AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 11 (November, 2026)
Available online at http://www.agrimagazine.in
©Agri Magazine, ISSN: 3048-8656

Artificial Intelligence in Soil Science and Plant Nutrient Management from Soil Testing to Smart Nutrient Decisions

*Diwakar M[1] and Sridevi G[2]
[1]Centre for Agricultural Nanotechnology (CANT), TamilNadu Agricultural University, Coimbatore, Tamil Nadu, India
[2]Department of Soil Science and Agricultural Chemistry, TamilNadu Agricultural University, Coimbatore, Tamil Nadu, India
*Corresponding Author's email: diwakar.pgnst2025@tnau.ac.in

Soil is the foundation of Agriculture, but managing and conserving soil fertility has become increasingly complex. Farmers must deal with declining soil organic matter, nutrient deficiencies, salinity, soil acidity, water stress, changing weather conditions and the rising cost of fertilizers. At the same time, applying fertilizers without considering the actual nutrient requirement of crops can lead to nutrient losses, environmental pollution and unnecessary production costs along with adverse effects on crops. Artificial Intelligence (AI) is emerging as an important tool for addressing these challenges by combining soil-test data, satellite images, sensors, weather information, crop characteristics and historical field records. AI can identify patterns and support more precise decisions on soil and nutrient management. "According to the global 4R Nutrient Stewardship framework, the future of soil management is not simply about adding more nutrients-it is about applying the Right nutrient, at the Right rate, in the Right place and at the Right time."

What is Artificial Intelligence in Soil Science?

Artificial Intelligence refers to computer-based systems that can analyze large amounts of information, identify patterns and provide predictions or recommendations.
In soil science, AI can process information such as:

- Soil pH
- Electrical conductivity (EC)
- Soil organic carbon
- Available nitrogen, phosphorus and potassium
- Secondary and micronutrients
- Soil texture
- Moisture content
- Temperature
- Crop growth characteristics
- Weather data
- Satellite and drone images
- Historical yield records

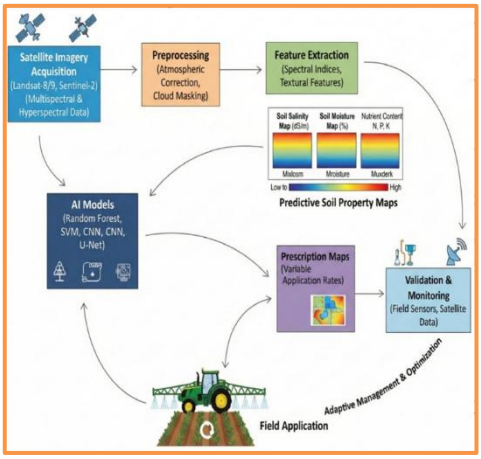
Machine learning, deep learning, computer vision and data analytics are some of the technologies used to transform these data into useful soil-management information.

Simple AI-based soil management pathway

Soil sampling + Sensor > AI and Machine Learning > Soil fertility assessment > Nutrient requirement prediction > Site-specific fertilizer recommendation > Improved crop growth + Higher nutrient-use efficiency

AI-Based Soil Testing

Conventional soil testing generally requires collecting soil samples and sending them to a laboratory. Although laboratory analysis provides reliable information, but it is time-consuming and may not always provide sufficiently detailed information for every part of a field. AI can complement conventional soil testing by rapidly analyzing large datasets and estimating soil properties from easily measurable parameters. For example, AI models can be developed to predict: Soil organic carbon, Soil pH, Nitrogen availability, Phosphorus status, Potassium status, Salinity, Soil moisture, Soil texture etc. These predictions can be generated using combinations of field observations, proximal sensors and remote-sensing data.



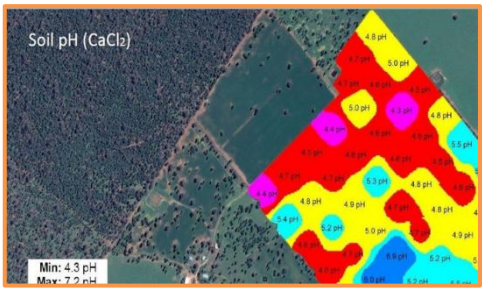
Mapping Soil Variability and Prediction

A field is rarely uniform. Soil properties may vary considerably from one location to another because of differences in texture, topography, drainage, organic matter and previous management practices. AI can analyze spatial data to identify these variations and generate digital soil maps. For example, an AI system may classify different portions of a field as:

Soil condition	Possible management
Low nitrogen	Higher N requirement
Adequate phosphorus	Avoid unnecessary P application
Low potassium	Additional K application
High salinity	Improved water and salt management
Low organic carbon	Organic matter management
High fertility	Reduced fertilizer input

This creates a foundation for **site-specific nutrient management**.

Plant Nutrient Assessment



AI-based image-analysis systems can examine leaf photographs and identify characteristic visual symptoms. One of the exciting applications of AI is **computer vision**. Smartphone, drones and cameras can capture crop images. Deep-learning algorithms can analyse these images and detect changes in:

- Leaf colour
- Leaf area
- Plant architecture
- Chlorosis
- Necrosis
- Canopy density
- Growth rate

These characteristics can be associated with possible nutrient stress. For example:
Leaf image > Computer vision > Pattern recognition > Possible nutrient deficiency > Field verification / soil and plant testing > Corrective nutrient management

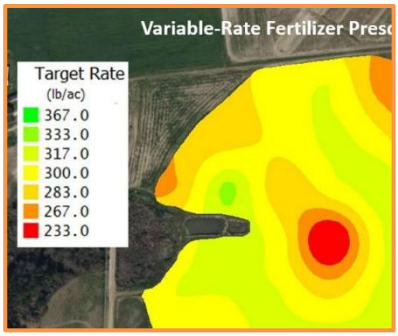
Such systems can provide rapid preliminary diagnosis, although laboratory and field confirmation remain important. However, AI should not assume that a particular symptom is caused by one nutrient. Similar symptoms can also result from **disease, drought, root damage, soil pH or salinity**. Therefore, AI diagnosis should ideally be combined with soil and plant analysis.






Soil Moisture Management

Nutrient availability is closely linked with soil moisture. Dry soils can restrict nutrient movement and root uptake, while excessive moisture can reduce oxygen availability and increase nutrient losses because water and nutrient management are interconnected. By analyzing Soil moisture sensor data, Weather forecasts, Crop water requirement, Soil type, Evapotranspiration and Irrigation history AI can predict when irrigation may be required.



Precision Nutrient Management

In precision agriculture AI plays an important role in nutrient management and also in various aspects. Instead of applying the same fertilizer rate throughout an entire field, AI can divide the field into management zones.

Conventional method

One field → One fertilizer rate

AI-supported precision method

One field → Multiple management zones → Different fertilizer rates

For example:

- Zone A → low nutrient status → higher requirement
- Zone B → medium nutrient status → moderate requirement
- Zone C → adequate nutrient status → maintenance requirement

This approach can improve **nutrient-use efficiency** and reduce unnecessary fertilizer application.

AI, Remote Sensing and Satellite Technology

Satellites provide repeated observations of agricultural land. AI can process these images to detect spatial and temporal changes in crop and soil conditions.

Useful information can include:

- Vegetation indices
- Canopy development
- Crop stress
- Soil moisture indicators
- Bare-soil characteristics
- Spatial variability

AI can combine satellite observations with ground-based measurements to develop field-specific nutrient and crop-management recommendations.

Role of Sensors and IoT

AI becomes more powerful when connected with **Internet of Things (IoT)** devices. Sensors can continuously collect information. The data can be transferred to a computer or cloud platform, where AI analyses it.

AI + IoT model

Field sensors > Real-time data > Cloud/data platform > AI analysis > Decision support > Farmer action

This allows soil and nutrient management to move from occasional testing toward **continuous monitoring.**

Benefits of AI in Soil and Nutrient Management

Benefit	Importance
Rapid data analysis	Large datasets can be processed quickly
Site-specific management	Fertilizers can be matched to field variability
Improved nutrient-use efficiency	Reduces unnecessary nutrient application
Early stress detection	Problems may be identified before severe yield loss
Reduced input wastage	Supports efficient use of fertilizers and water
Soil health monitoring	Long-term changes can be tracked
Better decision support	Multiple data sources can be integrated
Environmental protection	Can reduce nutrient losses
Record keeping	Historical field data can support future decisions

Challenges and Limitations

Despite its potential, AI is not a replacement for agronomic knowledge.

1. **Data quality:** AI models require reliable and representative data. Poor-quality soil samples or inaccurate sensor measurements can produce unreliable recommendations.
2. **Regional variability:** A model developed using data from one soil type, climate or crop may not perform equally well under different conditions.
3. **Limited ground-truth data:** AI predictions need field and laboratory observations for calibration and validation.
4. **Cost:** Sensors, drones, software and data services may be expensive for small and marginal farmers.
5. **Digital literacy:** Farmers and extension personnel require training to interpret AI-generated recommendations.
6. **Explainability:** Some sophisticated AI models operate as "black boxes," making it difficult to understand why a particular recommendation was generated.
7. **Human verification:** AI-generated nutrient deficiency diagnoses and fertilizer recommendations should be validated with agronomic knowledge, soil tests and field observations.

Future Prospects

The future of AI in soil science is likely to involve increasingly integrated systems. A future digital farm may combine:

- **Soil sensors**
- **Satellite imagery**
- **Drone images**
- **Weather stations**
- **Laboratory soil testing**
- **Crop growth data**
- **Historical yield data**

↓

Artificial Intelligence

↓

Real-time soil and crop diagnosis

↓

Nutrient + irrigation + crop management recommendation

This could move agriculture toward **predictive and site-specific soil management** rather than reactive management. It may also become increasingly useful for monitoring soil degradation, estimating soil organic carbon, improving fertilizer-use efficiency and supporting climate-resilient nutrient management.

Conclusion

Artificial Intelligence is creating new opportunities in soil science and plant nutrient management by bringing together information that was previously analysed separately. Soil-test results, sensor observations, remote sensing, weather data and crop information can be integrated to provide more precise management decisions. The major opportunity is not simply to use AI to replace conventional soil testing. Rather, AI can connect soil science, crop science, remote sensing and precision agriculture into one decision-support system. When combined with reliable field data, laboratory analysis and sound agronomic knowledge, AI can contribute to efficient fertilizer use, improved nutrient-use efficiency, better soil health monitoring and more sustainable crop production. **"Smart agriculture begins with understanding the soil—and AI can help turn that understanding into timely, field-specific decisions."**

References

1. Barbedo, J. G. A. (2019). Detection of nutrition deficiencies in plants using proximal images and machine learning: A review. *Computers and Electronics in Agriculture, 162*, 482–492. https://doi.org/10.1016/j.compag.2019.04.035 .
2. Sujatha, M., & Jaidhar, C. D. (2024). Machine learning-based approaches to enhance the soil fertility—A review. *Expert Systems with Applications, 240*, 122557.
3. Rahman, R., & Das, K. N. (2025). Artificial intelligence and machine learning in soil analysis for precision agriculture: A review. *Journal of Experimental Agriculture International, 47*(5), 511–524. https://doi.org/10.9734/jeai/2025/v47i53440 .
4. Sabharwal, A. (2026). Advancing sustainable agriculture: Integrating AI and IoT for soil nutrient management—A systematic review. *Soil Use and Management*. https://doi.org/10.1111/sum.70201 .
5. Rubio, C. A. N., Ángeles, H. M., Perea, M. T., Araiza, J. L. R., Ronquillo-Lomeli, G., Gonzalez-Garcia, I., Ventura Ramos, E., & Ríos Moreno, J. G. (2026). Applications of artificial intelligence in soil characterization and agriculture: A systematic review. *Agronomy, 16*(13), 1241. https://doi.org/10.3390/agronomy16131241 .
6. Ajith, S., Vijayakumar, S., & Elakkiya, N. (2025). Yield prediction, pest and disease diagnosis, soil fertility mapping, precision irrigation scheduling, and food quality assessment using machine learning and deep learning algorithms. *Discover Food, 5*, 67.
7. Precision agriculture technologies for soil site-specific nutrient management: A comprehensive review. (2025). *Artificial Intelligence in Agriculture,* 15, 147–161. https://doi.org/10.1016/j.aiia.2025.02.001 .
8. Machine learning in nutrient management: A review. (2023). Artificial Intelligence in Agriculture, 9: 1–11. https://doi.org/10.1016/j.aiia.2023.06.001 .
9. Exploring machine learning models for soil nutrient properties prediction: A systematic review. (2023). *Big Data and Cognitive Computing*, 7(2), 113. https://doi.org/10.3390/bdcc7020113 .
10. Advancements in soil quality assessment: A comprehensive review of machine learning and AI-driven approaches for nutrient deficiency analysis. (2024). *Communications in Soil Science and Plant Analysis*, 56(2), 251–276. https://doi.org/10.1080/00103624.2024.2406484 .
11. Rapid in-field soil analysis of plant-available nutrients and pH for precision agriculture—A review. (2024). *Precision Agriculture*, 25, 3189–3218. https://doi.org/10.1007/s11119-024-10181-6 .