Chapter 15

Monitoring of Soil Health in Digital Age

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Shailendra Thapliyal[1], Kailash Bisht[1] and Meenakshi Sharma[2]

Abstract

The health of society and humans depend on the soil, and human activity has an influence on the lifespan of the soil ecosystem. By taking social and cultural factors into account, a well-being perspective can enhance knowledge of soil health, match with societal objectives, and enrich policy frameworks. This paper presents an all-encompassing system for tracking environmental data economically that integrates sensing, networking, and visualization layers. With the integration of Internet of Things (IoT) systems, it makes possible strong statistical and mathematical models, which are essential for public health and sustainable smart city development. To provide farmers reliable information, the decision support system utilizes sensors, cloud computing, artificial intelligence (AI), and machine learning. In order to maximize output and reduce fertilizer usage, it employs an IoT-enabled algorithm to categorize soil nutrients and recommend crops. Automation is employed for data storage, processing, and collecting. Through encouraging cooperation, supporting data-driven decision-making, testing sensors, and educating users through cutting-edge visualization tools, the digital twin supports a variety of stakeholders, including farmers, agronomists, soil researchers, and law makers. Through integrating data and predictive models, it addresses climate change concerns and promotes soil research. Utilizing organic farming practices, beneficial fungus, and conservation tillage techniques to improve plant resistance, nutrient availability, and water usage efficiency are all components of agricultural sustainability. A fuzzy classifier categorizes real-time data from NPK sensors into sodium, potassium, and calcium parameters, enabling farmers to monitor soil health and track plant growth, enhancing productivity and minimizing resource wastage through an IoT-enabled fuzzy system. The study investigates the utilization of unmanned aerial vehicles, aerial imaging, and geographic information systems (GIS) for effective plant detection and enumeration in response to growing demand for food.

Keywords

NPK, Sensing Technologies, Smart Environmental Monitoring, Soil Health Monitoring, Soil Nutrient

[1]Uttaranchal Institute of Management, Uttaranchal University, Dehradun, India. shailendra@uumail.in, kailash.bisht1911@gmail.com
[2]Uttaranchal Institute Of Management, Uttaranchal University, Dehradun, Uttarakhand India, sharma.mnk12@gmail.com

Corresponding author:
Email id: sharma.mnk12@gmail.com

1. Introduction

In horticulture, soil nutrient assessment is essential; however, there are a number of barriers to consider, such as soil characteristics, plant uptake, geographic variability, and farm components. Innovations in technology can create economical, effective information systems that promote production, sustainability, and resource management on horticultural farms [1]. Analyzing and collecting data is complicated by the time-consuming and costly nature of traditional soil quality assessments. Continuous real-time soil monitoring provides up-to-date, first-hand information that facilitates decision-making and system control [2]. Agriculture is about to undergo a transformation as a result of the adoption of Internet of Things (IoT) technology, which contributes to sustainability, efficiency, and conventional techniques [3]. To achieve food production growth, Agriculture Automation is essential, utilizing technologies like artificial intelligence (AI), machine learning, and IoT. Soil Health Monitoring systems, facilitated by automation, help ensure optimal crop-specific nutrient availability [4]. By leveraging IoT technology, the agriculture industry has the capacity to overcome constraints such as slow, labor-intensive procedures and poor real-time data, eventually enhancing soil health and environmental conditions [5]. IoT systems transmit real-time data on soil, water, and air quality through a network of specialized devices to environmental sensors. However, a thorough framework for dependability and cost-effectiveness has not yet been explored [6]. Nutrient levels in the soil are crucial for farmers for improving agricultural productivity. Remote monitoring systems powered by machine learning could enhance quality and productivity by offering insightful crop recommendations [7]. Through the implementation of an IoT-enabled fuzzy system, farmers can monitor soil health and track plant growth, increasing productivity while minimizing resource waste. A fuzzy classifier divides real-time data from NPK sensors into sodium, potassium, and calcium parameter classifications [8]. The conventional approaches of assessing soil health are being revolutionized by developments in wireless and soil sensor technology. This facilitates for real-time, on-site monitoring in place of expensive, labor-intensive approaches [9]. Emploting unmanned ariel vehicles (UAVs) to remotely monitor subsurface volumetric water by developing a degradable Intelligent Radio Transmitting Sensor (DIRTS). Biodegradable materials are used in the tiny resonating antenna sensor to enable automated deployment and scalable manufacture [10]. To determine poor growth, manage weeds, discover loam land, and evaluate productivity, crop counting is significant. The processing durations and noise disruptions of traditional approaches are constraints. For plant counting and detection in smart agriculture, UAVs and GIS are employed [11]. Figure 1 shows how UAVs assists farmers with soil monitoring and assessing the crop and soil health for timely remedies required for enhancing the efficiency and productivity.

2. Soil Health in the Digital Age: Leveraging IoT Technology

The measurement of soil fertility is based on pH, water content, and nutrient levels. Considering a global perspective, smart agriculture maximizes the utilization of available resources, sustainable land usage, freshwater consumption, and pesticide application to boost crop production and farmers' revenue [12]. Applications of data science are transforming industries like IT, engineering, finance, retail, and healthcare. In agriculture, it's also employed for weather forecasting, plant weather monitoring, and soil temperature detection, among other purposes [13]. Agronomic decision-making requires careful observation of soil properties, meteorological trends, and water availability. Technological innovations such as the IoT, cloud computing, and machine learning have radically transformed the farming process by allowing farmers to analyze data, track development, spot diseases, measure crop maturity, and

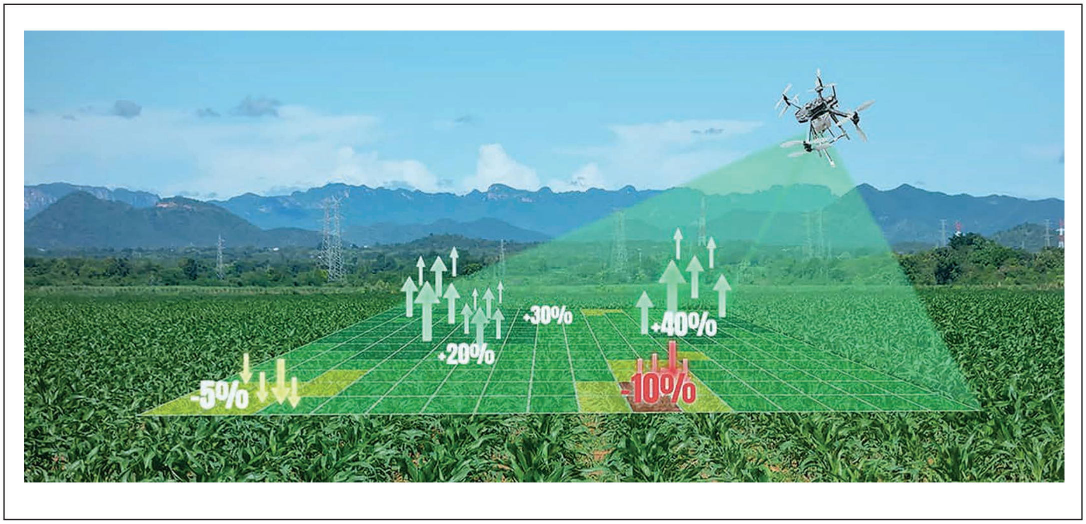

Figure 1. UAV assisted soil monitoring system

Figure 2. NPK sensor that can be deployed for soil health monitoring

harvest crops while receiving continuous support [14]. With real-time data on temperature, humidity, soil moisture, UV index, and infrared levels, smart farming—which makes use of the IoT—is transforming conventional agricultural practices and empowering farmers to adopt innovative practices aimed at boosting crop yields while maintaining resources [15]. Leveraging cutting-edge IoT technology and innovative sensor developments, smart environmental monitoring (SEM) is an essential tool for sustainable development and societal health, efficiently monitoring and maintaining the environment [16]. Growing numbers of small and medium-sized farms are adopting digital technologies for food production and necessitating to be monitored for regulatory compliance. To incorporate prediction models and show multi-sensor field data, a "digital twin" system is being established [17]. Analyzing and organizing data is made easier by the digital twin's integration of sensor data from diverse sources. It facilitates understanding of ecosystem services and many other components of soil. Visualizing environmental implications, such as changes in land use and climate, it is adaptable for scenario assessment [18]. Farmers can maximize crop output by employing Wireless Sensor Network (WSN) technology to measure soil nutrient levels. Preventing problems with crop productivity requires accurate documentation and monitoring of changes in relevant variables [19]. The behavior and spatial-temporal variability of soil must be understood in order to effectively utilize it. Further research is made possible by the trustworthy insights gathered through sensing technologies such as remote and proximal sensing, as well as laboratory spectroscopy [20]. With the objective of increasing soil organic matter and increasing yields while cutting costs and improving yield dispersion, regenerative agriculture employs NPK (nitrogen, phosphorus, and potassium) sensors to pinpoint problematic areas [21]. Farmers may monitor soil health and plant growth, increasing productivity and reducing resource waste, by employing a fuzzy classifier to categorize real-time data from NPK sensors into salt, potassium, and calcium attributes [22]. Figure 2 shows a kind of NPK sensor that can be deployed for real-time soil health monitoring by the farmers.

In order to forecast soil health characteristics, adoption of vis-NIR and MIR spectroscopy, model averaging techniques, and S-GEM algorithms. Four prediction models are evaluated as part of the

Figure 3. Handheld portable X-ray fluorescence spectrometry

assessment: partial least square regression, convolutional neural network, memory-based learning, and Cubist [23]. Understanding the behavior and variability of soil is necessary to comprehend its functions. Sensing technologies that offer trustworthy insights into soil variability encompass remote sensing, proximal sensing, and laboratory spectroscopy. With the assistance of these instruments, soil physical, chemical, and biological characteristics can be precisely described, allowing for field-based characterization and global, regional, and local soil monitoring [24]. Chemical sensors are becoming more and more popular because of their affordability, sensitivity, and convenience for application in environmental monitoring, especially for soil analysis. In order to improve soil quality and environmental health, they evaluate soil factors such as plant nutrition, contaminants, pH levels, moisture content, salt, and exhaled gases [25]. The sensitivity, affordability, simplicity of setup, and real-time analytical capabilities of chemical sensors have led to an increase in their application in soil analysis. They assess many soil characteristics, including moisture, pH, salinity, nutrients, contaminants, and exhaled gases, offering important information about the state of the soil and surrounding conditions [26]. Without requiring soil pretreatment, a soil nitrate sensor measures soil nitrate levels continuously and in real time using an ion-selective electrode (ISE) and electrochemical impedance spectroscopy (EIS). Its functionality and performance have been well-documented [27]. Innovative sensing techniques such as diffuse reflectance spectroscopy (DRS) and portable X-ray fluorescence spectrometry (PXRF) establish empirical models for various soil types to generate soil spectral libraries, which provide the rapid analysis of large samples in a relatively brief period of time [28]. A specimen of handheld portable X-ray fluorescence spectrometry is shown in figure 3.

3. Recommendations

Based on the literature review of past and present soil health monitoring techniques employed by the agriculture sector, we propose following recommendations.

- Some recommendations are to create on-site assessment tools, refine soil health indicators, implement national monitoring protocols, and enhance the Soil Management Assessment Framework (SMAF) and Comprehensive Assessment of Soil Health (CASH) evaluation tools.
- Sustainable growth through Smart Environment Monitoring (SEM) involves the implementation of smart sensors, AI, and WSN, with enhanced awareness, regulatory agencies, and environmentalists boosting effectiveness.
- An open-source structure built on cooperation and knowledge sharing must be put into place if soil science is to move forward and disciplinary boundaries across sectors are to be bridged.
- A versatile framework for policy evaluation is offered by the cognitive soil digital twin, allowing stakeholders to evaluate the effects of pollution reduction, land-use changes, and approaches for climate adaption.
- Managing the massive amounts of data produced by sensors, IoT devices, and Earth observation systems necessitates a strong data infrastructure that can handle sophisticated storage solutions, efficient processing, and accurate management systems.
- Future IoT-based soil health monitoring systems will generate maps, assess soil properties, and enhance agricultural production results utilizing sensor data, geolocation data, and machine learning algorithms.
- IoT devices and sensor networks gather environmental data in real-time, which helps maintain and update the cognitive digital twin.

- Optimizing crop growth and health is the primary objective of the rapidly emerging discipline of “smart agriculture,” a significant field of study that will likely see substantial future growth.

Conclusion

The health and sustainability of soil are influenced by human relationships and appreciation, which is vital for human life and well-being. The understanding of natural ecosystems is enhanced by its diverse values, which come from a range of social origins and impact collective societal viewpoints. Farmers will be able to make better judgments, take preventative measures, and comprehend the requirements of their land owing to sensor network technology, which will boost crop output while saving money, time, and labor. The spread of plant diseases influences the efficacy of detection methods, with fluorescence sensitivity and thermography reducing accuracy. To remove erroneous data, spectral information-based techniques necessitate intricate analysis. This paper explores the constraints and potential applications of the digital twin paradigm, emphasizing issues with data integration, privacy, model accuracy, and user interaction in addition to potential advantages. For intensive crop production systems, soil health is essential because it influences plant composition, productivity, and sustainability. Soil health is impacted by variables like the diversity, quantity, and stability of microorganisms. Arbuscular mycorrhizal fungi promote nutrient availability and water use efficiency.

ORCID iDs

Shailendra Thapliyal https://orcid.org/0009-0002-6212-2057
Kailash Bisht https://orcid.org/0000-0003-3659-2012
Meenakshi Sharma https://orcid.org/0009-0007-2977-3487

References

1. Postolache S., Sebastião P., Viegas V., Postolache O., Cercas F. (2022). IoT-based systems for soil nutrients assessment in horticul-ture. *Sensors*, *23*(1), 403.
2. Fan Y., Wang X., Funk T., Rashid I., Herman B., Bompoti N. ... Li B. (2022). A critical review for real-time continuous soil monitoring: Advantages, challenges, and perspectives. *Environmental Science & Technology*, *56*(19), 13546–13564.
3. Simo A., Dzitac S., Duțu A., Pandelica I. (2023). Smart Agriculture in the Digital Age: A Comprehensive IoT-Driven Greenhouse Monitoring System. *International Journal of Computers Communications & Control*, *18*(6).
4. Pallavi C. V., Usha S. (2022, November). IoT Based Site Specific Nutrient Management System for Soil Health Monitoring. In *2022 International Conference on Smart and Sustainable Technologies in Energy and Power Sectors (SSTEPS)* (pp. 166–170). IEEE.
5. Pechlivani E. M., Papadimitriou A., Pemas S., Ntinas G., Tzovaras D. (2023). IoT-Based Agro-Toolbox for Soil Analysis and Environmental Monitoring. *Micromachines*, *14*(9), 1698.
6. Pamula A. S., Ravilla A., Madiraju S. V. H. (2022). Applications of the Internet of Things (IoT) in Real-Time Monitoring of Contaminants in the Air, Water, and Soil. *Engineering Proceedings*, *27*(1), 26.
7. Mahangare A., Kumar J., Simon R., Mallick S., Jagtap A., Yeolekar R. (2022). Soil Health Monitoring System using Random Forest Algo-rithm. *International Journal of Research in Engineering, Science and Management*, *5*(6), 141–143.
8. Prasad R., Tiwari R., Srivastava A. K. (2023). IoT-Based Fuzzy Logic Controller for Smart Soil Health Monitoring: A Case Study of Semi-Arid Region of India. In *Presented at the 10th International Electronic Conference on Sensors and Applications (ECSA-10)* (Vol. *15*, p. 30).

9. Ramson S. J., León-Salas W. D., Brecheisen Z., Foster E. J., Johnston C. T., Schulze D. G. ... Malaga M. P. (2021). A self-powered, real-time, LoRaWAN IoT-based soil health monitoring system. *IEEE Internet of Things Journal*, *8*(11), 9278–9293.
10. Gopalakrishnan S., Waimin J., Zareei A., Sedaghat S., Raghunathan N., Shakouri A., Rahimi R. (2022). A biodegradable chipless sensor for wireless subsoil health monitoring. *Scientific reports*, *12*(1), 8011.
11. Hassan S. I., Alam M. M., Zia M. Y. I., Rashid M., Illahi U., Su'ud M. M. (2022). Rice Crop Counting Using Aerial Imagery and GIS for the Assessment of Soil Health to Increase Crop Yield. *Sensors*, *22*(21), 8567.
12. Kamble S., Gottiparthi P., Thool A., Ghadge P., Mhaiske P. (2018). Automatic Soil Detection Using Sensors.
13. Hossen M. H., Hasan M. M., Sajidul I. K., Hu W. (2022, January). Digital Revolution in the Agriculture Based on Data Science. In *2022 2nd Asia Conference on Information Engineering (ACIE)* (pp. 6–12). IEEE.
14. Senapaty M. K., Ray A., Padhy N. (2023). IoT-Enabled Soil Nutrient Analysis and Crop Recommendation Model for Precision Agricul-ture. *Computers*, *12*(3), 61.
15. Doshi J., Patel T., Bharti kumar S. (2019). Smart Farming using IoT, a solution for optimally monitoring farming conditions. *Procedia Computer Science*, *160*, 746–751.
16. Ullo S. L., Sinha G. R. (2020). Advances in smart environment monitoring systems using IoT and sensors. *Sensors*, *20*(11), 3113.
17. Madeira R. N., Santos P. A., Java O., Priebe T., Graça E., Sárközi E. ... Gómez R. P. B. (2022). Towards Digital Twins for Multi-Sensor Land and Plant Monitoring. *Procedia Computer Science*, *210*, 45–52.
18. Tsakiridis N. L., Samarinas N., Kalopesa E., Zalidis G. C. (2023). Cognitive Soil Digital Twin for Monitoring the Soil Ecosystem: A Conceptual Framework. *Soil Systems*, *7*(4), 88.
19. Singh G., Purohit V. M. (2017). PORTABLE LOW COST SOIL HEALTH-MONITORING SYSTEM. *International Journal of Technical Research and Applications*, *5*(3), 125–128.
20. Silvero N. E., Demattê J. A., Minasny B., Rosin N. A., Nascimento J. G., Albarracín H. S. R. ... Gómez A. M. (2023). Sensing technologies for characterizing and monitoring soil functions: A review. *Advances in Agronomy*, *177*, 125–168.
21. Cojocaru C., Ene A., Gojgar A. F. (2020). Farm's soil quality using wireless Npk sensor. *no. November*, 3–7.
22. Prasad R., Tiwari R., Srivastava A. K. (2023). Internet of Things-Based Fuzzy Logic Controller for Smart Soil Health Monitoring: A Case Study of Semi-Arid Regions of India. *Engineering Proceedings*, *58*(1), 85.
23. Xue J., Zhang X., Chen S., Lu R., Wang Z., Wang N. ... Shi Z. (2023). The validity domain of sensor fusion in sensing soil quality indica-tors. *Geoderma*, *438*, 116657.
24. Silvero N. E., Demattê J. A., Minasny B., Rosin N. A., Nascimento J. G., Albarracín H. S. R. ... Gómez A. M. (2023). Sensing technologies for characterizing and monitoring soil functions: A review. *Advances in Agronomy*, *177*, 125–168.
25. Nadporozhskaya M., Kovsh N., Paolesse R., Lvova L. (2022). Recent advances in chemical sensors for soil analysis: a re-view. *Chemosensors*, *10*(1), 35.
26. Fahey T., Pham H., Gardi A., Sabatini R., Stefanelli D., Goodwin I., Lamb D. W. (2020). Active and passive electro-optical sensors for health assessment in food crops. *Sensors*, *21*(1), 171.
27. Eldeeb M. A., Dhamu V. N., Paul A., Muthukumar S., Prasad S. (2023). Electrochemical Soil Nitrate Sensor for In Situ Real-Time Monitor-ing. *Micromachines*, *14*(7), 1314.
28. Swetha R. K., Mukhopadhyay S., Chakraborty S. (2020). Advancement in Soil Testing with New Age Sensors: Indian Perspective. *Soil analysis: Recent trends and applications*, 55–68.