

# Review Report – Manuscript: Soil Health Assessment and Proximal Sensing

## 1. Overview

The manuscript provides a comprehensive review of soil health assessment methods using sensor technologies (proximal sensing), highlighting the significance of soil health in ecosystem functioning and policy development. The topic is both relevant and timely, particularly in the context of sustainable soil management, with important implications for agricultural practices and environmental policies. The manuscript is well-structured and covers a wide range of methodologies, policy frameworks, and technological advancements. However, several areas require clarification and further elaboration to enhance its scientific quality, clarity, and impact. Specifically, improvements could be made in the comparative analysis of different sensor technologies and the integration of practical aspects for their broader implementation. Overall, while the article is valuable, **I recommend accepting the paper with major revisions.**

## 2. Strengths

- The article provides a solid synthesis of sensor technologies used for soil health assessment, making it an essential reference for researchers and practitioners in the field.
- The authors effectively highlight the potential of these technologies to enhance agricultural productivity and sustainability, particularly in the face of increasing pressures such as climate change and soil degradation.
- *Relevance of the Topic:* Soil health is a critical issue, especially in the context of global food security and climate change. The paper emphasizes the significance of soil health monitoring in tackling these challenges. Moreover, the integration of sensors with data modeling (e.g., machine learning and AI) is a particularly forward-looking aspect of the review, as it suggests ways to refine soil health assessments beyond traditional methods.

## 3. General comments

- Some sections, particularly in the abstract and introduction, contain lengthy sentences that could be streamlined for better readability.
- Although various frameworks and sensor technologies for soil health assessment are mentioned, a more in-depth comparative analysis of the different technologies and methods would be beneficial. The authors should integrate a detailed discussion on the advantages, limitations, and specific applications of each sensor.
- The manuscript briefly touches on policies related to soil health but lacks a deeper discussion on the practical challenges of implementing these policies, particularly regarding the integration of sensor technologies in large-scale soil management. A discussion on policy gaps and recommendations for improvement would add value.
- The review highlights the potential of sensor-based methods but does not sufficiently discuss their limitations, such as cost, accessibility, and calibration challenges.
- Throughout the manuscript, terms such as “soil health,” “soil quality,” and “soil function” appear interchangeably. Clarifying their distinctions and ensuring consistent usage would improve coherence.

## 4. Specific Comments

Abstract (Lines 1-16): The abstract summarizes the study well, but it lacks an explicit mention of the originality of the approach. Adding a sentence that highlights what makes this review unique would help clarify the contribution of the article.

Introduction (Lines 17-63): The introduction provides a solid background on soil health but delays presenting the research problem. Consider introducing the core problem earlier.

- Lines 39-50: The discussion on soil health policies could be expanded to critically analyze their limitations.
- Lines 54-63: The transition to technological advancements is abrupt. A smoother connection explaining the shortcomings of existing assessment methods would help justify the focus on sensing technologies.

Objectives (Lines 64-68): The objectives are clear but could be more specific in addressing identified research gaps. Consider refining Objective 1 to specify key limitations in current assessment methods. Objective 3 should explicitly mention the practical applications of sensing technologies.

Defining Soil Health (Lines 69-100): The historical context is well presented but contains some redundancy. Streamlining this section would enhance readability. The manuscript presents multiple definitions of soil health but does not take a clear stance. A brief discussion on the preferred interpretation would improve coherence.

Limitations of Current Definition (Lines 104-133): The section provides a comprehensive overview of the challenges associated with defining soil health. However, consider streamlining the discussion to eliminate redundancy and enhance clarity. A brief critique of the varying opinions on the necessity of the soil health concept could strengthen the argument for a more objective definition.

Current Soil Health Assessment Frameworks (Lines 134-157): While Table 1 summarizes the different assessment frameworks, this section could be enhanced by a more critical analysis of the differences between these frameworks and their applicability to different regions or contexts.

A discussion on adapting these frameworks for non-agricultural ecosystems would also be valuable. The authors could discuss the scalability of these frameworks. Which ones are best suited for broad implementation, and which face barriers to adoption?

A clearer connection between the limitations mentioned (e.g., scale and applicability) and specific examples or case studies would enhance the depth of the discussion

Soil Health Indicators (Lines 158-191): This section is well-developed, but it would be helpful to add a summary table of the 20 indicators mentioned to improve readability and understanding of the key points.

Measuring Soil Health Indicators (Lines 192-216): The section could benefit from examples of more innovative sampling strategies beyond those mentioned, illustrating advancements in the field. A discussion on the potential consequences of inadequate sampling methods on the interpretation of soil health assessments would provide additional context to the importance of robust sampling protocols.

Interpreting Soil Health Indicators (Lines 217-260): The section on interpreting soil health indicators provides a solid overview but could benefit from a few adjustments:

- It would be useful to explore the extent of bias introduced by ordinal scales and how it affects interpretation across different ecosystems.
- Clarifying the limitations of assumptions, such as "more is better," could strengthen the argument, particularly in complex soil systems.
- A discussion on challenges in model calibration and data collection for large-scale applications.

A Soil Health Index (Lines 261-278): While discussing the limitations of composite indices, it would be beneficial to:

- Clarify how data-driven methods, like principal component analysis, can address non-linear interactions among indicators.

- Consider a multi-tiered approach that combines composite indices with individual actionable indicators for more precise management recommendations.
- Discuss how a balance between simplicity and scientific rigor can be achieved in practice, especially when communicating with stakeholders.

*An Ecological Focus for Soil Health (Lines 279-311):* It would be useful to define key terms like “soil health” and “ecosystem services” at the start of the section to avoid ambiguity. Strengthen the ecological perspective on soil health by including concrete examples of methodologies that could be applied in this framework.

*Sensing Soil Health (Lines 312-326):* The section on sensor-based technologies should delve more into the challenges such as costs, calibration, and accessibility. Discuss how these limitations can be mitigated to make such technologies more viable for widespread use. If you mention sensor fusion, briefly explain how different sensors complement one another.

*Sensor-based soil health indicators (Lines 327-344):* Include examples of soil health indicators that can be measured with sensors. This will give readers a clearer picture of the practical applications of these technologies. While the manuscript discusses the advantages of sensor-based systems, it would be helpful to explore how current limitations, such as data quality or sensor calibration, might be overcome.

*Sensing for characterising soil health (Lines 345-421):* The manuscript discusses the potential of sensor technologies but lacks details on challenges such as cost, accessibility, and data interpretation. The section mentions sensor fusion but does not clearly explain how different methods complement each other. A brief clarification would be beneficial.

*Conclusion & Future Directions (Lines 422-440):* The conclusion summarizes key points well but could end with a stronger statement on policy implications and recommendations for future research. Consider adding a discussion on the practical steps needed to operationalize the proposed framework.

## 5. Suggestions for Improvement

- **Manuscript structure :**
  - Reorganize certain sections to avoid repetition and make the article flow more smoothly. For example, a dedicated section on the challenges and limitations of sensing technologies could be added just after presenting the methods.
  - Ensure that the definitions of key terms like "soil health," "soil quality," and "soil function" are explicitly given in the introduction and consistently used throughout the article.
- **Inclusion of Real-World case studies:** The article would benefit from the inclusion of real-world case studies or examples that demonstrate how sensor technologies have been successfully implemented in different agricultural settings. Case studies would help readers understand the practical implications of using these technologies and provide insight into how challenges such as calibration, data integration, and cost can be addressed in real-world contexts.
- **Comparison Table:** As mentioned earlier, a comparative table summarizing the strengths, weaknesses, costs, and typical use cases for the different sensor technologies would be an excellent addition. This would offer readers a clearer guide to choosing the right sensor technology based on their needs.
- **Future directions:** The authors briefly mention the integration of sensors with AI, but a more extensive discussion of future trends and research opportunities would strengthen the article. For instance, exploring the potential for integrating sensor data with other environmental data

sources (e.g., satellite imagery, climate data) could provide more holistic insights into soil health.

## **6. Questions for the Authors**

- **Sensor calibration and soil type variability:** How do you recommend dealing with the variability in sensor readings when applied to different soil types and environmental conditions?
- **Data integration:** What strategies do you suggest for integrating sensor data with other environmental data (e.g., weather, land use) to improve the accuracy of soil health assessments?
- **Implementation in developing regions:** Could you expand on the challenges and strategies for implementing sensor technologies in low-resource settings, especially in developing countries?

## **7. Conclusion and recommendations**

The manuscript provides a valuable contribution to the discussion on the use of sensor technologies for soil health assessment. However, to enhance its scientific impact, it is essential to clarify certain technical points, provide a more in-depth comparative analysis of the different technologies, and focus on the practical aspects of implementing these technologies for soil management. I recommend a major revision before publication.