

SMART SOIL ANALYSIS USING CUTTING-EDGE TECHNOLOGY

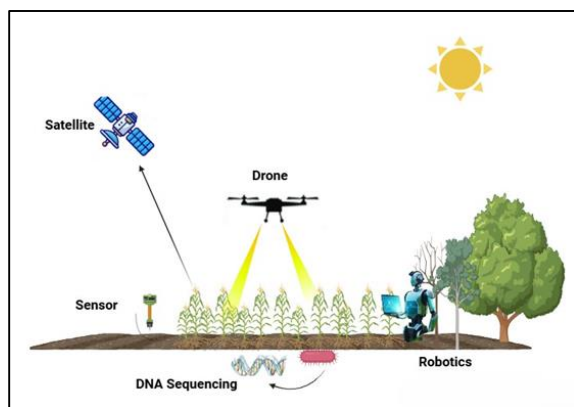
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Introduction

The term soil is considered "the foundation of agriculture" which supplies the necessary nutrients and nourishes plant growth. The ever-growing global population drives food demand forcing farmers to use smart and creative techniques that optimise yield while maintaining sustainability. Adaptation of new instruments and methodologies enables a more thorough understanding of the quality and resilience of the soil. Soil analysis plays a pivotal role in assessing soil fertility and cutting GHG emissions by advocating smart soil management practices. This article describes the numerous contemporary technologies used in soil analysis.



(Modern tools for smart soil analysis)

The Importance of Soil Analysis:

Examining soil's physical and chemical characteristics allows one to ascertain its pH, moisture content, nutrient content, and general health. It is essential to comprehend these elements for some reasons:

1. **Nutrient Management:** An accurate soil analysis enables farmers to apply amendments and fertilisers more efficiently at the right time using the right methods giving a better supply of nutrients for getting optimum yield. It also

helps in reportioning the doses of fertilizers thereby reducing the cost of cultivation.

2. **Crop Selection:** Each crop requires a particular pedo-climate for its growth and development. By assessing soil quality through soil testing, we can select different crops suitable for the particular area.
3. **Environmental Protection:** Soil analysis not only plays a key role in maintaining soil fertility but also assists in environmental protection like minimizing erosion, reducing runoff, enhancing carbon sequestration and improving biodiversity.

Traditional vs. Modern Soil Analysis:

Before delving into the modern techniques, it is essential to briefly discuss the traditional methods of soil analysis. For centuries, farmers and scientists have relied on visual inspection, simple chemical tests, and physical measurements to assess soil quality. These methods, while often effective for basic assessments, have limitations in terms of accuracy, precision, and time consumption.

Visual inspection mostly involves the estimation of the colour, texture, and structure of soil which can provide valuable clues about soil health. It is a qualitative method and can be influenced by factors such as moisture content and vegetation cover. Simple chemical tests, such as measuring pH and nutrient levels, can provide quantitative data on soil quality. However, these tests are often limited in scope and fail to explain the true potential of soil which is a complex phenomenon governed by physio-chemical and biological parameters. Physical measurements, such as soil density and particle size distribution can provide information about the

soil texture, nutrient and water-holding capacity etc. However, these measurements can be time-consuming and require more sophisticated instruments for getting a non-erroneous result.

In addition to the above-mentioned limitations, traditional soil analysis methods often suffer from a lack of spatial resolution. This means that it can be difficult to assess soil variability within a field, which is the most crucial factor for implementing precision agriculture practices.

Furthermore, traditional methods can be labour-intensive and may not provide results on time. This can make it difficult to make timely decisions about crop management and soil conservation.

To overcome the aforementioned constraints, a faster, more efficient, and more thorough soil analysis came into picturisation by using modern tools and technologies as described below;

1. **Remote Sensing:** Analysing the data through satellite imagery without contacting the source is known as remote sensing. With the aid of remote sensing farmers can get information about soils as follows:
 - a) **Soil Moisture Levels:** Farmers can go for effective scheduled irrigation by using satellites with specialised sensors that can assess moisture levels across large areas which will improve the water use efficiency as well as reduce the loss.
 - b) **Nutrient Mapping:** Remote sensing helps in capturing the nutrient gradients across the fields which will help the farmers in precision nutrient management for getting optimum yield.
 - c) **Intensity of Soil Erosion:** Remote sensing imagery provides a clear-cut picture of the increment or reduction of soil erosion in a particular area over a certain duration which can help the farmers take necessary preventive measures to reduce erosion and also choose suitable crops based on the intensity of erosion.

- d) **Carbon sequestration:** Remote sensing technology also indicates the spatial variation in carbon storage of soil by assessing the texture, moisture content and erosion status of the same soil.

Apart from the above, remote sensing also helps farmers to make data-driven decisions about soil health like NASA's Earth Observing System.

2. **Drones:** nowadays, the usage of drones for soil analysis is getting more important. Drones equipped with multispectral and hyperspectral sensors can take detailed pictures that provide important details on the state of the soil. The advantages of the use of drones include:
 - a) **High-Resolution Data:** Drones can offer precise pictures of the condition of the soil having a better resolution which will help us to take necessary steps if any maintenance is needed. It can provide a bird-eye view of soil problems like erosion, salinization, mining etc.
 - b) **Efficient time management:** A drone can complete surveys over vast landscapes much faster than a ground survey which will help the government during the allocation of budgets for different agricultural activities.

Precision Hawk (2022) and Drone Deploy are two businesses offering drone technology specifically designed for agricultural use, allowing farmers to keep a close eye on their fields.

3. **Soil Sensors:** On-site soil analysis has been transformed by portable soil sensors. These instruments provide real-time data on a range of parameters, such as pH, electrical conductivity, moisture content, temperature, primary nutrients etc. The major advantages of using sensors are:
 - a) **Rapid Response:** Farmers can evaluate soil conditions quickly and make instant decisions on fertilisation and irrigation schedules.
 - b) **Cost-Effectiveness:** Although laboratory testing may be costly, portable sensors

are reasonably priced and have a long lifespan.

- c) No skilled labour: It requires less skilled personnel to assess soil parameters as the values are reflected in the display screen directly.
- d) Easy carriageable: Sensors can be easily taken to the ground station for the analysis which consumes more time to send samples to laboratories followed by analysis.

Innovative soil moisture sensors are being developed by businesses like Soil Scout (2023), which send data in real-time and provide farmers with the necessary insights in the field.

4. Machine Learning and AI: Processes for soil analysis are increasingly using machine learning and artificial intelligence (AI). These tools are capable of pattern recognition, large-scale dataset analysis, and soil behaviour prediction. Examples of applications are:

- a) Predictive Analytics: AI can forecast how soil would react to various farming techniques, enabling farmers to adapt proper management practices to maximise their productivity. It also predicts the fertility status of soil receiving a particular land management practice under a changing climate scenario.
- b) Particularised Suggestions: Machine learning algorithms can assess certain soil conditions and suggest customised management strategies.

According to research from the University of California, Davis, in 2020 AI can enhance soil health monitoring and management tactics.

5. Soil Health Monitoring Platforms: Several platforms are providing concrete suggestions to the farmers for a sustainable enhancement of crop production by offering a thorough analysis of soil health using several cutting-edge technologies. These solutions provide farmers with a comprehensive understanding of their

soil by combining data from sensors, AI, and remote sensing. The main advantages are:

- a) User-Friendly Interfaces: Farmers can easily comprehend data.
- b) Practical Takeaways: These systems combine information from several sources to offer useful suggestions for managing soil.

Platforms such as CropX (2023) and Farm Logs are leading the way in soil health monitoring, which empowers farmers to make well-informed decisions by utilising a multitude of data.

6. DNA Sequencing: The term "DNA sequencing" is a broad scientific method used to ascertain the precise arrangement of bases, or nucleotides, within a DNA molecule. Nowadays, the study of DNA is not limited to disciplines like biotechnology or medical science but is more frequently used to assess soil health through capturing microbial populations i.e. soil metagenomics.

Soil Metagenomics: The sequencing of the soil microbial DNA gives a better insight into the occurrence of disease and pests, the biogeochemical cycling of essential nutrients and the carbon stabilizing potential of soil.

7. Spectroscopy: Spectroscopy involves the study of soil properties through the absorption or emission of light of a particular wavelength. It correlates the concentration of nutrients with the intensity of absorption or emission. Apart from UV and visible spectroscopy, two types of spectroscopies are more frequently used in soil analysis which are as follows;

- a) Near-Infrared Spectroscopy (NIR): Soil samples can be quickly analysed by NIR spectroscopy to find out the amount of organic matter, nutrient levels, and possible contaminants.
- b) Mid-Infrared Spectroscopy (MIR): By identifying certain minerals and organic molecules in the soil, MIR spectroscopy

offers important insights into the physical and chemical characteristics of the soil.

Challenges and Considerations:

While there are many benefits to using current technology for soil analysis, it has also some drawbacks to take into account:

- **Cost of Technology:** Higher initial costs associated with cutting-edge technology may prevent smaller farms from accessing it. So, it may not be feasible for small marginal farmers in India.
- **Data Interpretation:** Interpretation of metadata may need some skilled personnel for implementation and execution of management practices in the field.
- **Integration of Systems:** Some difficulties are also observed during the integration of several tools and technologies under a common platform.

Future Prospects for Soil Analysis:

The future of soil analysis is aimed at revolutionizing agriculture by enhancing productivity and sustainability through precision nutrient management. Probably, advancements in sensor technology, data analytics, and machine learning will provide farmers with ever more accurate and useful insights. The technology-driven agricultural practices will lead to enhancement of biodiversity, reduction in synthetic use, improvement in nutrient use efficiency and thereby protect the soil from degradation.

Conclusion:

Smart soil analysis will be helpful for the farming community giving farmers the precise information and resources they need to make decisions that support sustainability and productivity. Farmers may improve the methods of crop and land management and contribute to a more sustainable agricultural future by utilising remote sensing, drones, soil sensors, and artificial intelligence (AI).

Undoubtedly, in the upcoming decades, these technologies will become indispensable in addressing the problems associated with world

food production and making a sustainable environment by maintaining good soil health. So, adaptation of smart technologies particularly smart soil analysis in the field of agriculture is highly essential to prevent crop loss under changing climate scenarios. Hence smart soil analysis can be considered as the future of Soil Science.