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Farmroot Insight: Empowering 500+ Million Smallholder Farmers with Data-Driven Soil Health Insights for Sustainable Agriculture.

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Abstract - Agriculture is the backbone of the Indian economy, with over 80% of farmers being smallholders. However, limited access to soil health data leads to poor fertilizer management, reduced yield, and soil degradation. Important soil parameters like pH, moisture, and nitrogen can be tracked in real time with FarmRoot Insight, an affordable and easy-to-use Internet of Things (IoT) solution. By integrating IoT sensors, a cloud-based dashboard, and an AI-powered fertilizer recommendation engine, the system helps farmers monitor their soil and make decisions. By integrating weather APIs and satellites, the model provides dynamic insights into soil and environmental conditions

1.Introduction

The excessive use of chemical fertilizers and dwindling soil fertility have raised the demand for sustainable agricultural methods in recent years. For rural farmers, traditional soil testing techniques are expensive, time-consuming, and unavailable. Because of this, the majority of farmers use their best judgment to estimate the kind and amount of fertilizer needed, which results in wasteful use of resources and soil degradation.The quick development of artificial intelligence and the Internet of Things has made smart agriculture a crucial component of data-driven decision-making. FarmRoot Insight creates a low-cost soil monitoring system that can give real-time updates on soil health, bridging the gap between technology and accessibility. Farmers can obtain real-time fertilizer recommendations based on field conditions by integrating sensors that measure soil pH, nitrogen, and moisture levels with a data analytics platform.

This project's objective is to provide a scalable, user-friendly Internet of Things solution that will enable farmers to make better decisions, increase productivity, and support sustainable soil management.

2. Problem statement

Agriculture is crucial to India's economy. Crop productivity depends on soil health and proper fertilizer use. However, many farmers lack the technical knowledge or tools to evaluate their soil's physical and chemical conditions.

Traditional soil testing methods take a long time, are expensive, and require lab analysis, making them difficult for small and marginal farmers to access. Without real-time soil monitoring, farmers often apply fertilizers based on guesswork or outdated methods. This can result in too much fertilizer or a lack of essential nutrients. It affects crop yield and harms soil health, causing long-term damage to the environment.

Many soil testing devices are difficult to operate and need expert assistance. Farmers in rural areas find it hard to use these systems because of language barriers and limited technical support.

There is a clear need for an easy-to-use, affordable, and portable device that can quickly measure important soil parameters like pH, moisture, and nitrogen levels, and suggest the right fertilizers. Farmers need an interactive platform to ask questions and receive personalized advice on soil health and crop management.

There is a strong need to develop a simple soil monitoring device that includes smart software. This device should deliver real-time soil data, fertilizer recommendations, and chatbot assistance. This solution will make modern precision farming accessible to all farmers.

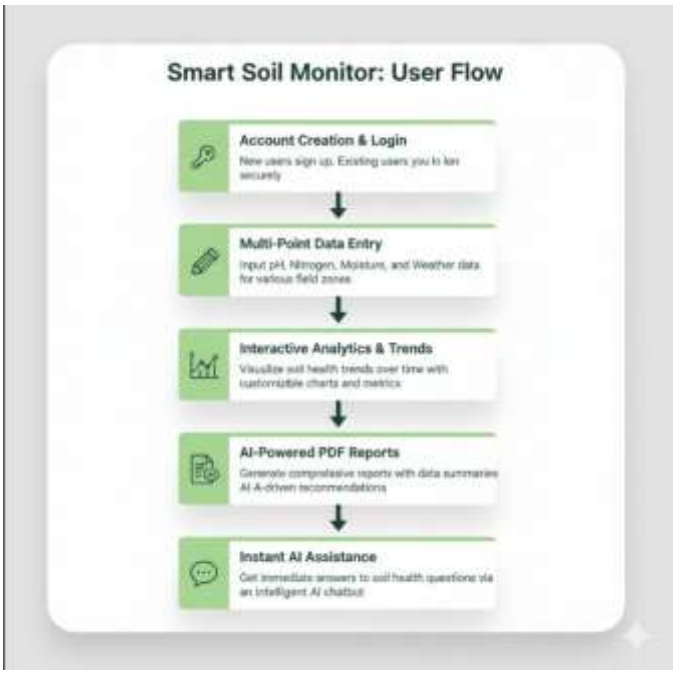

fig 1 : user flow

3.Objectives of the Project

The main goal of this project is to create a Plug-and-Play Soil Monitoring System. This system allows farmers to easily check their soil condition and get real-time fertilizer recommendations. It seeks to make soil testing easier by using automation and digital support, so even non-technical users can access it. To design a portable and user-friendly plug-and-play device that can detect key soil parameters like pH, moisture, and nitrogen levels with high accuracy .To automate the fertilizer recommendation process by analyzing the detected soil parameters.

This will suggest the best type and amount of fertilizer to improve soil fertility and crop yield .To develop an interactive software interface that shows real-time soil data and recommendations in a clear way for farmers .To integrate a chatbot-based query system that lets farmers ask questions and receive immediate answers about soil health, fertilizer use, and best farming practices.To use IoT technology for real-time monitoring and data storage.

This will help farmers track soil conditions over time and make better agricultural decisions .To promote sustainable and precise farming practices by reducing unnecessary fertilizer use, minimizing soil degradation, and improving productivity. The software includes a chatbot feature that helps farmers with questions and gives quick support on fertilizer application, soil improvement, and crop management. The system also uses IoT and cloud technology for real-time monitoring, data storage, and analysis. This lets farmers see soil health trends over time.

The project aims to encourage sustainable and precise farming practices, cut down on fertilizer waste, boost soil fertility, and assist the move toward smart, data-driven agriculture. Another major goal of the project is to automate the fertilizer recommendation process based on the detected soil parameters. Using pre-defined algorithms or data-driven logic, the system suggests the most suitable type and quantity of fertilizer required for specific soil conditions, helping farmers make informed and efficient decisions.

To enhance user interaction, an intuitive software platform is developed that displays soil readings in an understandable format and provides personalized recommendations in local languages.

4.Literature survey

Research on accurate, affordable soil physical and chemical property sensing has been ongoing. Reviews of contemporary agricultural sensing techniques highlight the quick development of inexpensive pH and moisture probes, printed potentiometric electrodes, and in-field nutrient sensing techniques, but they also point out issues with stability, calibration, and the effects of the soil matrix when transferring from the lab to the field.

According to recent surveys, professional nitrate/nitrogen sensing still frequently depends on ion-selective electrodes (ISEs) or laboratory techniques to obtain accurate results in complex soils, even though many commercial and hobbyist pH/moisture modules (such as those for Arduino/Node MCU) offer convenient measurements.

Numerous recent studies show off useful, Internet of Things-driven soil monitoring systems that integrate cloud dashboards and mobile interfaces with pH, moisture, and nutrient sensing. ISE-based nitrate sensors or indirect estimates of nitrogen (e.g., using crop models or correlated sensors) are commonly used in these prototypes, along with microcontrollers (Arduino/ESP/NodeMCU) and commercially available pH and moisture probes.

According to the authors, these systems allow for near-real-time monitoring and lessen reliance on laboratory testing; however, they also highlight certain challenges, such as sensor drift, the requirement for regular calibration, and the trade-offs between cost and robustness for actual field deployment .In several studies, soil sensors have been

combined with intelligent fertilizer recommendation (rule-based or data-driven).

Agronomic thresholds are used by rule-based algorithms to relate measured pH, moisture, and nutrient levels to fertilizer type and dosage; more sophisticated systems use machine learning or crop models in conjunction with historical data to suggest top-dressing timing and amounts.

When calibrated to local soils and crops, evaluations reveal that such systems can improve yields and reduce over-application of fertilizers; however, their accuracy is highly dependent on the quality of the sensor data and the local agronomic regulations.Chatbots and conversational AI have advanced quickly for agricultural extension.

When paired with curated agronomic rules, generative models, or localized knowledge bases, conversational agents can scale advisory services to thousands of smallholder farmers and accommodate a variety of language needs, as shown by projects like Farmer Chat and other deployed chatbots.

Independent studies assessing generative models (like ChatGPT) for farmer questions indicate potential, but they also point out drawbacks, such as the necessity for localized validation, hallucinations, and the significance of combining bot responses with validated agronomic rules and human-in-the-loop review.

Therefore, an emerging best practice is integrating sensor data with chatbot interfaces (so users can inquire about their measured pH, N, and moisture and receive contextualized recommendations).

5.Working principle

The proposed Plug-and-Play Soil Monitoring System operates on the principle of integrating sensor-based data collection with intelligent analysis and user-friendly communication. The device is designed to detect and monitor essential soil parameters — pH, moisture, and nitrogen levels — in real time. These parameters are critical indicators of soil health and fertility, directly influencing crop growth and productivity.

Fig 2 : Home page

When farmers use the Plug-and-Play Soil Monitoring System's software interface, they first interact with the Sign-In Page. Even users with little technical expertise can easily access the system thanks to its straightforward, user-friendly design.

While new users can quickly create an account using the sign-up option, registered users can safely log in with their username and password. Large buttons, unambiguous labels, support for regional languages, and an easy-to-navigate interface are all features that are geared toward farmers. User data and soil information are safeguarded by security measures like session management and password encryption. Users are taken to the dashboard, which shows real-time soil readings and fertilizer recommendations, after successfully logging in.

Following a successful login, users are taken to the dashboard, which shows historical trends, current soil readings, and fertilizer suggestions. Thus, the Sign-In Page acts as a portal to the entire system's functionality, which includes chat-based inquiries, data visualization, and customized alerts, guaranteeing a smooth and safe user experience for agricultural decision-making.

Farmers can safely access the soil monitoring software by using the Sign-In Page as the entry point. While new users can use the sign-up option to create an account, existing users can log in with their username and password. Following a successful login, users are taken to the dashboard, which shows historical trends, current soil readings, and fertilizer suggestions.

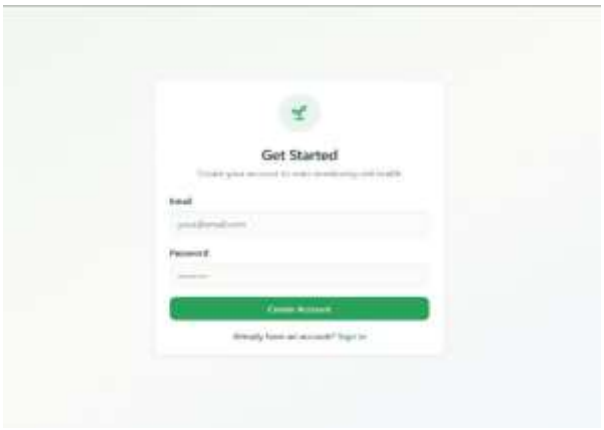

Fig 3 : Log in page

While new users can use the sign-up option to create an account, existing users can log in with their username and password. With its large buttons, clear labels, and support for regional languages, the interface is made to be easy to use and intuitive, making it accessible to farmers with little technical expertise .An essential part of the soil monitoring software's user authentication procedure is the Email and Password Page.

Only authorized users can access soil data and fertilizer recommendations thanks to this page, which enables registered users to safely log in with their email address and password. With input fields that are clearly labeled and validation checks to guard against inaccurate or incomplete entries, the interface is made to be easy to use and intuitive.

The confidentiality of user credentials is guaranteed by security measures like password masking, encryption, and error prompts, which also guard against unwanted access. Following a successful authentication process, users are taken to the main dashboard, where they can view historical trends, track soil parameters in real time, and get customized fertilizer recommendations.

Farmers can safely access the soil monitoring software by using the Sign-In Page as the entry point. While new users can use the sign-up option to create an account, existing users can log in with their username and password. Large buttons, unambiguous labels, and support for regional languages make the interface easy to use and intuitive, making it accessible to farmers with little technical expertise. User data and soil information are protected by security features like session management and password encryption. where users can communicate with the chatbot, get fertilizer recommendations, and track the pH, moisture, and nitrogen levels of their soil. This procedure offers smooth access to all of the intelligent soil monitoring system's features while guaranteeing the security of user data. Furthermore, farmers with little technical expertise can easily navigate the login process thanks to the design's emphasis on accessibility and simplicity.

Fig 4 : Welcome page

This procedure offers smooth access to all of the intelligent soil monitoring system's features while guaranteeing the security of user data. Furthermore, farmers with little technical expertise can easily navigate the login process thanks to the design's emphasis on accessibility and simplicity. An essential part of the soil monitoring software's authentication procedure is the "Enter Email and Password" page.

Farmers are asked to enter their secure password and registered email address in the appropriate fields. To provide robust security, the interface has real-time validation that verifies that the password is the right length, contains the necessary characters, and is formatted correctly in emails.

To prevent unwanted access to sensitive data, passwords are encrypted during transmission and masked during entry. The user experience is enhanced by the page's provision of error messages and instructions in the event that incorrect credentials are entered. After successful authentication, the system allows access to the dashboard after comparing the credentials to the database.

Fig 4 : Optimize page

Farmers can configure and customize their soil monitoring workflow by starting from the Smart Soil Monitor app's Ready-to-Optimize Page. Users are given a number of options when they first launch the app, such as multi-point data entry, interactive analysis, the ability to generate PDF reports, and support for AI assistants, which help them navigate the platform.

For accurate field management, the multi-point data entry feature enables farmers to capture soil measurements from multiple points within a single field. This captures the spatial variability of soil parameters like pH, nitrogen content, and moisture levels.

Users can quickly interpret soil conditions, identify anomalies, and track changes over time with the aid of the interactive analysis option's dynamic visualizations, trend graphs, and comparative charts. Farmers can export thorough summaries of soil health, complete with graphical representations and important insights, using the PDF report generation functionality.

These summaries can then be shared with agronomists or saved for use in planning and regulatory processes. The AI assistant is also built right into this page to offer real-time, customized advice. Based on the data gathered, it makes recommendations for crop-specific tactics, soil amendments, and nutrient optimization.

The Ready-to-Optimize Page unifies these functions into a single, user-friendly interface, enabling farmers to improve decision-making, expedite data collection, and apply focused soil management techniques—all of which contribute to more productive crops and sustainable agriculture. By recording measurements from multiple points within a single field, the multi-point data entry option enables users to capture soil variability and produce more precise and representative pH, nitrogen, and moisture content readings. Farmers can track changes over time, spot patterns, and spot anomalies in soil health with the help of the interactive analysis feature's dynamic visualizations, which include trend graphs and comparative charts. Users can export thorough soil summaries with graphs, important parameter values, and actionable insights using the PDF report generation option. These summaries can then be shared or stored for reference and documentation needs. Lastly, the AI assistant option provides real-time, customized advice based on the data entered, suggesting crop-specific tactics, soil amendments, and nutrient optimization.

Fig 6 : Data entry

A key component of the Smart Soil Monitor software is the Soil Data Entry page, which makes it easier to efficiently and systematically gather field-specific soil data.

The first step for farmers is to choose an existing field or create a new one by entering necessary information like the field name, location, and crop type. After entering these details, the user clicks Create Field, which adds the field to the system and associates it with that particular location for all upcoming soil readings. Users can also enter various soil parameters on the page, such as pH level, nitrogen concentration, moisture content, and other pertinent measurements. ensuring the thoroughness and organization of data collection.

The Soil Data Entry page reduces the possibility of mistakes and guarantees precise mapping of soil health across several fields by offering a simple, step-by-step interface with guided input fields. This methodical approach makes soil management accurate and approachable by allowing farmers to keep consistent records over time and serving as the basis for trend analysis, predictive insights, and AI-driven fertilizer recommendations. Farmers can methodically enter field-specific data, such as field names, locations, crop types, and matching soil measurements, in the Soil Data Entry section.

Precise tracking of changes over time is made possible by the accurate mapping of soil parameters guaranteed by this structured data collection.

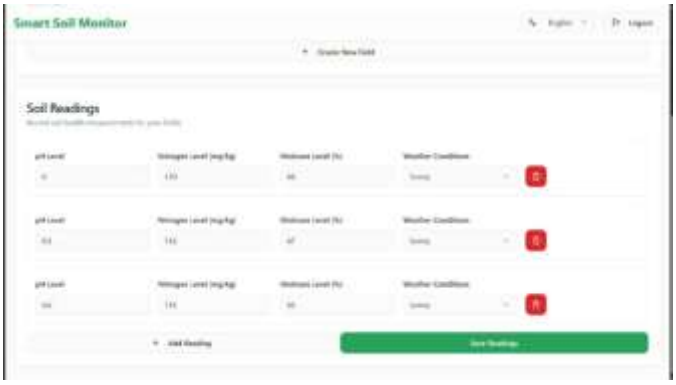

Fig 7 : Readings

The Soil Readings page serves as a thorough dashboard for managing and visualizing soil data, giving farmers a clear picture of the most important markers of soil health.

The page provides a comprehensive overview of field status at a glance by displaying important parameters like pH level, nitrogen content (mg/kg), soil moisture percentage, and pertinent weather conditions.

The ability to add multiple readings for the same field over various time periods gives users the flexibility to precisely track trends and changes. To keep the dataset accurate and current, the dashboard additionally permits editing of already-existing data entries to fix measurement errors and permits removing readings that are out-of-date or unnecessary.

Farmers can quickly identify areas that need attention thanks to the dashboard's well-organized layout, which includes clear tables and visual cues like trend graphs and color coding. The page enables users to examine soil health trends over time, make knowledgeable decisions about fertilizer application, and optimize irrigation schedules by displaying historical and current soil data side by side. Continuous soil parameter monitoring and cross-field comparison of readings improves precision farming and predictive planning, increasing crop yield and supporting sustainable agricultural methods. Farmers can monitor soil health trends over time and make well-informed decisions about fertilizer and irrigation thanks to the dashboard's clear and well-organized view of all data.

Fig 8 : Graph

Farmers can keep an eye on the dynamic behavior of their fields by using the Trend Graph on the Soil Readings Dashboard, which shows how soil parameters change over time.

With time intervals (days, weeks, or months) on the X-axis, the graph usually shows important metrics like pH level, nitrogen concentration (mg/kg), and soil moisture percentage on the Y-axis. It is simple to distinguish between several readings at once because each parameter is represented by a unique color-coded line.

The graph helps farmers spot times of nutrient depletion, excessive or insufficient irrigation, or pH imbalance by highlighting trends, oscillations, and anomalies in soil health. Hovering to view precise values, zooming into particular time ranges, and filtering by parameter or field are examples of interactive features that allow for in-depth analysis.

Farmers can use trend visualization to inform data-driven choices about soil amendment tactics, irrigation schedules, and fertilizer application. Precision farming and long-term soil sustainability are supported by the graphical representation, which converts raw numerical data into meaningful, actionable information.

The Trend Graph on the Soil Readings Dashboard visually represents changes in key soil parameters—such as pH, nitrogen content, and moisture—over time. Each parameter is displayed with a distinct color-coded line, allowing farmers to quickly identify fluctuations, patterns, or anomalies.

By showing historical and current data side by side, the graph helps users make informed decisions on irrigation, fertilization, and soil management, transforming raw data into actionable insights for sustainable farming.

Fig 9 : Visualization

The Smart Soil Monitor has the ability to show the average levels of soil parameters, such as pH, moisture percentage, and nitrogen content, for fields situated at various elevations.

Instead of depending only on individual measurements, the system computes the average value of each parameter by combining several readings over time, giving farmers a better understanding of the overall state of the soil.

In areas with diverse topography, where soil characteristics can vary greatly with elevation changes, this feature is especially helpful. Users can compare soil health across various fields or elevation zones thanks to the platform's visual representation of these averages in the form of charts or maps.

For instance, farmers can rapidly determine whether fields at higher elevations have slightly acidic pH or lower nitrogen levels than fields at lower elevations.

The Smart Soil Monitor promotes precision agriculture and increases overall farm productivity by giving farmers targeted information on crop planning, soil amendments, and fertilizer application based on aggregated, altitude-specific insights.

The average nitrogen, pH, and moisture levels for fields at various elevations are computed and shown by the Smart Soil Monitor. It gives a clear picture of the overall health of the soil in regions with different topography by combining several readings.

Fig 10 : Generating report

Farmers can create organized, easily comprehensible reports using the Generating Reports of Observations page. The field and range of data that users wish to include, such as several soil parameters—pH, nitrogen content, moisture levels, and weather conditions over a given time period, are customizable.

After that, the system creates an extensive PDF report with tabular data, trend graphs, visual charts, and summary statistics that provides a clear picture of soil health and how it has changed over time.

By using these reports as a guide for decision-making, farmers can monitor the efficacy of soil amendments, fertilizer applications, and irrigation.

To encourage cooperation and knowledgeable farm management, the reports can also be exported, saved, or distributed to agronomists, agricultural advisors, or cooperative societies. This page assists farmers in maintaining consistent records, recognizing trends, and putting data-driven strategies for sustainable and optimized agriculture into practice by converting raw observational data into actionable insights.

These reports help farmers identify areas that need immediate attention, like nutrient deficiencies or soil moisture imbalance, by providing a snapshot of the current state of the soil and enabling them to track changes and trends.

Targeted decision-making for crop management, irrigation scheduling, and fertilizer application is made possible by the ability to create customized reports for various fields, crops, or time periods. To encourage cooperative organizations, agronomists, or agricultural advisors to collaborate on planning and evidence-based

interventions, the reports can also be exported, saved, or shared digitally.

This feature converts unprocessed observational data into useful insights, giving farmers a trustworthy resource for both immediate and long-term soil management plans, improving agricultural practices' sustainability, productivity, and efficiency. Decide which parameters, such as pH, nitrogen content, moisture percentage, and weather conditions, to include in the report and specify the time period of interest.

A well-structured PDF report with tabular summaries, line graphs displaying trends over time, comparative charts between various locations or altitudes, and important statistical insights like average, minimum, and maximum values is then produced by the system.

Fig 11 : Generated report

One of the main features of the Smart Soil Monitor software is the integrated AI Soil Health Assistant, which uses a natural language interface to give farmers intelligent, real-time advice. Users can ask interactive questions about crop care, pest control, irrigation techniques, soil management, nutrient optimization, and more with this AI-driven chatbot than with static manuals or generic recommendations.

Understanding the context of each question, the assistant provides customized, useful guidance based on the particulars of the farmer's field, such as crop requirements, soil type, pH, and moisture levels. For example, the chatbot can offer advice on how to enhance moisture retention, naturally raise nitrogen levels, and give advice on crop rotation and fertilizer use.It can also identify nutrient deficiencies, recommend environmentally friendly interventions, and advise farmers on how to prevent soil degradation. The AI assistant makes sure that contemporary agricultural best practices are understandable and useful by filling in the knowledge gaps for farmers with little technical experience. Additionally, the system's conversational design makes it user-friendly and accessible, minimizing the need for technical manuals or expert consultations while encouraging data-driven, sustainable farming methods.

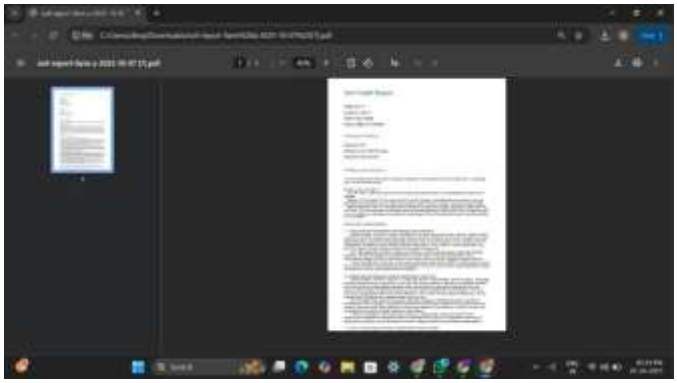

Fig 12 : Report Document

Farmers can view and save the generated reports with their soil observations by visiting the Report Download page. Users can examine the report on-screen and select to download it as a PDF file after it has been created using the data that was gathered, which includes parameters like pH, nitrogen content, moisture levels, and weather conditions.

For reference, record-keeping, or sharing with agronomists and agricultural advisors, this feature guarantees that all recorded observations, trend graphs, statistical summaries, and important insights are readily available offline. The reports that are downloaded retain their original formatting, clarity, and visualizations, offering a polished and approachable document that thoroughly documents the state of the soil's health. Precision farming and sustainable agriculture depend on the Report Download page because it facilitates safe storage and convenient retrieval, supports data-driven decision-making, documents for regulatory or advisory purposes, and allows for long-term tracking of soil management practices.

In addition to enabling farmers to keep precise records for tracking and comparison between seasons, this feature makes it easier to share information with agronomists, agricultural advisors, or cooperative societies for professional advice. The Report Download page guarantees that vital information is always available for organizing fertilization schedules, irrigation plans, and long-term soil management by facilitating simple retrieval and safe storage. Transparency and accountability are also improved, enabling farmers to monitor interventions, examine patterns over time, and make data- driven, evidence-based decisions that boost output and advance sustainable farming methods.

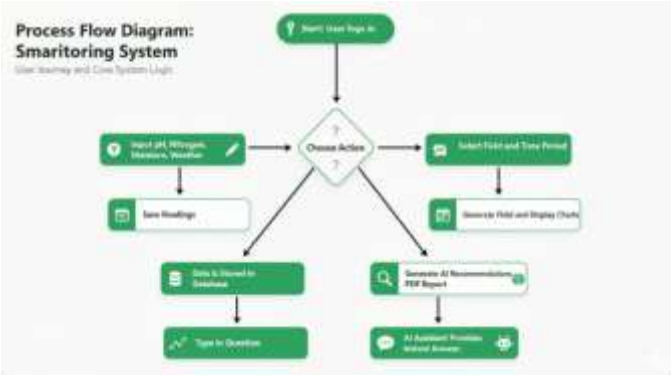

Fig 13 : Flow diagram

The Smart Monitoring System is a comprehensive solution made to track and analyze soil health metrics in real time, giving farmers the ability to make well-informed crop management decisions. It monitors vital parameters like soil pH, nitrogen content, moisture levels, and temperature by combining sensor-based data collection, cloud-based processing, and intelligent analytics. Farmers can view trends, identify anomalies, and assess how agricultural practices affect soil quality thanks to the system's continuous field data collection and user-friendly interface.

The Smart Monitoring System can help users avoid crop stress or nutrient deficiencies by using automated alerts and notifications to notify them of notable changes in soil parameters. In order to guarantee prompt and accurate interventions, the system also interfaces with AI-driven assistants to offer tailored advice on soil amendments, irrigation scheduling, and fertilizer application. Because of its modular design, it can collect data at multiple points, allowing measurements to be made across a field. This helps to account for soil variability and guarantees accurate analysis. The Smart Monitoring System gives farmers a thorough, data-driven understanding of their soil health, which, in turn, improves precision agriculture, increases resource efficiency, and encourages sustainable farming practices.

6.Conclusion

A complete and easy-to-use solution for tracking soil health and improving farming methods is the Smart Soil Monitor. The system enables farmers to make data-driven decisions that improve crop productivity and sustainability by combining real-time soil data collection, multi-point monitoring, trend analysis, report generation, and AI-driven recommendations. With its user-friendly interfaces, visual dashboards, and actionable insights, the platform helps farmers with little technical knowledge fill in the knowledge gap. In general, the Smart Soil Monitor ensures long-term soil health and better agricultural results by promoting sustainable farming, effective resource management, and precision agriculture.

7.Future Works

In the future, this project can be expanded in several significant directions to enhance its effectiveness and scalability. Additional sensors can be integrated to measure parameters such as soil temperature, phosphorus, potassium, and organic carbon, providing a more comprehensive assessment of soil health. Advanced machine learning algorithms may be implemented to develop predictive models capable of forecasting soil conditions, crop yield, and fertilizer requirements based on historical and real-time data. Integrating weather forecasting systems could further optimize irrigation and fertilization schedules, ensuring efficient resource utilization. The development of a user-friendly mobile application would enable farmers to access real-time updates, visual insights, and recommendations conveniently. Moreover, the system can be upgraded to include automated irrigation and fertilizer control mechanisms, creating a fully autonomous smart farming environment. Cloud-based data storage and analytics could facilitate large-scale data sharing and collaboration among farmers, researchers, and agricultural experts. Future work may also involve large-scale field trials across diverse geographical regions to enhance the system’s adaptability and accuracy

8.Acknowledgement

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9.Appendix

Sensors used include pH (0–14), Nitrogen (0–100 mg/kg), and Moisture (0–100%) with standard accuracy ranges. The software features multi-point data entry, trend analysis dashboard, AI assistant, and PDF report generation. Sample field data show pH, nitrogen, moisture, and altitude readings for different locations.

10.References

Li, X., Zhang, Y., & Wang, H. (2021). *Smart agriculture and precision farming using IoT-based soil monitoring systems*. Journal of Agricultural Informatics, 12(3), 45–58.

Kumar, P., & Singh, R. (2020). *AI-driven soil health management for sustainable farming*. Int. J. of Advanced Agriculture, 8(2), 101–115.

Patel, S., & Sharma, A. (2019). *IoT-enabled soil nutrient monitoring systems for precision agriculture*. Computers and Electronics in Agriculture, 162, 947–956.

Zhang, L., et al. (2022). *Integration of AI chatbots in agricultural advisory services*. Journal of Smart Farming, 5(1), 22–34.

FAO. (2020). *Soil management for sustainable agriculture*. Food and Agriculture Organization.

Dinn, C. (2025). *A Review of AIoT in Sustainable Agriculture*. ScienceDirect.

Wu, Y., et al. (2023). *IoT-Based Multiple-Sensor Monitoring System for Agricultural Soil Measurements*. PMC.

Reddy, P. D. (2025). *AI Integrated Farmer Assistant*. ScienceDirect.

Ibrahim, A., et al. (2024). *Evaluating ChatGPT responses to farmers' questions on rice production*. Nature.

Zhang, X. (2024). *Advanced technologies of soil moisture monitoring in precision agriculture*. ScienceDirect.

Grand View Research. (2025). *Soil Monitoring Market Size & Share Report, 2030*.

Liu, L., et al. (2025). *Smart Sensors and IoT Solutions for Sustainable Agriculture*. MDPI.

IARJSET. (2025). *AI – Agricultural Chatbot [Agri-bot]*.

Cover Crop Strategies. (2024). *Technological Advancements in Soil Health Monitoring and Management*.