farmers might require, much like the recommendation engines used in e-commerce today.

4. AI Model Development Tools:

Python Programming Language: The main language for data analysis, machine learning, and development of AI models

5. Metrics and Techniques for Evaluation:

Accuracy, Prediction speed, Error rate and F1-score: These metrics would indicate the extent to which the soil classification model performed.

Cross-validation: Techniques like k-fold crossvalidation would make sure it generalizes well to unseen data.

Confusion Matrix: To picture how well the classification model is performing (correct vs. incorrect predictions).

6.Real-time Data Integration :

IoT Devices: Integration with smart soil sensors that collect real-time data from the devices and feed it to an AI system, to continuously monitor.

4.3 Design considerations

1. Sensor Selection and Placement

- Sensor Type: Choose appropriate sensors for soil parameters such as NPK levels, pH, moisture content, and electrical conductivity.
- Accuracy and Sensitivity: Sensors should have low error margins and high sensitivity for detecting small variations.
- Environmental Durability: Sensors must withstand harsh environmental conditions like temperature fluctuations, moisture, and dust.
- Optimal Placement: Sensors should be strategically positioned at various depths and locations to capture accurate data, considering soil heterogeneity.

2. Data Collection and Connectivity

- Data Frequency: Determine how often sensors collect and transmit data. Real-time monitoring may require continuous data, while periodic data is suitable for long-term analysis.
- Connectivity Options: Use reliable communication protocols like LoRaWAN, NB-IoT, or Wi-Fi depending on field size and network availability.
- Power Management**:** Implement low-power sensors with solar charging or battery backup to ensure uninterrupted data collection.
- Data Redundancy: Use multiple sensors and backups to prevent data loss.

3. Data Processing and Preprocessing

- Data Normalization: Standardize data values to ensure consistency across different sensors and environmental conditions.
- Missing Data Handling: Implement interpolation or imputation methods to handle missing or incomplete data.

- Real-time vs. Batch Processing: Real-time analysis is suitable for irrigation control, while batch processing can be used for seasonal soil analysis.

4. AI Model Selection and Training
   - Model Type: Choose suitable AI models based on application requirements:
     - Regression Models: For predicting soil nutrients and moisture levels.
     - Classification Models: For determining soil types and identifying nutrient deficiencies.
     - Recommendation Systems: For suggesting organic fertilizers based on soil characteristics.
   - Training Data: Ensure diverse, labeled datasets with soil samples from various regions to improve model generalization.
   - Validation and Testing: Use cross-validation and performance metrics like RMSE (Root Mean Square Error) for model evaluation.

5. Fertilizer Recommendation Logic
   - Organic Fertilizer Database: Maintain a database of organic fertilizers, including compost, manure, and biofertilizers with nutrient compositions.
   - Rule-based Recommendations: Develop AI algorithms that apply agronomic rules to suggest fertilizers based on soil nutrient levels and crop requirements.
   - Optimization Algorithms: Implement algorithms like Genetic Algorithms (GA) or Particle Swarm Optimization (PSO) to recommend the most effective fertilizer combination.
   - Customization: Provide personalized recommendations based on the crop type, soil health, and environmental factors.

6. User Interface and Accessibility
   - Farmer-Friendly Dashboard: Develop mobile or web applications with a simple interface to display real-time soil data and fertilizer suggestions.
   - Multilingual Support: Provide regional language support to ensure accessibility.
   - Alert System: Implement notifications for abnormal soil conditions or critical nutrient deficiencies.
   - Data Visualization: Use graphs and maps for intuitive understanding of soil properties.

7. Sustainability and Scalability
   - Eco-Friendly Sensors: Prefer sensors with low energy consumption and recyclable materials.
   - Scalability: Design the system to scale from small farms to large agricultural regions using distributed sensor networks.
   - Data Privacy: Ensure data security through encryption and compliance with agricultural data protection regulations.
   - Integration: Provide APIs for integration with external agricultural management platforms and government databases.

Chapter 5 : Implementation

5.1 Description of how the project was executed

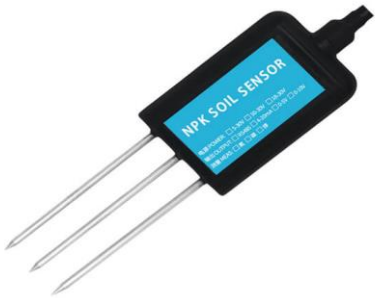
1. Project Scheduling and Goal Establishment

The project team set out to create a machine learning model that would use sensor data to analyze soilproperties and suggest appropriate organic fertilizers.
Improved agricultural productivity, sustainability, and farmer-friendliness through an intuitive application were the objectives.
To find suitable techniques for soil characterization and fertilization, a great deal of research was done.

2. Data Collection and Sensor Deployment

- **Sensor Selection:** The team chose RS485 NPK sensors for nutrient analysis and pH sensors for monitoring soil acidity.

Ph Sensor



NPK Sensor

- **Component Assembly:** Sensors were integrated with an Arduino Board and other hardware components, including a breadboard and connecting wires.

- **Soil Data Collection:**
  - Different types of soil samples were collected.

  - Sensors provided real-time data on nitrogen (N), phosphorus (P), potassium (K), and pH levels.
- Additional soil datasets were sourced from platforms like Kaggle to enhance the dataset for model training.

3. Data Collection of Organic fertilizations

- Compost: 2% N, 1.5% P, 1.5% K
- Manure: 2% N, 1% P, 1% K
- Fish emulsion: 9% N, 0% P, 0% K
- Cow manure: 2.5% N, 1% P, 1.5% K
- Blood meal: 12% N, 1.5% P, 0.5% K
- Bone meal: 4% N, 20% P, 0% K
- Feather meal: 12% N, 0% P, 0% K
- Fish meal: 10% N, 5% P, 4% K
- Alfalfa meal: 2.5% N, 1% P, 1.5% K
- Bat guano: 8% N, 6% P, 1% K
- Cotton seed meal: 6% N, 3% P, 1% K
- Corn gluten meal: 0.5% N, 0.5% P, 1% K
- Seaweed: 1% N, 2% P, 5% K
- Chicken manure: 3.5% N, 1.5% P, 1.5% K
- Greensand: 1% N, 1% P, 5% K
- Soybean meal: 3% N, 0.5% P, 2.5% K
- Worm castings: 5% N, 3% P, 2% K
- Mealworm frass: 3% N, 3% P, 2% K
- Banana shoots: 0.5% N, 1% P, 0.5% K

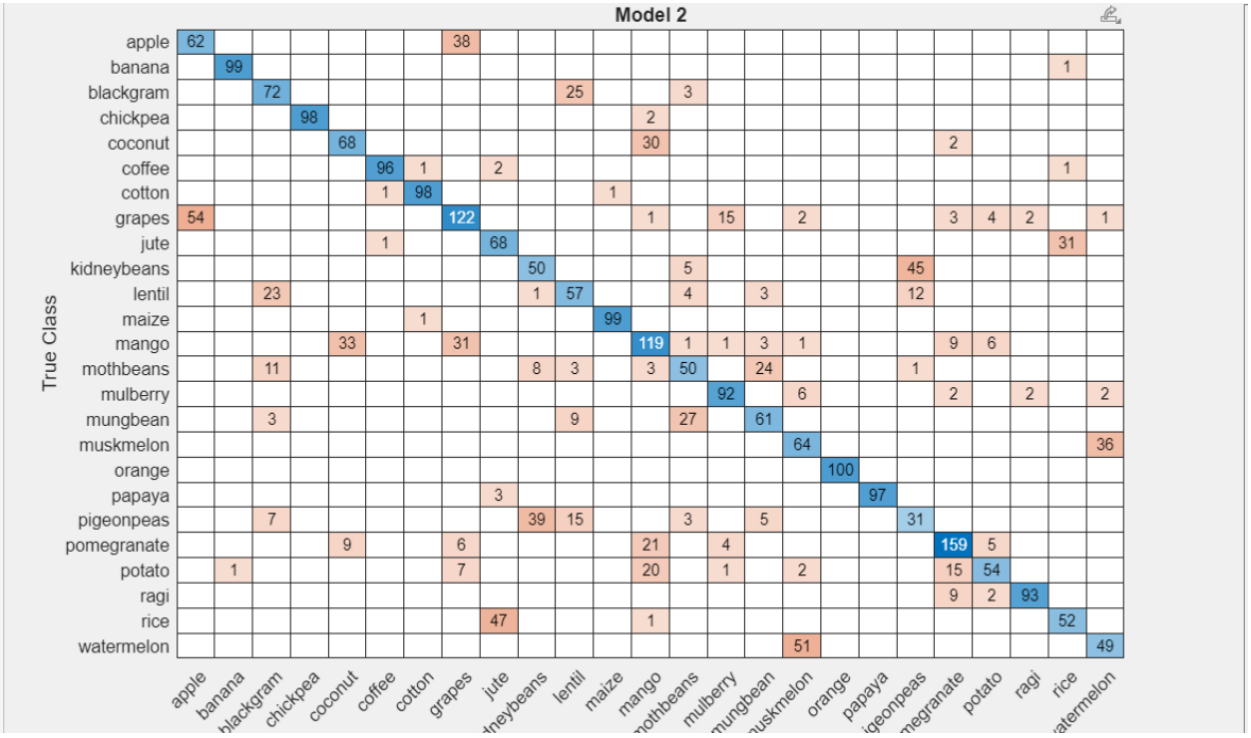
4.AI Model Selection and Training

1. Model Selection

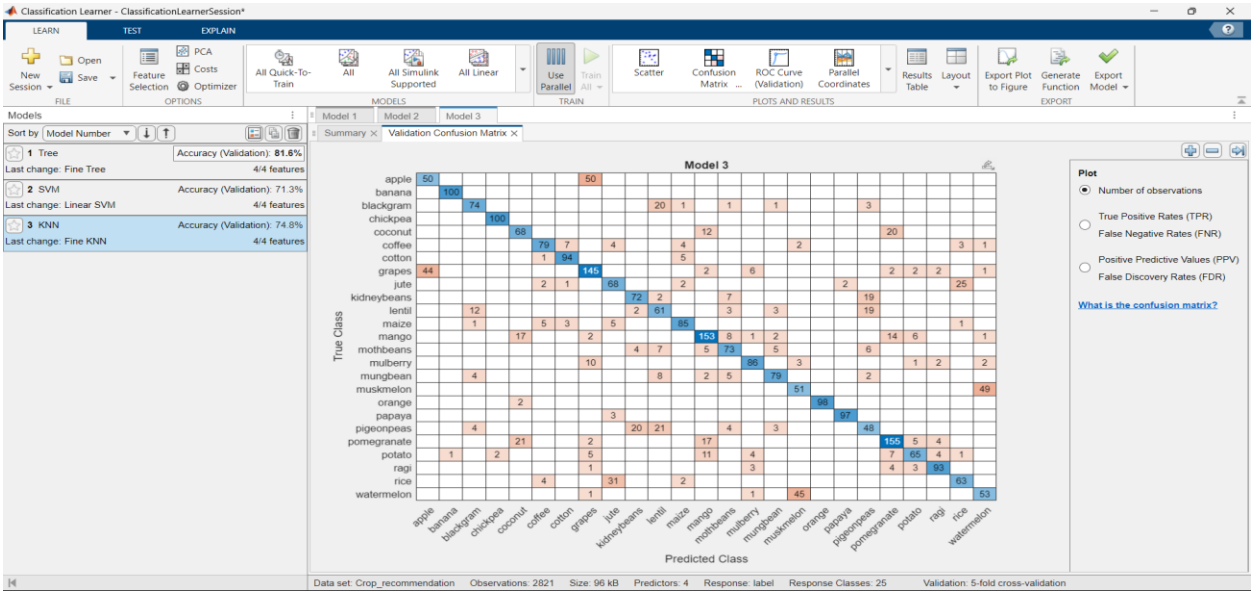
- Algorithms Evaluated: During the selection process, multiple machine learning algorithms were considered, including:
  - Support Vector Machine (SVM) - Known for its effectiveness in classification tasks.
  - K-Nearest Neighbors (KNN) - A simple and efficient algorithm for soil classification based on proximity to neighbors.
  - Decision Tree - Provides interpretability and clear decision-making logic.
- Final Model:
  - After comparative evaluation, Decision Tree was chosen as the primary model due to its high accuracy in classifying soil types based on non-linear data.

Training Data in MATLAB - Classification Learner App

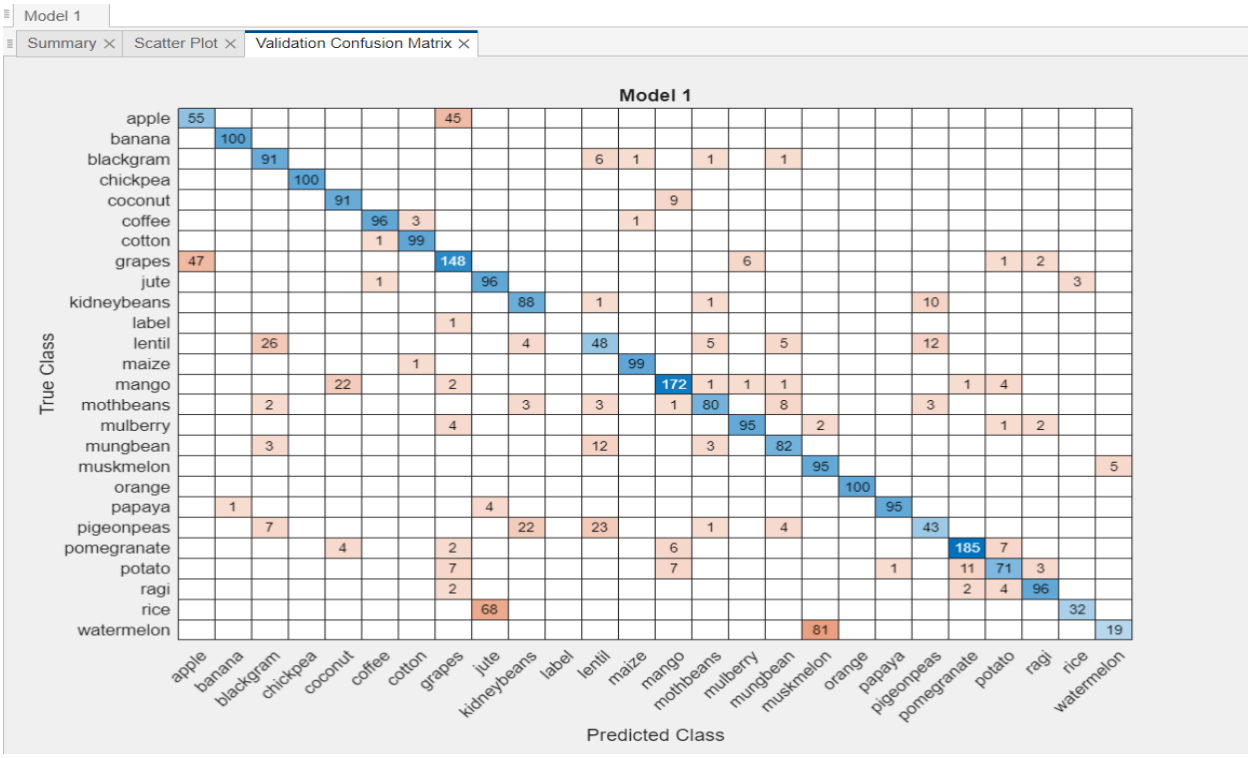
SVM-Support vector machine algorithm



KNN-k-nearest neighbours algorithm



Decision Tree algorithm (Final Model)used:



Training Results

Accuracy (Validation)	80.7%
Total cost (Validation)	545
Error rate (Validation)	19.3%
Prediction speed	~29000 obs/sec
Training time	10.677 sec
Model size (Compact)	~105 kB

Model Hyperparameters

Preset: Fine Tree
Maximum number of splits: 100
Split criterion: Gini's diversity index
Surrogate decision splits: Off

2. Data Preparation

- Data Cleaning and Normalization:
  - The sensor data from NPK sensors and pH sensors were cleaned to remove any noise or inconsistencies.
  - Normalization was applied to scale the data within a defined range, improving model convergence.
- Feature Selection:
  - Features such as Nitrogen (N), Phosphorus (P), Potassium (K) and pH Level were selected as inputs to the model.

	A	B	C	D	E
1	N	P	K	ph	label
2	90	42	43	6.5029853	rice
3	85	58	41	7.0380964	rice
4	60	55	44	7.8402071	rice
5	74	35	40	6.9804009	rice
6	78	42	42	7.6284729	rice
7	69	37	42	7.0734535	rice
8	69	55	38	5.7008057	rice
9	94	53	40	5.7186272	rice
10	89	54	38	6.6853464	rice
11	68	58	38	6.3362535	rice
12	91	53	40	5.3861678	rice

5.MATLAB GUI (App Designer)

What is MATLAB GUI?

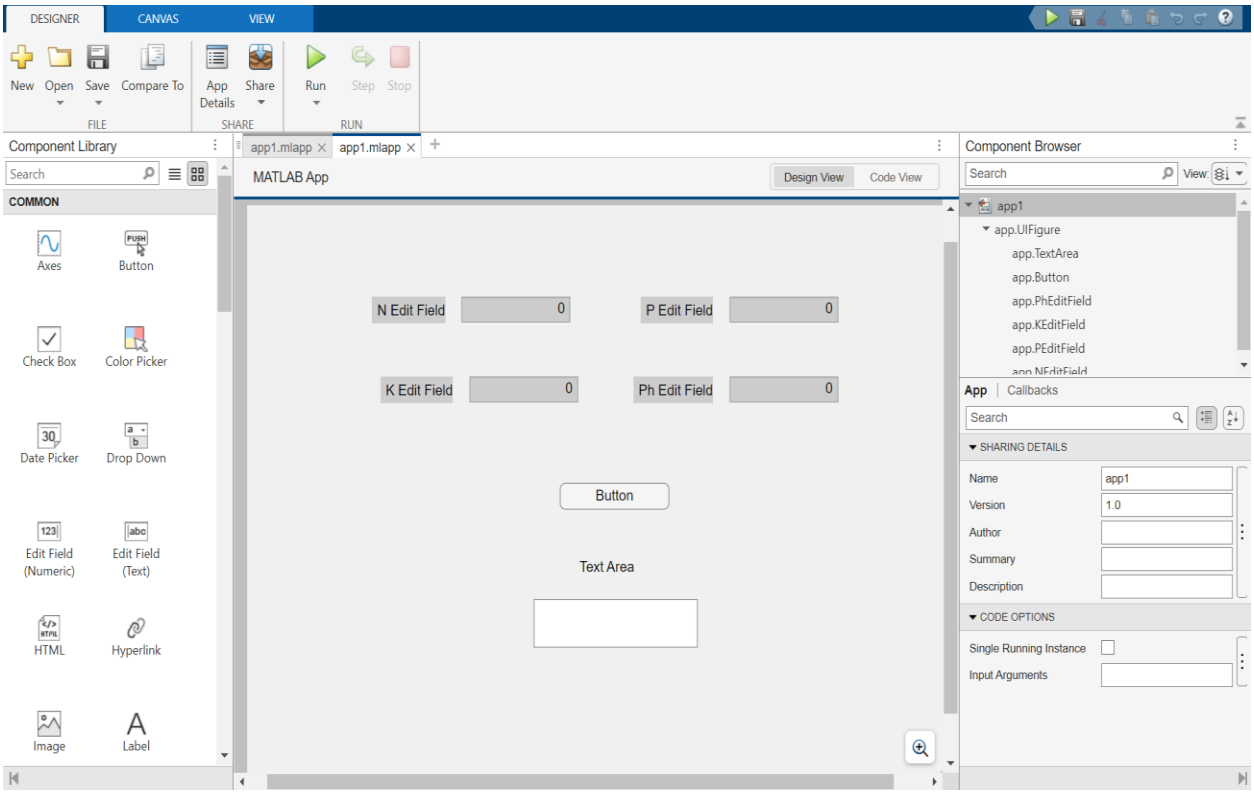
- MATLAB GUI (Graphical User Interface) allows users to create interactive applications.
- It enables users to interact with MATLAB programs using buttons, sliders, text fields, and other UI elements instead of writing code in the command window.

Why Use MATLAB GUI?

✓User-Friendly–No need to type complex commands; just click buttons.
✓Visual Representation–Easier data visualization and interaction.
✓Automation–Helps automate tasks without requiring programming knowledge.
✓Customization – Design interfaces tailored to specific applications.

MATLAB GUI Tools

App Designer – A drag-and-drop tool to create professional apps .
GUIDE (Legacy) – Older tool for building UIs (now replaced by App Designer).



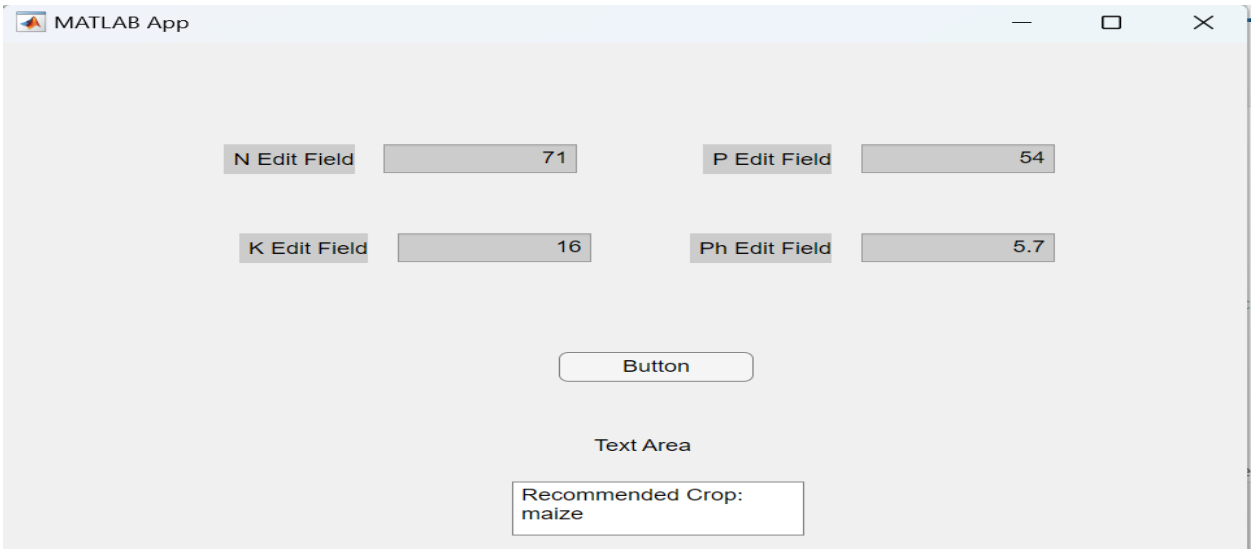
5.2 Challenges faced and solutions implemented

Challenge	**Solution Implemented**
Inaccurate Sensor Readings	Recalibrated the sensors using test soil samples and applied noise reduction algorithms.
Data Integration Issues	Standardized data using normalization techniques and handled missing data using interpolation.
Model Overfitting	Applied cross-validation and optimized hyperparameters to enhance model generalization.
Difficulty in Sensor Communication	Used RS485 module for reliable data transmission from sensors to Arduino.
Limited Dataset for Specific Soil Types	Augmented data using publicly available soil datasets from Kaggle for better model training.
Complex User Interaction	Developed a MATLAB GUI with a simplified, intuitive interface for real-time soil analysis.

Chapter 6:Results

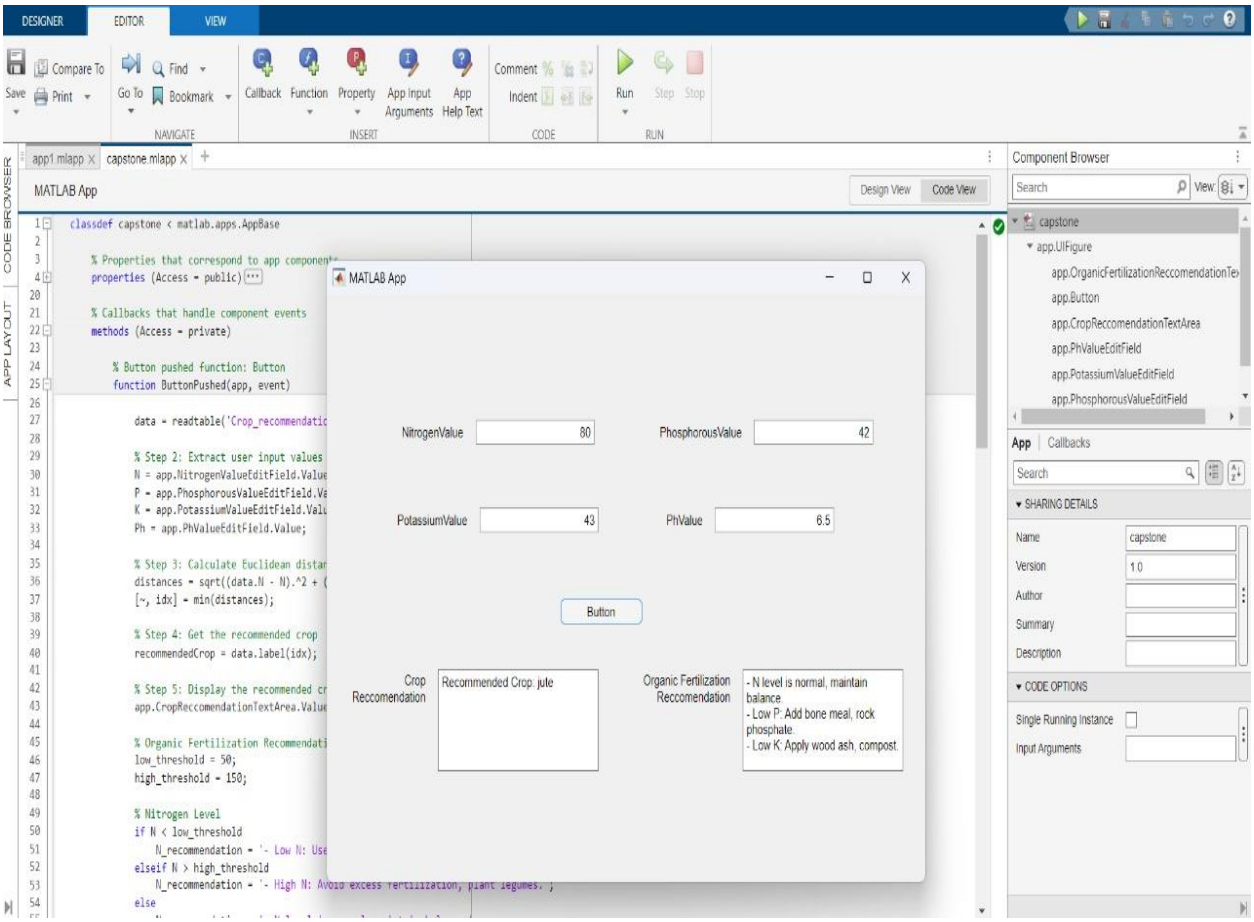
6.1 outcomes

Implementation 1 outcome:



Implementation 2 outcome:

Final Outcome :



6.2 Interpretation of results

- **Soil Characterization Accuracy:**
  The Decision Tree algorithm model provided a classification accuracy of over 80.7% for soil type prediction.
- **Fertilizer Recommendations:**
  The system effectively suggested organic fertilizers like compost, manure, or bone meal based on the analyzed soil parameters.
- **User Experience:**
  The MATLAB GUI allowed farmers to easily input soil data and receive instant fertilizer recommendations.

6.3 Comparison with existing literature or technologies

Current Technologies: Laboratory analysis is the foundation of conventional soil testing techniques, which are expensive and time-consuming. On the other hand, the suggested AI model uses inexpensive sensors to provide real-time soil analysis.

AI Implementation: This project applied several models (SVM, KNN, and Decision Trees) and chose the most accurate one, in contrast to existing models that only use one algorithm.

Recommendation for Organic Fertilizer: Chemical fertilizers are frequently suggested by current systems. By recommending organic fertilizers according to soil requirements, this project encourages sustainable farming.

Benefit: Sustainable, economical, and quicker soil management.

Existing AI-Based Solutions:

Feature	Existing AI Solutions	Proposed System
Model Selection	Often limited to single algorithms.	Utilized multiple models (SVM, KNN, Decision Tree) to compare and select the best.
Fertilizer Recommendation	Typically recommends both chemical and organic fertilizers.	Focuses solely on sustainable, organic fertilizers.
Sensor Integration	Uses sensors with basic soil analysis.	Integrated calibrated RS485 sensors for real-time, accurate data.
User Interface	Some systems lack intuitive designs for farmers.	Developed a simple MATLAB GUI for user-friendly interactions.

Chapter 7: Conclusion

There are numerous chances for additional study and development to improve the functionality and impact of the AI-based soil characterization and organic fertilization recommendation system, even though it has demonstrated encouraging results.

Including Cutting-Edge Sensors:

For a more thorough soil analysis, add more sensors to measure soil temperature and micronutrients (such as calcium, magnesium, and sulfur).
Use hyperspectral or multispectral sensors to collect comprehensive data on soil health.
Including Weather Information:

Create a system that uses APIs to incorporate real-time weather data and modify fertilizer recommendations according to temperature, humidity, and rainfall.
Use weather patterns to forecast the rates of soil nutrient depletion.
Improvement of AI Models:

For intricate soil data analysis, use Deep Learning models such as Recurrent Neural Networks (RNNs) or Convolutional Neural Networks (CNNs).
Create self-learning AI models with real-time feedback and ongoing data collection to increase accuracy.
Crop-Specific Suggestions:

Using the soil analysis and anticipated nutrient needs, extend the recommendation system to offer crop-specific recommendations.
To suggest fertilizers that optimize crop productivity, incorporate a predictive yield model.
Geographical Analysis:

Create soil health maps for sizable agricultural areas by incorporating GIS (Geographic Information System) data.
Make tailored, local fertilizer recommendations.

Chapter 8 : Future Work

1.Development of Mobile Applications:

a. Create a smartphone app that gives farmers access to real-time soil data and suggestions.

b. Make it accessible to farmers in rural areas by implementing a multilingual interface.

2.Cloud-Based Information Management:

a. For long-term monitoring and remote access, store sensor data in a cloud database.

b. Permit data exchange for regional soil analysis with agricultural researchers and policymakers.

3.Alerts and Notifications in Real Time:

a. Give farmers immediate notifications of dangerous soil conditions, such as excessive acidity or nutrient deficiencies.

b. Use automated alerts to suggest preventive measures.

4.Sustainability Tracking:

a. Create a feature that allows you to monitor how organic fertilization affects soil health over time.

b. Reports on increased soil biodiversity and a smaller carbon footprint should be provided.

5.Community and Information Exchange:

a. Create a platform for farmers to share insights, experiences, and best practices related to soil management.

b.Provide access to educational resources and agricultural consultancy through the platform.

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