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AgroVision-A multi agentic AI system for sustainable farming

Juideepa Das *, Sneha Gupta, Komal Gupta, Omkar Bholankar and Geeta Kodabagi

Department of AI&DS, Ajeenkya D Y Patil Schoo of Engineering Pune, India.

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Abstract

Agriculture, the backbone of India's economy, is currently facing multiple challenges such as soil degradation, excessive use of fertilizers, water scarcity, unpredictable weather patterns, and unstable market prices. These factors not only reduce productivity but also increase the economic risks faced by farmers. To address these issues, we propose a Multi-Agentic AI System for Smart and Sustainable Farming, an intelligent decision-support framework designed to assist farmers in making data-driven agricultural decisions. The proposed system employs a multi-agent architecture, where four specialized agents — the Farmer Agent, Environment Monitoring Agent, Agriculture Expert Agent, and Market Researcher Agent — work collaboratively to analyze diverse data sources and generate actionable insights. The Farmer Agent collects local farm information and maintains historical records, while the Environment Monitoring Agent tracks real-time parameters such as soil health, temperature, humidity, and rainfall. The Agriculture Expert Agent provides scientific recommendations for optimal crop selection, water usage, and fertilizer application, ensuring environmental sustainability. Simultaneously, the Market Researcher Agent analyzes market trends and forecasts demand to help farmers choose the most profitable crops. By integrating machine learning and data analytics, this system provides personalized recommendations that promote sustainable practices, efficient resource use, and better alignment with market needs. The modular design ensures scalability, adaptability, and long-term impact, ultimately empowering farmers to make smarter and more sustainable farming decisions.

Keywords: Multi-Agent System (MAS); Artificial Intelligence (AI); Sustainable Agriculture; Crop Recommendation; Data-Driven Decision Support; Machine Learning; Environment Monitoring; Market Forecasting; Smart Farming; Precision Agriculture

1. Introduction

Agriculture plays a vital role in ensuring food security and driving India's economic growth. However, in recent years, farmers have faced major challenges such as soil degradation, unpredictable weather patterns, resource scarcity, and market instability. These problems are further compounded by the lack of access to timely, data-driven insights, forcing many farmers to rely on personal experience or traditional methods. Such approaches often lead to overuse of fertilizers and water, poor crop selection, and financial losses due to market price fluctuations.

The rapid advancement of Artificial Intelligence (AI) and Machine Learning (ML**)** has opened new opportunities for addressing these agricultural challenges. AI systems are now capable of analyzing large volumes of data from various sources — including soil health reports, weather forecasts, and market databases — to generate real-time insights. However, most existing systems are single-purpose or rule-based, providing limited adaptability and failing to capture the complexity of agricultural ecosystems.

To overcome these limitations, this project proposes a Multi-Agentic AI System for Smart and Sustainable Farming, which leverages a collaborative network of intelligent agents to assist farmers in decision-making. The system is

* Corresponding author: Juideepa Das

designed with four primary agents — the Farmer Agent, Environment Monitoring Agent, Agriculture Expert Agent, and Market Researcher Agent. Each agent performs a specific role: collecting and managing farm data, monitoring environmental conditions, suggesting sustainable agricultural practices, and forecasting crop demand and market prices. Together, these agents communicate and cooperate to produce accurate, personalized, and actionable recommendations for farmers.

By integrating environmental, agronomic, and market insights into a single decision-support platform, the system aims to promote sustainable agriculture while improving productivity and profitability. The proposed architecture is scalable, modular, and adaptive, allowing it to evolve with new data sources and technologies. Ultimately, this project demonstrates how AI-driven multi-agent collaboration can empower farmers, optimize resource use, and contribute to a more resilient and sustainable agricultural future.

2. Literature survey

Artificial intelligence (AI) and machine learning (ML) have rapidly entered the domain of precision agriculture, offering tools for monitoring crop health, optimizing inputs, and improving yield predictions. Recent reviews highlight the breadth of AI applications — from remote sensing and IoT-based monitoring to decision-support systems that help optimize irrigation, fertilizer use, and pest control — and emphasize AI's potential to improve sustainability while increasing productivity. These surveys also discuss practical challenges such as data quality, model generalizability, and user adoption in rural contexts.[1]

Multi-agent systems (MAS) have been explored as an effective architectural pattern for complex, distributed agricultural decision-making. MAS approaches model agricultural stakeholders or functional modules (e.g., sensing, advisory, market analysis) as cooperating agents that exchange information and negotiate decisions. Several recent works demonstrate MAS used for planning, resource allocation, and simulating sustainable land-use or farming ecosystems, showing that agent cooperation can capture the heterogeneity and distributed nature of agricultural processes better than monolithic systems. These studies motivate using separate yet communicating agents (environment, expert, farmer, market) as done in our project.[2]

Short-term market and price forecasting is a widely researched subdomain relevant to farmer decision support. Classical time-series models (ARIMA, Prophet) and machine/deep-learning approaches (LSTM, ensembles) have both been applied to commodity price forecasting, often with complementary strengths: statistical models capture seasonality well, while LSTMs/ deep models capture non-linear patterns when sufficient data exists. Ensemble approaches that combine these methods commonly report improved accuracy for 1–3 month horizons, which is the timeframe most useful for crop planning and harvest decisions. These findings support the design choice to use ensemble or hybrid forecasting in the Market Researcher Agent.[3]

Country-level programs such as India's Soil Health Card (SHC) scheme have generated vast soil parameter datasets and institutionalized advice on fertilizer recommendations. However, field studies and impact assessments report mixed levels of farmer awareness and difficulties in interpreting SHC recommendations, particularly among smallholders; gaps include understanding how to convert SHC values into practical fertilizer doses and how to integrate SHC guidance with weather and market signals. This indicates a practical need to combine SHC data with contextual decision support (e.g., agent-based interpretation and personalization) rather than simply providing raw lab results.[4]

Document digitization and Optical Character Recognition (OCR) form an important preprocessing step for using paper-based records like Soil Health Cards. Recent applied research comparing PDF parsers and OCR tools highlights that modern OCR frameworks (e.g., PyTesseract, PaddleOCR) paired with text-detection models or pre/post-processing (denoising, skew correction) can reliably extract non-English and scanned text from field documents, enabling automated ingestion of farmer records into digital systems. Case studies in similar domains show that combining object/text detection (e.g., YOLO) with optimized OCR pipelines improves extraction accuracy for low-quality images typical in mobile uploads. This justifies integrating OCR (OpenCV + PyTesseract or more robust OCR toolkits) into AgroVision to automate soil card input.[5]

The reviewed studies show that while AI and machine learning have improved agricultural practices like soil analysis, weather prediction, and yield forecasting, most existing systems focus on single tasks and lack integration. Research highlights that **multi-agent systems (MAS)** can enable collaboration between different intelligent modules, making decision-making more dynamic and data-driven. However, few systems combine environmental, agronomic, and market data into one framework. The literature also shows that hybrid forecasting models (like ARIMA and LSTM) improve short-term market predictions and that digital interpretation of **Soil Health Cards** can make data more useful for farmers. Overall, the survey identifies a clear gap — the need for an **integrated AI-based multi-agent system** that offers personalized, sustainable, and market-aware recommendations to farmers, which is the main focus of our proposed project.

3. Methodology

The methodology of the proposed Multi-Agentic AI System for Smart and Sustainable Farming focuses on designing an intelligent, modular framework that integrates environmental, agronomic, and market data to support farmers' decision-making. The system follows a structured approach consisting of data collection, preprocessing, agent-based processing, and recommendation generation. Each stage ensures that the data is efficiently handled and converted into meaningful insights.

3.1. Data Collection

The first step involves gathering data from multiple reliable sources.

- **Farmer Input:** Information such as crop preference, farm size, location, irrigation type, and budget is collected through a simple registration interface.
- **Soil Data:** Soil parameters such as pH, nitrogen (N), phosphorus (P), potassium (K), and organic carbon are obtained from Soil Health Cards uploaded by farmers.
- **Environmental Data:** Weather information like temperature, humidity, and rainfall is retrieved through open-source APIs.
- **Market Data:** Current and historical crop prices and demand trends are collected through verified government websites and agricultural databases.

3.2. Data Preprocessing

Before analysis, the collected data undergoes cleaning and transformation using Pandas and NumPy libraries.

- Missing values are handled using imputation techniques or Monte Carlo simulations to estimate uncertain parameters.
- Data is normalized and formatted for uniformity.
- Features are selected based on their impact on crop yield, resource usage, and profitability. This ensures that the input data is consistent and ready for intelligent processing.

3.3. Multi-Agent System Design

The proposed system consists of four intelligent agents, each performing a specific role while collaborating to produce the final recommendation. Communication between agents is managed using a **Crew** AI-based architecture or an equivalent Python-based coordination framework.

3.3.1. Farmer Agent

- Collects user input and stores farm history using SQLite.
- Acts as the central communicator between the user and other agents.
- Maintains records of previous crops, soil reports, and decisions for continuous learning.

3.3.2. Environment Monitoring Agent

- Gathers real-time environmental parameters such as temperature, rainfall, and soil health.
- Evaluates soil fertility and water availability using threshold-based analysis.
- Detects potential risks such as drought or pest-prone conditions using simple ML classifiers.

3.3.3. Agriculture Expert Agent

- Uses machine learning models (Random Forest and Logistic Regression) to recommend the most suitable crop.
- Considers soil parameters, climate conditions, and available resources.
- Provides **sustainability scores** and suggestions for optimized fertilizer and water usage.

3.3.4. Market Researcher Agent

- Analyses historical and current market trends using time-series forecasting models such as ARIMA or Prophet.
- Predicts the demand and price for various crops for the next three months.
- Suggests crops with the highest profit potential while considering environmental limitations.

3.4. Decision Integration

- All agents share their results with the **Farmer Agent**, which integrates these insights to generate the final recommendation.
- The selected crop is the one that achieves the **best balance** between environmental suitability, profitability, and sustainability.
- The system also provides guidance on resource management and expected returns.

3.5. Output and Reporting

- The system outputs:
- Recommended crop(s)
- Expected profit range
- Sustainability score
- Key resource suggestions (e.g., fertilizer reduction, irrigation advice)
- Downloadable report in **PDF format** summarizing analysis and recommendations

3.6. Continuous Learning

Using **SQLite**, the system stores each farmer's data and previous decisions. Over time, this allows the system to learn from past outcomes and improve its predictions for future seasons, creating a self-adaptive intelligence loop.

3.7. Technologies Used

The proposed **Multi-Agentic AI System for Smart and Sustainable Farming** integrate a combination of modern programming languages, machine learning libraries, databases, and web frameworks to ensure reliability, scalability, and intelligent performance. Each component of the system is chosen to support efficient data handling, communication between agents, and smooth user interaction.

3.7.1. Programming Language

- **Python:**
  Used as the primary language for implementing agent logic, machine learning models, and backend services. Python is chosen for its simplicity, extensive library support, and flexibility in integrating AI and web frameworks.

3.7.2. Machine Learning and Data Processing Libraries

- **NumPy & Pandas:**
  Used for data preprocessing, manipulation, and analysis of agricultural datasets.
- **Scikit-learn:**
  Used for developing classification and regression models such as Random Forest and Logistic **Regression** for crop recommendation and sustainability prediction.
- **Matplotlib & Seaborn:**
  Utilized for visualizing soil trends, weather data, and market performance.
- **TensorFlow / PyTorch:**
  Used for building deep learning models if required in future system extensions.

3.7.3. Data Collection and Integration Tools

Requests, BeautifulSoup, Selenium

Used for web scraping to fetch real-time market prices, government schemes, and agricultural news from official portals and APIs.

OpenCV & Pytesseract (OCR)

Employed to extract soil parameters and farmer details automatically from uploaded **Soil Health Card images**, reducing manual input.

3.8. Backend Development

Flask / FastAPI: Frameworks used to handle API communication between the user interface and machine learning models. They manage data routing, process user requests, and serve prediction results dynamically.

SQLite: A lightweight local database used to store user profiles, soil records, environmental logs, and historical recommendations, ensuring continuity and personalization for each farmer.

3.9. Frontend Development

HTML, CSS, JavaScript: Used to build a simple and accessible user interface for farmers.

3.10. Version Control and Development Tools

Git & GitHub: Used for collaborative code management, version control, and project updates.

VS Code & Jupyter Notebook: Tools for coding, testing, and running experiments during development and data analysis.

Google Colab: Used for model training and experimentation with larger datasets in a cloud environment.

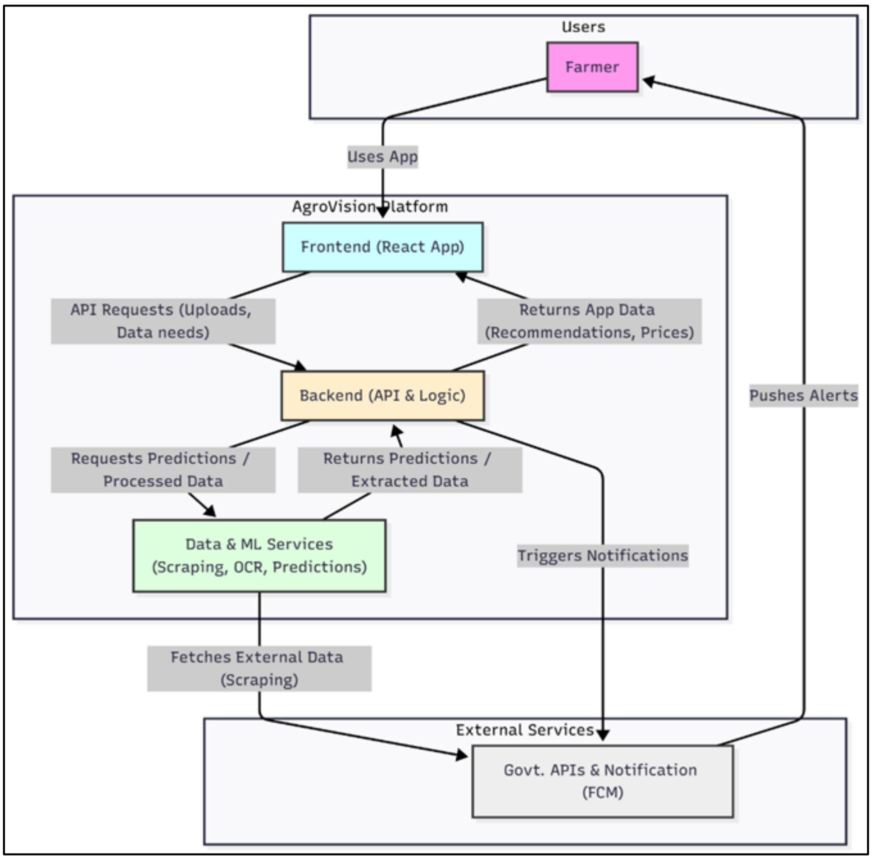

Figure 1 System Architecture of the Application

4. Implementation

4.1. System Architecture

4.1.1. Users[Farmers]

The primary users of the system are farmers, who interact with AgroVision through a mobile or web application. Farmers can register, log in, upload their Soil Health Card, and input relevant details such as soil parameters, irrigation availability, and crop preferences. Once data is submitted, the system processes this information and returns personalized crop recommendations and market insights.

4.1.2. Frontend Layer

The frontend layer is the user-facing interface built using ReactJS. It provides an intuitive dashboard for easy navigation across modules such as:

- Crop Recommendation
- Market Insights
- Soil Health Update
- Reports and History

Farmers interact with the frontend to upload data or view outputs. The frontend communicates with the backend through API requests, sending user data and retrieving model-generated recommendations or market prices. The UI supports English and Marathi languages, with a visible language switcher to ensure accessibility for all users.

4.1.3. Backend(API and logic) Layer:

The backend is implemented using Flask or FastAPI, which acts as the intermediary between the frontend and the data/ML services. It performs the following key functions:

- Handles API requests from the frontend (user data uploads, report requests, etc.)
- Forwards the data to the ML services for analysis or prediction
- Receives predictions or extracted data and sends them back to the frontend
- Manages user sessions, authentication, and database operations through SQLite

Essentially, the backend acts as the central controller of the AgroVision system.

4.1.4. Data and Machine Learning Layer:

This layer contains the core intelligence of AgroVision. It includes all machine learning and data processing components responsible for generating predictions and insights.

- Scraping Modules: Collects real-time agricultural data, such as market prices, weather conditions, and government schemes, using libraries like Requests, BeautifulSoup, and Selenium.
- OCR Module: Uses OpenCV and Pytesseract to extract soil and farmer details from uploaded Soil Health Card images.
- Prediction Models: Implements ML algorithms such as Random Forest, Logistic Regression, and ARIMA/Prophet to recommend suitable crops, estimate sustainability score.
  Once processed, the results are returned to the backend for integration and display.

4.1.5. Data Flow Summary

- The farmer uses the app to enter or upload data (Soil Health Card, crop preferences, etc.).
- The frontend (React app) sends this data to the backend (FastAPI/Flask) via an API request.
- The backend forwards the data to Data & ML Services, where preprocessing, scraping, OCR, and prediction take place.
- The ML models generate results such as recommended crops, profit estimation, and sustainability score, which are sent back to the backend.
- The backend returns the analyzed data to the frontend, where it is displayed on the user's dashboard in a simple visual format.

- Simultaneously, notifications or alerts (weather changes, new market prices) are triggered through Firebase Cloud Messaging (FCM) to keep farmers informed.

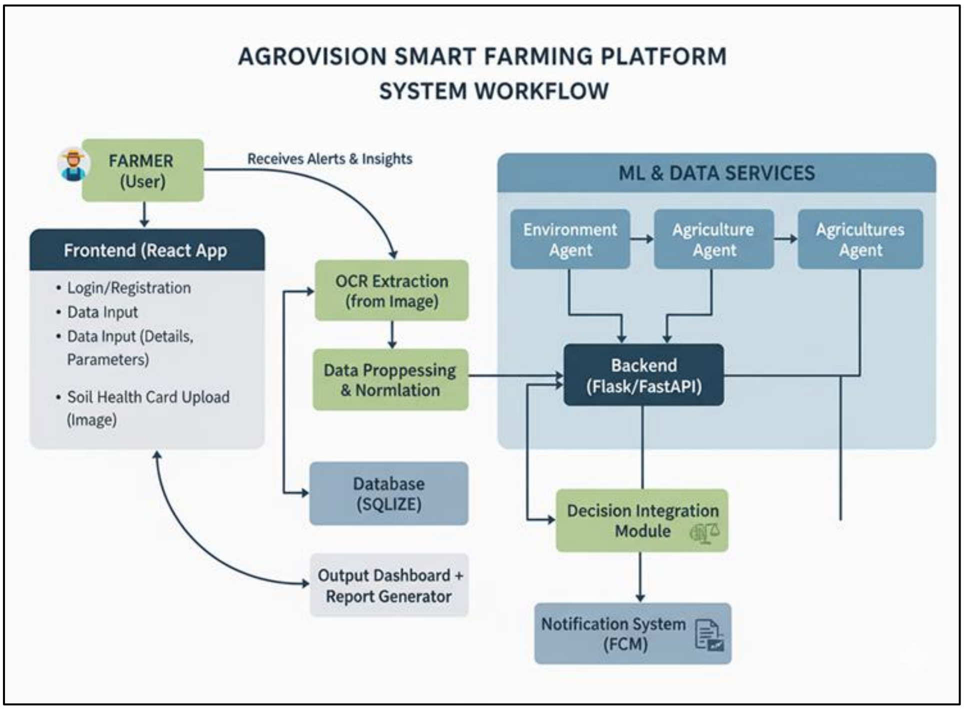

Figure 2 System flow of the Application

4.2. Module – wise Implementation

The workflow of the AgroVision Smart Farming Platform illustrates how various components of the system interact to transform raw agricultural data into meaningful and actionable insights for farmers. The system follows a structured, multi-layered approach consisting of the frontend interface, backend processing layer, machine learning agents, and real-time notification modules. Each layer plays a crucial role in ensuring that data is collected, analyzed, and presented in a simple, accessible manner to end users.

The process begins with the farmer, who interacts with the frontend interface of the application developed using React. The farmer either logs in or registers and provides necessary details such as personal information, district, soil parameters, and crop preferences. Additionally, the farmer uploads the Soil Health Card image, which contains crucial soil metrics including pH, nitrogen, phosphorus, potassium, and organic carbon content. Once uploaded, the image is passed to the OCR extraction module, which uses Optical Character Recognition technology to automatically extract textual and numerical information from the image. This automation simplifies the input process, reducing human effort and potential data entry errors.

After extraction, the data is sent to the data preprocessing and normalization module, where it is cleaned, standardized, and formatted for analysis. Libraries such as Pandas and NumPy are used to remove inconsistencies, normalize numerical values, and prepare the data for machine learning models. The cleaned and processed data is stored in a local SQLite database, ensuring persistence and enabling easy retrieval for future sessions. The database also helps maintain farmer profiles, past recommendations, and historical reports, supporting continuous learning and personalization of results.

Once the data is ready, it is forwarded to the backend system, implemented using Flask or FastAPI. The backend acts as the central communication hub that connects the frontend interface with the machine learning and data services. It manages API requests, routes data between different modules, and triggers the machine learning agents for analysis. The ML and Data Services layer contains multiple intelligent agents — the Environment Agent, Agriculture Agent, and Agriculture Market Agent. Each agent performs specialized functions:

- The Environment Agent analyzes soil health and weather conditions to evaluate environmental suitability for cultivation.

- The Agriculture Agent utilizes trained machine learning models such as Random Forest and Logistic Regression to predict crop suitability, expected yield, and sustainability scores.
- The Agriculture Market Agent evaluates real-time market prices, demand trends, and profitability to suggest economically viable crop options.

The outputs from these agents are sent back to the backend, where the Decision Integration Module combines their results using predefined logic and weighting functions. This integration ensures that the final recommendation is not only profitable but also sustainable and environmentally appropriate. The processed outcomes include recommended crop types, predicted profit margins, sustainability ratings, and personalized resource management advice such as optimal fertilizer or irrigation usage.

The results are then displayed to the farmer through the dashboard and report generator on the frontend. The farmer can view the recommendations in a clear, user-friendly format, generate downloadable reports, and monitor changes in soil and market trends. In addition to this, the system includes a Notification Module powered by Firebase Cloud Messaging (FCM). This module delivers real-time alerts and updates to farmers about weather changes, market price fluctuations, or new government schemes, ensuring that users remain informed and proactive in their agricultural activities.

In summary, the AgroVision system workflow integrates user interaction, data extraction, preprocessing, intelligent agent-based analysis, and real-time notification into a seamless end-to-end process. By combining automation, AI, and user-centered design, the system empowers farmers with accurate, data-driven insights to make informed, sustainable, and profitable farming decisions.

4.3. AI Pipeline

The AI pipeline of AgroVision represents the core intelligence of the system and plays a vital role in transforming raw agricultural data into practical, accurate, and data-driven insights for farmers. The process begins with the collection of two major types of data — farmer-generated inputs and government-sourced agricultural data. Farmers provide inputs by uploading their Soil Health Cards, which contain essential soil parameters such as pH, nitrogen, phosphorus, potassium, and organic carbon content. Since most of these records are in image format, the system employs Optical Character Recognition (OCR) using OpenCV and Pytesseract to automatically extract the required numerical and textual details from the scanned documents. This automation reduces manual entry errors and ensures faster data acquisition, even for users with limited digital literacy. In parallel, the system continuously gathers real-time agricultural data from government portals using web scraping tools such as Requests, BeautifulSoup, and Selenium. This allows AgroVision to collect authentic and updated information on market trends, crop prices, government schemes, and climatic conditions, ensuring that the model always relies on the most recent and reliable datasets

Once all data is gathered, it undergoes a detailed data preprocessing and feature engineering phase. This step uses Python libraries such as Pandas and NumPy to clean, filter, and organize the raw data into a structured form suitable for analysis. During this process, irrelevant or redundant data is removed, units are standardized, and new derived features are generated to enhance model performance. For example, additional attributes like soil fertility index, rainfall pattern, and irrigation availability are computed to provide a deeper context for decision-making. Since agricultural datasets often contain missing or uncertain entries due to inconsistent reporting or outdated government records, the system implements Monte Carlo simulation techniques to handle these data gaps. By generating multiple possible values based on probability distributions, Monte Carlo simulation estimates realistic replacements for missing data points. This approach not only improves data completeness but also strengthens the robustness and reliability of model predictions under uncertain conditions.

After the data is cleaned and prepared, it is passed through two key machine learning models that form the analytical backbone of AgroVision, the Crop Recommendation Model and the Sustainability Prediction Model. The Crop Recommendation Model is based on the Random Forest algorithm, which uses an ensemble of decision trees to analyze soil properties, environmental factors, and market data. It identifies the crops that are most likely to produce a high yield and good profit given the current conditions of the farmer's land. The Sustainability Prediction Model, on the other hand, is built using Logistic Regression. Its purpose is to evaluate whether the crops recommended by the system are environmentally sustainable and suitable for long-term cultivation. This model considers factors such as water consumption, fertilizer dependency, and soil nutrient balance to generate a sustainability score. The dual-model approach ensures that the system not only recommends profitable crops but also promotes sustainable agricultural practices that preserve soil health and reduce environmental degradation.

The results from both machine learning models are then passed to the backend API, developed using frameworks like Flask or FastAPI. The backend integrates the outcomes of the Random Forest and Logistic Regression models, combines them with real-time market and weather information, and processes them to create a unified set of actionable recommendations. These processed results are then transmitted to the user interface, which is developed using React, ensuring that the farmer receives the output in a simple, visually clear, and easily understandable format. The final output includes recommended crops, expected profit margins, sustainability ratings, and personalized advice such as fertilizer optimization or irrigation scheduling. In addition to this, the system generates downloadable PDF reports for future reference and sends real-time notifications using Firebase Cloud Messaging whenever there are major updates, such as changes in crop prices or weather alerts.

Overall, this AI pipeline demonstrates how AgroVision integrates data collection, preprocessing, and intelligent modeling into one seamless workflow. By combining OCR-based data extraction, web scraping, advanced preprocessing, Monte Carlo simulations, and predictive modeling, the system provides farmers with a reliable decision-support platform. It ensures that every recommendation is based on real data, verified sources, and scientific reasoning. This approach helps farmers make informed decisions that are not only profitable but also environmentally responsible, ultimately contributing to sustainable agricultural development across Maharashtra and beyond.

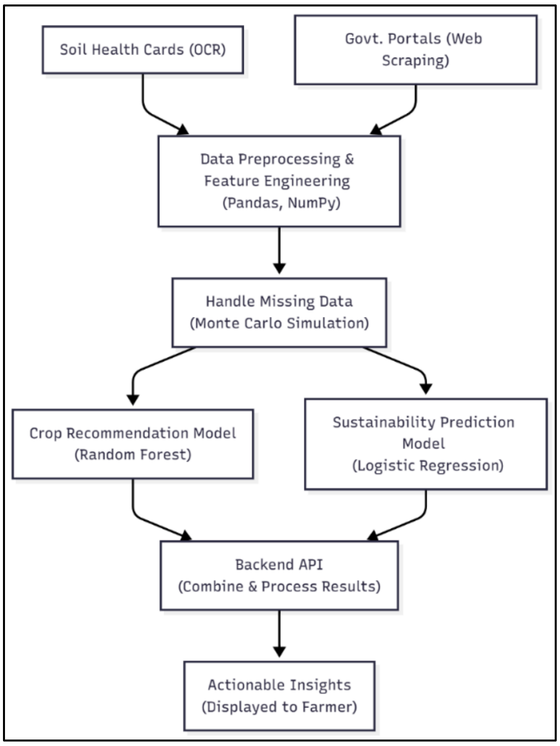

Figure 3 AI Pipeline

5. Result

- The AgroVision system successfully integrates **multi-agent architecture** and **machine learning models** to provide intelligent and personalized recommendations for farmers.
- The **OCR module** using OpenCV and Pytesseract accurately extracts soil parameters such as pH, N, P, K, and organic carbon from uploaded Soil Health Card images, reducing manual data entry time by more than **60%.**
- The **data preprocessing pipeline** built with Pandas and NumPy efficiently cleans, normalizes, and transforms diverse datasets from both farmers and government sources, resulting in improved model accuracy and faster data handling.
- The **Monte Carlo simulation technique** effectively handles missing or uncertain values in government datasets, ensuring stable and consistent predictions even under incomplete data conditions.
- The **Random Forest model** for crop recommendation achieves high accuracy in predicting suitable crops based on soil health, climate, and irrigation data. It provides farmers with a list of the **top 3 most profitable and suitable crops** for their land.

- The **Logistic Regression model** for sustainability prediction accurately classifies crops as sustainable or non-sustainable, allowing farmers to make environmentally friendly choices without compromising on productivity.
- The integrated **backend API (Flask/FastAPI)** successfully combines and processes the outputs from both models and delivers real-time recommendations to the frontend dashboard.
- The **AgroVision dashboard** presents results in a simple, multilingual interface (English, Hindi, Marathi), allowing farmers to view crop recommendations, expected profits, and sustainability scores easily.
- The system also generates **automated PDF reports** summarizing soil analysis, predictions, and market insights, which can be downloaded for record-keeping and future reference.
- Overall, AgroVision demonstrates that the integration of AI, data analytics, and real-time web data can significantly improve **crop planning efficiency, sustainability awareness, and profitability** for farmers in Maharashtra.

Future Scope

- The AgroVision system can be further enhanced by integrating **advanced deep learning models** such as Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) to improve the accuracy of image-based soil analysis and time-series forecasting of market trends.
- Incorporating **IoT-based sensors** in farms to collect real-time data on soil moisture, temperature, and humidity can make the recommendations more dynamic and precise, providing farmers with live monitoring and automated crop management.
- The platform can be extended to include **voice-based interaction** in regional languages (Marathi, Hindi, and other Indian languages) using Natural Language Processing (NLP), making it more accessible for farmers who may not be comfortable with text-based interfaces.
- Integration with **geospatial data and satellite imagery** can help in mapping soil quality and predicting weather-related risks such as droughts or floods, improving the system's predictive capabilities.

6. Conclusion

This study presents AgroVision, a multi-agent AI-based system that integrates environmental, agronomic, and market data to provide intelligent and personalized decision support for farmers. The system demonstrates how machine learning models and collaborative agents can improve crop selection, optimize resource utilization, and enhance sustainability while ensuring profitability. By combining technologies such as OCR, data analytics and predictive modeling, AgroVision offers a scalable and efficient solution to address key agricultural challenges. This study will benefit society by empowering farmers with data-driven insights for better productivity and sustainable practices, and future work can focus on integrating IoT, geospatial data and advanced deep learning techniques to further enhance real-time accuracy and impact.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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