

12. Artificial Intelligence in Assessment of Soil Fertility

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Introduction

Agriculture is crucial to the economic growth and food security of nations, particularly in countries like India, where approximately 60% of the rural population relies on agriculture for their livelihood. With mounting population pressures and soil quality degradation resulting from intensive cultivation, however, growth in agricultural production has become a significant global challenge. The Food and Agriculture Organisation (FAO) estimates that the world population will reach over 9 billion by 2050, which means that current production needs to be intensified by 70% to accommodate the increasing food demand. Alarmingly, no more than 10% of this added production can be realised by the development of arable land. Hence, the remaining 90% has to be realised through the intensification of already developed farming practices. Nevertheless, with overfarming, the inappropriate use of fertilisers, and shifts in climatic patterns, soil conditions are declining in most regions of the world. Conventional approaches to determining soil fertility—

such as manual sampling and laboratory analysis—are typically time-consuming, labour-intensive, and have a limited spatial extent, precluding the efficient scale-up of effective nutrient management strategies. With the ever-increasing global food demand, the necessity for quicker, more precise, and lower-cost ways of monitoring and managing soil health cannot be overstated.

Artificial Intelligence (AI) has become a revolutionary tool in agriculture, providing superior capabilities in data analysis, pattern recognition, and predictive modelling. When used to analyse soil fertility, AI can survey vast amounts of soil data from various sources—e.g., satellite images, remote sensors, IoT sensors, and past soil test reports—to give real-time, site-specific information about soil nutrient content. Machine learning software can recognise patterns, identify nutritional deficiencies, and even suggest ideal fertiliser varieties and amounts based on particular crops and soil conditions. The inclusion of AI in soil fertility evaluation not only enhances accuracy and efficiency

but also enables sustainable agriculture by minimising excess fertiliser application and environmental effects, such as nutrient loss in runoff and groundwater pollution. In the context of an increasingly digitising agricultural industry, AI-based soil fertility evaluation is a key innovation, enabling farmers to make good decisions, reduce inputs, and maximise productivity while maintaining soil health for generations to come.

For this to be realised, the application of advanced technologies in agriculture is no longer a choice, but an inevitable necessity. Among these, Artificial Intelligence (AI) has been a revolutionary force, providing novel solutions to age-old issues. Aware of its potential, the Indian government has initiated proactive steps to integrate AI into agricultural growth. In the 2018–19 Union Budget, the government authorised NITI Aayog (National Institution for Transforming India) to prepare the 'National Strategy for Artificial Intelligence,' aiming to utilise AI to drive inclusive economic growth and enhance agricultural output. Furthermore, steps are being taken to leverage big data in farming, with Agriculture Secretary Sanjay Aggarwal reiterating that "AI and big data are going to be a game-changer in the agriculture sector," and setting a target to gather 80% of the pertinent data by 2030.

These efforts are part of a broader strategy to transform Indian agriculture through data-informed decision-making, precision agriculture, and efficient resource utilisation. As India moves toward a future of digital agriculture, the integration of AI offers a promising approach to addressing food security challenges, improving farmer incomes, and promoting environmental sustainability in line with global sustainability goals.

Artificial intelligence

Artificial intelligence is a branch of learning and technology that deals with the development of intelligent machines, and computer programs in particular, capable of duplicating human thought and behaviour. AI can be two-fold. One is to leverage the capability of computers to enhance human thinking. The other approach is to leverage a computer's intelligence, in the form of artificial intelligence, to understand how humans think. John McCarthy, an American scientist, coined the term "artificial intelligence" in 1956, referring to the analytics and decision-making capabilities of data gathered by IoT.

Stages of Artificial Intelligence

1. Artificial Narrow Intelligence (ANI):

Also known as weak AI, ANI is the level of artificial intelligence in which machines are capable of carrying out only a narrow, specified set of explicit tasks.

Ex: Alexa, Google Translate

2. Artificial General Intelligence (AGI):

Also known as strong AI, AGI is the level of artificial intelligence development where machines will have the capacity to think and decide just like us humans.

Ex: Robots

3. Artificial Super Intelligence (ASI):

ASI is the level of artificial intelligence where the functionality of computers will be more than that of human beings.

Ex: Hypothetical situations observed in movies and science fiction books

Domains of Artificial Intelligence

1. Artificial Intelligence: It is the study and field of developing intelligent systems or machines that are capable of doing things that need human intelligence.

2. Machine learning: It is a subset of AI that deals with making machines learn automatically from data and then making informed choices without being specifically programmed.

3. Deep learning: A branch of machine learning that employs multi-layered neural networks to examine intricate patterns and tackle sophisticated problems.

IOT (Internet of Things):

Refers to the convergence of sensors, cameras, and other smart devices to capture all the factors and actions involved in farming and convert them into data, a term

used by Kevin Ashton in 1999. IOT is a technology that links all objects worldwide to the Internet. It is also known as *Machine-to-Machine* (M2M), *Skynet* or *Internet of Everything*. Some technologies used for the Internet of Things are: RFID tags.

Internet of Things and Artificial Intelligence

The devices, such as sensors and cameras, capture data on various properties, including humidity, temperature, and moisture. The sensor data is then taken to the cloud with the help of IOT devices. Then the sensor's data are aggregated, categorised, and analysed, and forwarded to the user via app or website.

Applications of artificial intelligence in agriculture

1. Agricultural robots are employed to harvest crops at a quicker pace, weed.
2. Sensors detect a weed-infested region, and herbicide is sprayed there to cut down on the use of more herbicide.
3. Hamster bot sensors are employed for the estimation of soil composition, moisture, and temperature.
4. Rowbot engaged in applying N fertilisers.

5. Soil sampling is done using a bright core.

Most commonly used sensors: Thermal sensors, Visible light sensors, Multispectral sensors, Hyperspectral sensors

Software tools for image processing: QGIS, ArcGIS, Pix4D, ERDAS, MATLAB, and Adobe Photoshop.

Artificial intelligence in soil science

Artificial intelligence holds significant importance in agriculture, as soil science is the primary branch of the field. AI has left a mark on it. The application of AI in various areas of soil science encompasses soil testing, monitoring of soil/land cover, assessment of soil fertility, detection of nutrient deficiencies, and carbon sequestration. Since soil testing techniques are complex and consuming, AI is among the advanced tools that can be used to improve the speed of soil evaluation.

1. Agropad

Chemical testing techniques in modern times tend to be intricate and time-consuming, posing a challenge to small farmers, who account for 80% of agricultural output. In 2018, IBM built a mini soil testing device that accurately analysed five parameters: pH, nitrogen dioxide, aluminium, magnesium, and chlorine, using a method that involves colour-based analysis. The farmer places a drop of water or soil on a test strip, and it is

then chemically analysed. A smart camera captures an image of the strip, and AI-based software rapidly interprets it, providing results to the farmer in seconds. The app also recommends changing the fertiliser to optimise crop development.

Multi-temporal remote sensing maps are used to define a physical correlation between brightness temperature, soil moisture and soil physical properties, based on an ANN-based framework for models (Chang & Islam, 2015). Several statistical and machine learning methods — namely multiple linear and nonlinear regression, classification and regression trees (C&RT), artificial neural networks like multilayer perceptron (MLP), and k-nearest neighbours (k-NN) — were utilised to develop pedotransfer functions to predict cation exchange capacity (CEC) (Jalali *et al.*, 2019).

2. Identification of nutrient deficiency symptoms

Traditional techniques of detecting nutrient deficiencies tend to be costly and ineffective. Artificial intelligence has been more efficient in this case. Fluorescence transients measured from nutrient-deficient solution-grown plants serve as input data for artificial neural networks to forecast nutrient deficiencies. Deep convolutional neural network models (DCNNM), specifically neural network models, have

been used to identify, classify, and predict nutrient deficiencies in tomato plants (Tran *et al.*, 2019).

3. Carbon sequestration

Artificial neural networks (ANN) are utilised to recognise different carbon sources. Vegetation density is used as input data in carbon sequestration models. Historical information and wildfire data are utilised as inputs in models estimating future carbon storage sinks. In greenhouse gas emission models, carbon dioxide emissions, in conjunction with population density, are used as the input variable. For carbon flow modelling, CO₂ emissions resulting from human activities and fluctuations in ecosystem carbon uptake are considered as inputs. In order to improve soil organic carbon prediction model accuracy, different machine learning algorithms are utilised, such as support vector machines (SVM), artificial neural networks (ANN), regression trees, random forest (RF), extreme gradient boosting (XGBoost) and conventional deep neural networks (DNN) (Emadi *et al.*, 2020).

Conclusion

Artificial Intelligence is emerging as a significant boon for agriculture. Its application has been identified as a sound way of approximating soil's physical and chemical properties based on fewer soil samples, which could reduce the cost

involved in laboratory tests. The varied applications of AI, ranging from assessing soil nutrients via visual-based platforms such as AgroPad, diagnosing nutrient deficiencies with the help of fluorescence information and neural networks, and even advanced carbon sequestration modelling, underscore the enormous potential of AI in making agriculture more intelligent, accurate, and eco-friendly. By minimising labour-based practices and maximising fertiliser use, AI not only enhances crop productivity but also ensures long-term soil preservation and health. Through government support of AI and significant data convergence, coupled with favourable research results, the extensive application of AI in soil fertility evaluation can bring a significant change to Indian agriculture. In the near future, AI-based soil science can become a key to safeguarding food security, empowering farmers, and advancing the vision of a digitally advanced, sustainable agricultural economy.

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