Chapter 3

Soil Health Assessment and Monitoring Techniques

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Abstract

Soil quality emerges as a pivotal concern for both human civilization and environmental well-being, akin to the significance of water and air quality. It proves critical in promoting agricultural productivity while curbing environmental damage. The myriad factors contributing to soil degradation, including erosion, pollution, and compaction, result in food and water scarcity, heightened energy consumption, and increased environmental risks. Distinguishing soil quality from soil health, the systematic approach required for monitoring and assessing soil quality and health is paramount, encompassing data collection, index development, continuous monitoring, and integrated management techniques. This holistic approach can enhance agricultural output, mitigate environmental degradation, sequester carbon, and preserve biodiversity, addressing critical challenges like food security and climate change. (NIRS) Near-infrared reflectance spectroscopy offers a revolutionary means of real-time soil quality monitoring, while soil health management practices, including organic amendments and sustainable agriculture, play a pivotal role in improving and safeguarding this invaluable resource, demanding collaborative research efforts to ensure its preservation for future generations amidst the multifaceted challenges posed by soil degradation and the maintenance of soil health.

Keywords: erosion, soil degradation, soil quality and soil health

I. INTRODUCTION

Soil quality, like water and air quality, is critical to human civilization and environmental quality (Doran *et al.,* 2018). It refers to a soil attribute that may be derived from soil parameters or extensive observation. Fertile soil promotes and sustains higher agricultural output while minimizing environmental damage (Reynolds *et al.,* 2009). Long-term production without degrading soil quality or generating land degradation is critical for the agricultural system's survival. Wind and Water erosion, salinization, acidification, desertification, pollution, sealing, organic Carbon reduction, compaction, floods, soil biodiversity loss, and landslides all contribute to dangerous levels of soil degradation. Soil degradation causes food and water shortages, increases global energy use, and increases environmental risks (Qi *et al.,* 2009). Soil hazards have been identified to aid in the direction of risk assessment processes by emphasizing locations where soil function may be impacted. Soil quality evaluation entails identifying sensitive soil features that reflect a soil's ability to operate properly and can be used as indicators of soil viability. Healthy soils perform a number of ecological functions, including erosion prevention, retention of water and storage, nutrient conservation, and ecological buffering (Mairura *et al.,* 2007). However, as soils do not respond instantaneously to modifications in land use and management approaches, establishing universal goal standards for soil quality is challenging. There are two methodologies to the history of soil quality, one stressing intrinsic soil properties and the other emphasizing the influence of human management. The concept of soil quality was initially introduced by Mausel (1971), who defined it as the capacity of soil to produce wheat, soybeans, and corn under intensive management practices. Subsequently, Doran and Parkin (1994) expanded on this definition by emphasizing the soil's ability to ethically function within the constraints of the ecosystem and land-use practices. They highlighted the importance of maintaining biological activity, preserving the sustainability of the environment, and supporting the health of plants and animals. The terms "soil health" and "soil quality" are sometimes used interchangeably; however, there is a distinction between the two variablites. Soil health primarily pertains to the ongoing capacity of the soil to support plant growth and functionality, whereas soil quality pertains to the soil's capacity to meet specific human needs, such as facilitating agricultural cultivation.

Monitoring and assessing soil quality and health necessitate a systematic and methodical approach to enable accurate assessments, data-driven choices, and successful soil management techniques (Volchko *et al.,* 2013). Without such a strategy, sustainable soil resource management becomes difficult, and the implications of soil degradation, such as lower agricultural output, increased greenhouse gas emissions, and biodiversity loss, become more likely. Given the importance of soil in maintaining ecosystems and agriculture, improving soil quality is a critical endeavor. Soil quality and health are diverse features that need a systematic process for accurate evaluation and successful management. This method entails thorough data collecting, the establishment of soil quality indexes, ongoing monitoring, and integrated management methods (Mc Bratney *et al.,* 2018). By using this system, we may increase agricultural output, decrease environmental degradation, trap carbon, and maintain biodiversity while tackling critical issues such as food security and climate change.

II. SOIL HEALTH VS. SOIL QUALITY

In science literature and research papers, the words "soil quality" and "soil health" are commonly employed interchangeably. Agricultural and environmentalists tend to favor the term "soil quality," while farmers or producers typically opt for "soil health" (Maikhuri and Rao, 2012). Some individuals hold a preference for the term "soil health" due to its portrayal of soil as a dynamic and interconnected entity, as opposed to a static and lifeless amalgamation of sand, silt, and clay. The term "soil quality" is employed by certain individuals to refer to the intrinsic quantitative biological, chemical, and physical properties of soil. The term "soil quality" pertains to the capacity of soils within a given landscape to support biological productivity, uphold environmental integrity, and enhance the well-being of plants and animals. Soil health refers to the overall state and suitability of soil to fulfill certain purposes, such as supporting crop growth. It is primarily governed by the fundamental properties of the soil and is particularly vulnerable to human-induced disturbances. In extreme situations, soil health is severely constrained. (Angon *et al.,* 2023). Both of these phrases establish a connection between soil and various health concepts, including environmental health, human health, plant health, and the well-being of animals. Soil health and soil quality are conceptual frameworks that assess the suitability of soil for a diverse range of functions. Consequently, soil health can be understood as synonymous with soil quality.

Alternatively, some argue that soil health can be defined as the state of the soil at a particular point in time, encompassing the dynamic soil attributes that exhibit short-term variations (GaticaSaavedra *et al.*, 2023). Organic matter concentration, variety and quantity of organisms, and microbial components or products are all examples of dynamic soil features. Soil quality can relate to both permanent soil qualities and soil condition (Gilliam *et al.*, 2023).

III. SOIL QUALITY ASSESSMENT TECHNIQUES

The framework to evaluate soil quality gives site-specific interpretations of soil quality indicator values. The implementation of a framework-based strategy for soil quality parameters is employed due to the dependence of soil quality definition on several factors such as management objectives, climatic conditions, crop types, and soil characteristics peculiar to our area. This allows for the essential variations in interpretation of indicator data based on location and purpose. The index framework consists of three major steps:

- The selection of indicators for the purpose of efficiently and effectively monitoring critical soil processes.
- The process of interpreting signals in relation to soil function involves utilizing expected ranges derived from the inherent capabilities of the soil.
- Creating an integrated index of soil quality by combining indicator scores (optional). As a result, a relative estimate of the soil's capacity to execute the functions required for its intended application is produced.

1. Indicator Selection

A minimum dataset refers to a compilation of indicators that are employed for the purpose of evaluating the soil's quality. The person's text is too short to be rewritten in an academic manner. There are two fundamental approaches that have been identified for the purpose of choosing a suitable data set: expert opinion and data from statistical sources reduction. A comprehensive comprehension of the system is necessary in order to provide an expert opinion. The utilization of a hierarchical framework for the selection of indicators can enhance the systematic nature of the process. The soil functions of interest are determined by the objectives of management, which consequently necessitate the use of appropriate indicators. Filtering and buffering play a crucial role in soil processes, particularly when the objective is to manage animal waste disposal in a specific agricultural area. The utilization of organic matter content and pH levels can serve as potential indicators during the processes of filtering and buffering. Further improvement of the indicator set is necessary, taking into consideration factors such as climate, soil composition, plant community dynamics, and other relevant features. The strategy employed by the Soil Management Assessment Framework is as follows.

Previous studies have demonstrated the effectiveness of statistical data reduction techniques in selecting indicators for various soil systems (Andrews and Carroll, 2001 Brejda *et al.*, 2000). This methodology has the potential to mitigate disciplinary bias that may arise from the selection of expert indicators. However, it is important to note that the effectiveness of this technique relies on the inclusion of pertinent candidate indicators in the initial dataset, hence necessitating a certain level of knowledge. One significant drawback of employing this particular technique is the necessity of possessing a substantial preexisting dataset. There is a lack of certainty over the availability of data sets with adequate scale, in terms of the number of indicators monitored or observations recorded, for managers to effectively implement this strategy on an individual basis. If you believe you have a large enough data collection and want to use this selecting strategy.

2. Interpreting Indicators

To comprehend how each measure relates to the soil's function of interest and to allow indicators to be aggregated by reducing unit disparities, indicators must be scored. Non-linear scoring functions are a frequent scoring approach. Scoring functions are commonly utilized as utility functions in economics (Norgaard, 2011), decision functions in many-objective conclusion making (Yakowitz *et al.*, 1993), and modeling tools in organisms engineering (Wymore, 1992). This idea was initially used to soil indicator interpretation by Karlen and Stott (1994). Previous studies have demonstrated the effectiveness of statistical data reduction techniques in selecting indicators for various soil systems (Andrews and Carroll, 2001). Three distinct scoring curves were utilized, namely the "more is better," and "less is better 'mid-point optimum" approaches. This identical approach is used in the soil quality evaluation framework, but with a greater diversity in curve form. The best score would be awarded in all circumstances when an indicator value signified high function in the specific soil, i.e., if the indicator was not limited to related soil functions and processes such as filtration and buffering, nutrient cycling, or structural stability (table 1). Some crop-specific indicators exist. The determination of the appropriate soil pH score is contingent upon the specific crop under cultivation. The vast majority of indicators are site-specific, with interpretation dependent on intrinsic soil qualities.

Table 1: Soil quality indicators

Physical indicators	**Chemical indicators**	**Biological indicators**
Rooting depth	Electrical conductivity	Organic matter content
Bulk density	Soil reaction or pH	Earthworms
Water holding capacity	Organic matter	MBC, MBN
Water infiltration rate	Cation exchange capacity	Active carbon
Aggregate stability	Available nutrients	Enzyme activity
Hardness	Soil acidification	Decomposition rate
Surface crust	Soil salinization	Earthworm populations
Penetration resistance	Exchangeable sodium	Weed seed bank
Surface and subsurface hardness	Heavy metals	Nematode communities
Infiltration	Soil mass movement	Soil proteins
Texture	Ions exchange phenomena	Respiration

***MBC- Microbial Biomass Carbon, MBN- Microbial Biomass Nitrogen*

3. Indicator Score Combination

After being assigned scores, indicators have the potential to be combined using several methods, such as additive (Andrews and Carroll, 2001), balanced (Winiwarter *et al.*, 1998), or exponential (Larsen and Pierce, 1991 Doran and Parkin, 1997) Larsen and Pierce, 1991) indices. Andrews *et al.* (2001) discovered minor changes in index outcomes derived by different approaches when comparing indexing strategies. This site's soil quality evaluation framework index is additive, although users can weight indicator scores.

IV. DEVELOPING SOIL QUALITY INDICES (SQIs)

1. Additive Quality Index (AQI)

This index was calculated according to Nabiollahi et al., 2017 using the following equation:

$$AQI = \sum_{i-0}^{n} s/n$$

Where S is the score of the indicator and n is the number of indicators used in the index.

2. Weighted Additive Quality Index (WQI)

In this approach, each indicator was assigned a weight value using PCA in two ways: (i) the variability score of PCA, which refers to a frequently indexed set of vectors or functions that are cantered at a mean and are used to depict variation in a sample (Mukherjee et al., 2014); and (ii) the communality score of PCA (the sum of squared loadings across components), which refers to what proportion of the variance, in the variable is due Weights for the TDS were computed by dividing the communality of an indicator by the sum of the communality of all indicators. Weights for the MDS were computed using the two techniques. The variance weights were obtained by dividing the variation of each PC (%) by the total percentage of variation of all PCs with, eigenvectors greater than one. The MDS was applied to another PCA to extract communalities, and weights were determined as a result. The WQI was calculated according to Raiesi (2014) as follows:

$$WQI = \sum_{i-0}^{n} Wi \times Si$$

Where, W is the weight value of the indicator and S is the PCA score of the indicator.

3. Nemoro quality index (NQI)

This index evaluates soil quality based on the minimum and average scores of indicators (Guo et al., 2017, and Nabiollahi et al., 2017), as follows:

$$\mathrm{NQI} = \sqrt{\frac{\mathrm{P}_{\mathrm{aver}}^{2} + \mathrm{P}_{\mathrm{min}}^{2}}{2}} \times \frac{n-1}{n}$$

Where P_{aver} and P_{min} are the average and minimum of indicator scores, and n is the number of indicators included in calculations.

V. SOIL QUALITY CLASSES

Five grades were taken into account for each soil quality index (SQI): extremely high (Q1), high (Q2), medium (Q3), poor (Q4), and extremely poor (Q5). The range of values for each SQI was divided by the desired number of intervals, which was 5. Subsequently, the outcome of the division was employed as the measurement for the breadth of each interval. By including this value with the minimum value of each SQI, the initial threshold of the first interval was attained, and thereafter, this process was repeated until the upper boundary of the SQI was attained (Sanchez *et al.,* 2015).

1. Comparison between Indexing Models

In order to evaluate notable distinctions between the indicators and indices techniques, a one-way analysis of variance (ANOVA) test was conducted. In order to enhance comprehension of the link, further analyses were conducted, including correlations between indices and regression utilizing indicator techniques. Sensitivity analysis is a mathematical technique employed to examine the effects of variations in model parameters on model outputs. Its purpose is to identify the model parameters that contribute significantly to the variability observed in model predictions (Ferretti *et al.,* 2016). The authors Cude and Oregon (2000) employed sensitivity analysis to ascertain the factors that exerted the most influence on the soil health index model. Sensitivity analysis is a method used to examine how variations in the input parts of a numerical model might be attributed to differences in its output. To assess the correctness and validation of all of the models, the sensitivity index (SI) was computed in the following manner. (Chen *et al.*, 2013):

$$\mathrm{SI}=\frac{SQI\ max}{SQI\ min}$$

The variables SQI max and SQI min represents the highest and lowest values of soil quality observed inside each indexing model, respectively. According to Pianosi *et al.* (2016), a parameter exhibiting significant sensitivity suggests that its estimated value is more accurate, while low sensitivity indicates poor recognition of the parameter and a substantial level of ambiguity. The model with better sensitivity demonstrates enhanced accuracy due to its consideration of various soil management strategies, including tillage and reconsolidation, no-tillage and surface residues, plants and crop rotations, water supply, manure, and fertilization treatments, as well as grazing maintenance.

VI. QUANTITATIVE LAND EVALUATION

The utilization of a quantitative approach in research and analysis is a method that involves the collection and interpretation of numerical data. Quantitative land evaluation involves the measurement and assessment of the physical advantages derived from land. The process is typically conducted as a foundation for economic analysis; however, it has inherent challenges. In order to quantify the advantages, all parameters related to the land are determined.

1. Storie Index Rating

Soil characteristics can be utilized to assign a classification to soil based on its suitability for a specific purpose. The Storie Index (Storie, 1978) quantifies the comparative appropriateness of soil for the purpose of widespread intensive agricultural practices. The ranking is determined by four key factors: soil profile characteristics (Factor A), texture of the surface (Factor B), elevation (Factor C), and supplementary factors such as drainage, alkali levels, and others (Factor X).

Ratings ranging from 0 to 100 are awarded to individual criteria based on the prevailing conditions in the field. A rating of 100 percent denotes the most favorable circumstances, whilst a rating below 100 percent signifies the least favorable circumstances. The ultimate index is determined through the multiplication of each rating utilized for evaluation. The utilization of a single mild element can have a substantial impact on diminishing the overall value of the index, hence imposing limitations on its applicability.

$$\mathrm{I} = A \times B \times C \times x$$

For eg.: The final rating of the soil, which is characterized by a depth of over 120 cm on recent alluvial sediments (Factor A = 100%), a clay loam texture without gravel or stones (Factor B = 85%), occurring in a gently undulating relief of 2% (Factor C = 95%), being well drained, highly fertile, and free from erosion or alkali/acidity limits (Factor X = 100%), is determined to be:

$$\mathrm{I} = A \times B \times C \times x = 100\% \times 85\% \times 95\% \times 100\% = 81\% \text{ or } 0.81$$

Storie regrouped the index values into six soil grades

Grade	Rating	Remark
I	80-100	Excellent
II	60-79	Good
III	40-59	Fair
IV	20-39	Poor
V	10-19	Very poor
VI	<10	Not suitable for agriculture

2. Productivity Index Rating

Riquier *et al.* (1970) have developed a method for evaluating soil quality based on its current and future productivity. This is a revised iteration of the Storie Index. The Productivity Index (P) is determined by evaluating nine elements on a scale of 0-100. These factors include moisture (H), drainage (D), deep (P), texture (T), saturation of bases (N), soluble salts (S), organic matter (O), cation exchange capacity (CEC) (A), and mineral reserves (M). The individual ratings for each factor are then added together to get the cumulative Productivity Index.

Productivity index is obtained using the below formulae:

$$PI = H \times D \times P \times T \times N \times S \times O \times A \times M$$

The soil is classified based on the cumulative rating it receives.

Similarly, the Potentiality Index (P') is produced after considering potential management strategies like as reclamation, fertility supervision, and others. The ratio of two scores indicates how much production may be increased. This ratio is known as the coefficient of improvement.

$$\text{Coefficient of improvement} = \frac{\text{Potential productivity rating}}{\text{Present prductivity rating}}$$

This methodology does not explain yield variation, and it is difficult to give values to elements such as drainage. Second, one limiting factor significantly decreases the production index. Furthermore, criteria should be chosen based on the constraints impacting crop development within a certain location to produce a more realistic productivity rating.

VII. ECOSYSTEM SERVICES-BASED APPROACH FOR SOIL QUALITY ASSESSMENT

The examination of the connections between soil characteristics and ecosystem services enables a shift from localized measurements to a more comprehensive analysis that encompasses various land utilization patterns, soil classifications, climatic zones, and a more precise understanding of the impact of soil quality on human endeavors. (Rinot et al., 2019). ***first step*** suggested technique begins with collecting soil samples from diverse soil types, land uses, and climatic zones and assessing, biological, chemical and physical properties. The generated database may be used to choose important soil attributes for assessing soil quality. Because they require a large dataset and may differ in interpretation, quantitative statistical approaches are preferred over expert-based models. To reduce the amount of characteristics required, autocorrelation and main component analysis are utilized. When paired with basic additive approaches, expert opinion can be useful, but measurement costs and other factors must be addressed. The ***second step*** in evaluating soil function is to turn raw data into normalized scores, which may or may not be applicable to different fields, garners, land uses, and geographies. To solve this, soil ES should be utilized as the goal value for assessing soil functioning. Soil ecosystem services (ES) should be defined and measured, and their relative performance should be represented on a standard scale (0-1 or 0-100). This scoring technique is more trustworthy than the present method because it allows for the evaluation of the quality of services and benefits offered by the soil and eliminates the difficulty of comparing soil features that are inherently different in location and time. Least squares models should be used to determine the relationship between selected measured soil properties and normalized ES goal values. The ***third step*** is integrating least squares models to determine each attribute's contribution to each soil ES. This aids in the elimination of low-component qualities and the creation of a holistic model. Based on a variety of soils, land uses, and agro ecosystems, this model determines the most important features for evaluating their contribution to each ES and soil health evaluation.

VIII. MONITORING OF SOIL QUALITY USING NEAR-INFRARED REFLECTANCE SPECTROSCOPY (NIRS)

Soil quality evaluation has traditionally depended on time-consuming and labour-intensive laboratory approaches that need significant sample preparation and processing. Although these traditional procedures are precise, they do not allow for on-the-spot decision-making, which is frequently necessary in modern agricultural and management of the environment. Furthermore, they might be expensive and create a lot of waste owing to sample destruction. NIRS, alternatively, represents a breakthrough in soil quality measurement by providing a quick, low-cost, and non-destructive alternative (Cécillon *et al.,* 2009). Near-infrared spectroscopy (NIRS) is a popular technique in several fields, including food science and pharmacology. However, its employment in soil applications is still in its early stages. Portable and flexible near-infrared (NIR) devices have the potential to supply the extensive spatial data needed for soil condition monitoring and soil process simulation. The interaction of near-infrared light and molecular vibrations inside soil samples provides the basis for NIRS. A near-infrared light beam is partially absorbed and partially demonstrated when directed toward a soil sample. Researchers and land managers may learn a lot about the chemical, physical, and biological aspects of the soil by examining the reflected light. This contains information about essential characteristics such soil organic matter content, nutrient levels, pH, moisture content, and even microbial activity. NIRS is appealing not just because of its quickness and non-destructive nature, but also because of its potential for high-throughput analysis. It enables farmers, agronomists, and researchers to make educated decisions regarding crop management, fertilizer application, and soil remediation tactics by assessing soil quality in real time. Furthermore, because NIRS may be utilized in the field, it eliminates the need for costly and time-consuming soil sample transportation to distant laboratories.
For soils, there are three types of NIRS measurements: laboratory measures, The utilization of proximal sensing measurements, as well as remote sensing measurements, is a common practice in various academic disciplines. (Cécillon *et al.,* 2009). Laboratory measurements acquire spectral data in situ, which is

often used to map soil parameters. Handheld measuring may also be utilized in proximal sensing, which is used as a quick technique to observer soil parameters in situ. Remote sensing of soil characteristics has been explored using aerial pictures and multispectral or hyper-spectral photographs (imaging spectroscopy). Imaging spectroscopy varies from Imaging by multispectral means in that it has a higher number of wavebands, allowing for exact spectrum capture and thorough study of spectral features of the soil upper surface.

IX. SOIL HEALTH MANAGEMENT PRACTICES

Organic amendments refer to materials that are introduced into soil with the purpose of enhancing its physical, chemical, and biological characteristics, hence promoting the development of plants (Kassam *et al.*, 2009). The aforementioned compounds are commonly obtained from organic origins, including animal dung, compost, and agricultural wastes. The term "organic" refers to a classification system that pertains to the production and cultivation Amendments offer a variety of advantages to soil and plants, such as enhanced levels of the enhanced availability of nutrients, better structure of the soil, and higher capacity for water retention. Increased soil biodiversity and improved capability. Furthermore, the advantages of these practices extend to soil health. A variety of organic amendments are utilized in soil management and agriculture. The implementation of cover crops as part of crop rotation, the preservation of crop residue mulch, the adoption of Integrated Nutrient Management (INM), which combines chemical, and bio fertilizers, and the eradication of soil mechanical disturbances are all suggested. Potential benefits of implementing farming and cultivation systems include enhanced soil quality, facilitated restoration of ecosystem services, and long-term agricultural productivity sustainability. Farming and cropping systems encompass a range of methods, including but not limited to crop rotations and soil fertility management. The Crop management strategies, erosion control methods, grazing and stocking rates, and water management techniques. The occurrence, pace, and severity of soil may be significantly influenced by many factors. Degradation can occur through the influence on the pool of soil organic carbon and the structural components. The study of morphology, as well as other soil qualities, is of great significance in academic research. The execution of various agricultural crops Rotations and grazing strategies have the potential to significantly influence the soil organic carbon pool (Ryan *et al.*, 2008).

X. CONCLUSION

Soil degradation can take many forms, including physical deterioration such as structural loss, compaction, erosion, crusting, anaerobiosis, and water imbalance, as well as chemical changes such as acidification and salinization.

Elemental imbalances that cause toxicity or deficiency, as well as nutritional deficiencies depletion, biological deterioration manifested by decreased soil organic matter Carbon pool, soil biodiversity loss, and microbial biomass reduction Carbon, as well as ecological disruptions such as disruptions in elemental cycles and lowered carbon sequestration capability. As a result of soil deterioration in reduced ecological activities and services critical to human survival well-being and ecological protection. The SOC pool is washed-out as a outcome of soil deterioration. We may work towards recovering soil by studying the causes and effects of soil degradation, identifying soil-specific features, and using holistic techniques. Soil quality and long-term land management strategies are essential. Over we can protect this limited resource with further research and collaboration. And work to create the environment healthy for future generations.

References

[1] Andrews, S. S., & Carroll, C. R. (2001). Designing a soil quality assessment tool for sustainable agroecosystem management. *Ecological Applications*, *11*(6), 1573-1585.

[2] Angon, P. B., Anjum, N., Akter, M., KC, S., Suma, R. P., & Jannat, S. (2023). An Overview of the Impact of Tillage and Cropping Systems on Soil Health in Agricultural Practices. *Advances in Agriculture*, *2023*.

[3] Brejda, J. J., Karlen, D. L., Smith, J. L., & Allan, D. L. (2000). Identification of regional soil quality factors and indicators II. Northern Mississippi Loess Hills and Palouse Prairie. *Soil Science Society of America Journal*, *64*(6), 2125-2135.

[4] Cécillon, L., Barthès, B. G., Gomez, C., Ertlen, D., Génot, V., Hedde, M., & Brun, J. J. (2009). Assessment and monitoring of soil quality using near- infrared reflectance spectroscopy (NIRS). *European Journal of Soil Science*, *60*(5), 770-784.

[5] Chapman, W. L., Bahill, A. T., & Wymore, A. W. (1992). *Engineering modeling and design* (Vol. 2). CRC Press.

[6] Chen, Y.D.; Wang, H.Y.; Zhou, J.M.; Xing, L.; Zhu, B.S.; Zhao, Y.C.; Chen, X.Q. (2013). Minimum data set for assessing soil quality in farmland of Northeast China. Pedosphere 2013, 23, 564–576.

[7] Cude, C.G. Oregon (2000). Water Quality Index: A Tool for EvaluatingWater Quality Management Effectiveness. J. Am. Water Resour. Assoc. 2001, 37, 125–137.

[8] Dinakaran, J., & Krishnayya, N. S. R. (2008). Variations in type of vegetal cover and heterogeneity of soil organic carbon in affecting sink capacity of tropical soils. *Current science*, 1144-1150.

[9] Doran, J. W., & Parkin, T. B. (1997). Quantitative indicators of soil quality: a minimum data set. *Methods for assessing soil quality*, *49*, 25-37.

[10] Doran, J. W., and T. B. Parkin. (1994). Defining and assessing soil quality. In *Defining Soil Quality for a Sustainable Environment*, ed. J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart, 3–21. Madison, WI: SSSA. Volchko, Y., J. Norrman, M. Bergknut, L. Rosén, and T. Söderqvist. 2013. Incorporating the soil function concept into sustainability appraisal of remediation alternatives. *Journal of Environmental Management* 129:367–76.

[11] Doran, J. W., Jones, A. J., Arshad, M. A., & Gilley, J. E. (2018). Determinants of soil quality and health. In *Soil quality and soil erosion* (pp. 17-36). CRC Press.

[12] Ferretti, F.; Saltelli, A.; Tarantola, S. (2016). Trends in sensitivity analysis practice in the last decade. Sci. Total Environ. 2016, 568, 666–670.

[13] Gatica- Saavedra, P., Aburto, F., Rojas, P., & Echeverría, C. (2023). Soil health indicators for monitoring forest ecological restoration: A critical review. *Restoration Ecology*, *31*(5), e13836.

[14] Gilliam, F. S., Hargis, E. A., Rabinowitz, S. K., Davis, B. C., Sweet, L. L., & Moss, J. A. (2023). Soil microbiomes of hardwood- versus pine- dominated stands: Linkage with overstory species. *Ecosphere*, *14*(7), e4537.

[15] Karlen, D. L., & Stott, D. E. (1994). A framework for evaluating physical and chemical indicators of soil quality. *Defining soil quality for a sustainable environment*, *35*, 53-72.

[16] Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of conservation agriculture: justification, sustainability and uptake. *International journal of agricultural sustainability*, *7*(4), 292-320.

[17] Larson, W. E., & Pierce, F. J. (1991). Conservation and enhancement of soil quality. *Evaluation for sustainable land management in the developing world*, *2*.

[18] Maikhuri, R. K., & Rao, K. S. (2012). Soil quality and soil health: A review. *International Journal of Ecology and Environmental Sciences*, *38*(1), 19-37.

[19] Mairura, F. S., D. N. Mugendi, J. I. Mwanje, J. J. Ramisch, P. K. Mbugua, and J. N. Chianu. (2007). Integrating scientific and farmers' evaluation of soil quality indicators in central Kenya. *Geoderma* 139:134–43.

[20] Mausel, P. W. (1971). Soil quality in Illinois—an example of a soil's geography resource analysis. *The Professional Geographer* 23:127–36.

[21] McBratney, A. B., M. Moyce, D. Field, and A. Bryce. (2018). The concept of soil security. In *Global soil security: towards more science-society interfaces: Proceedings of the global soil security 2016 conference*, A. Richer de Forges, F. Carré, A. B. McBratney, J. Bouma, and D. Arrouaysed., December 5-6, 2016, 1st, 1–26. Paris, France: CRC Press.

[22] Norgaard, K. M. (2011). Living in denial: Climate change, emotions, and everyday life. mit Press.

[23] Pianosi, F.; Beven, K.; Freer, J.; Hall, J.W.; Rougier, J.; Stephenson, D.B.; Wagener, T. Sensitivity analysis of environmental models: A systematic review with practica workflow. Environ. Model. Softw. 2016, 79, 214–223 Storie, R. E. (1978). *Storie index soil rating* (Vol. 3203). Division of Agricultural Sciences University of California.

[24] Qi, Y., J. L. Darilek, B. Huang, Y. Zhao, W. Sun, and Z. Gu. (2009). Evaluating soil quality indices in an agricultural region of Jiangsu Province, China. *Geoderma* 149 (3–4):325–34.

[25] Reynolds, W. D., C. F. Drury, C. S. Tan, C. A. Fox, and X. M. Yang. (2009). Use of indicators and pore volume function characteristics to quantify soil physical quality. *Geoderma* 152:252–63.

[26] Rinot, O., Levy, G. J., Steinberger, Y., Svoray, T., & Eshel, G. (2019). Soil health assessment: A critical review of current methodologies and a proposed new approach. *Science of the Total Environment*, *648*, 1484-1491.

[27] Riquier, J., Bramao, L., Cornet, S.P., (1970). A New System or Soil Appraisal In Terms of Actual and Potential Productivity: FAO Soil Resources No 38. Rome, Italy.

[28] Ryan, J., Masri, S., Singh, M., Pala, M. and Harris, H. (2008) Implications of cereal-based crop rotations, nitrogen fertilization, and stubble grazing on soil organic matter in a Mediterranean-type environment. *Turkish Journal of Agriculture and Forestry* 32(4), 289- 297.

[29] Volchko, Y., Norrman, J., Bergknut, M., Rosén, L., & Söderqvist, T. (2013). Incorporating the soil function concept into sustainability appraisal of remediation alternatives. Journal of environmental management, 129, 367-376.

[30] Winiwarter, S., Bonham, N. M., Ax, F., Hallberg, A., Lennernäs, H., & Karlén, A. (1998). Correlation of human jejunal permeability (in vivo) of drugs with experimentally and theoretically derived parameters. A multivariate data analysis approach. *Journal of medicinal chemistry*, *41*(25), 4939-4949.

[31] Yakowitz, D. S., Lane, L. J., & Szidarovszky, F. (1993). Multi-attribute decision making: dominance with respect to an importance order of the attributes. *Applied mathematics and computation*, *54*(2-3), 167-181.