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Derleme Makalesi / Review Article

Some Indicators for the Assessment of Soil Health: A Mini Review

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Abstract

Soil health depends on a delicate balance of biological, chemical and physical parameters, each of which affects the overall vitality and productivity of the soil ecosystem. Biological parameters include organism populations, microbial diversity and enzyme activity. Organic matter content fuels microbial activity improves nutrient cycling and soil structure. Chemical parameters such as pH, nutrient levels and salinity determine nutrient availability and microbial function. Optimum pH levels sustain microbial diversity and enzymatic activity, which is crucial for nutrient cycling. Physical parameters such as soil texture, structure and porosity govern water infiltration, root penetration and air exchange. Adequate porosity ensures oxygen availability for root respiration and microbial activity, while soil structure determines water retention and drainage. These parameters are interconnected and changes in one aspect can propagate throughout the entire soil ecosystem. For example, increased organic matter increases microbial biomass and enzymatic activity, improving nutrient cycling and soil structure. Conversely, chemical imbalances or physical compaction can inhibit microbial function and degrade soil structure. Therefore, holistic soil management strategies should aim to synergistically optimise biological, chemical and physical parameters. Sustainable practices such as crop rotation, cover cropping and reduced tillage increase organic matter content, regulate pH levels and maintain soil structure. Monitoring and managing these parameters holistically promotes soil health, resilience to environmental stressors and long-term agricultural productivity while maintaining ecosystem integrity.

Keywords: Soil health, biological, chemical and physical parameters

1. Introduction

The human interest in soil quality and health and functionality can be traced back to the earliest periods of civilisation (Brevik and Sauer, 2015). According to Lal (2016), around 1400 BC, Moses summarised the functionality or quality of soil to his followers entering Canaan with the following words: 'Look at what the land looks like and see if the people living there are strong, whether they are few or many. What kind of soil do they live on? Is it good or bad? What is the soil like? Is it fertile or poor? Are there trees or not? Do your best to get fruit from the soil' (Number 13:18-20). Before the development of soil science, people used to decide whether the soil was healthy or not by looking at its yield and morphological structure. If the soil was fertile, they would comment on its health status by considering parameters such as darkness and lightness of soil colour, lightness and softness.

In approximately 60 BC, Columella established a correlation between human health and soil conditions and described diseases that could be transmitted from marshes (Sylvia et al., 1998). In the Sanskrit manual 'Artha Sastra', Chanukya/Kautilya (4th century BC) describes techniques for land managers to improve soil function by applying fertiliser and other systems to manage soil fertility and conserve water. Ibn al-Awwam, a 12th century Moorish philosopher, wrote in his Book of Agriculture (Kitab-Al-Felaha): 'The first step in agriculture is to recognise the soil and how to distinguish good quality from poor quality. The depth of the soil should also be taken into account, because often the surface layer can be black'.

Since the 1970s, soil quality and health have received increasing attention due to the growing world population (Doran and Zeiss, 2000). Today, three interrelated terms are used for soil indicators: soil quality, soil functionality and soil health. Soil quality is defined as 'fitness for use' (Larson and Pierce, 1991) and 'the capacity of soil to function' (Karlen et al., 1997). Consequently, the functions of soil, which are intricately linked to soil quality, depend on the specific land use. These include plant and animal productivity (in the case of agricultural land use), forest productivity (in the case of silviculture land use), air and water quality related to human health and settlement (in the case of urban land use), contamination with heavy metals (in the case of mine lands and urban lands), and so forth (Daily et al., 1997).

Although the terms soil quality and soil health are similar, they are not intended to be used interchangeably. Soil quality relates to the functions of soil or what soil does, whereas soil health presents soil as a finite and dynamic living thing and is directly related to plant and animal health. More specifically, soil health is defined as 'the capacity of soil to function as a vital living system to sustain biological productivity, maintain environmental quality and promote plant, animal and human health' (Doran et al., 1996; Doran and Zeiss, 2000).

The concern to protect/improve soil health emerged much later than the concern for water and soil. Soil processes have come to be seen as an ecosystem in their own right rather than as a component of the soil ecosystem. While criteria, indicators and standards for water and air quality are clear and universally recognised, the concept of soil quality, further elaborated as soil health, is still evolving and only a few countries have so far established soil quality legislation (Filip, 2002; Nortcliff, 2002).

The integration of various factors, including physical, chemical, biological and enzymatic activity, can facilitate more accurate and better soil assessment (Liao et al., 2014). These factors should be used together as indicators of soil quality assessment (Liao et al., 2014).

Agricultural practices such as tillage, natural disturbances, irrigation, stubble burning, pesticide and fertiliser applications can result in an imbalance in physical and chemical parameters, including soil structure, soil moisture, pH and organic matter (Vallejo et al., 2012). Nevertheless, organic carbon also serves as an important indicator of soil fertility, microbial activity and soil health (Obalum et al., 2017).

Soil is an important component of the terrestrial ecosystem and contains various life forms, including soil organisms (microorganisms) that assist in nutrient cycling and nutrient recycling (Nielsen et al., 2002). Soil health parameters represent an effective bio-indicator tool for monitoring environmental quality and ecological changes, as they respond promptly to any disturbance in the soil ecosystem (Winding et al., 2005). Due to the need to feed the growing population and commercial concerns, intensified agricultural practices have reduced the organic matter and microbial activities in soils over time, leading to decreased soil fertility. There are studies emphasizing the importance of using microorganisms and organic materials alongside mineral applications to enrich soils with organic matter and restore quality factors to ensure sustainability (Sarıoğlu et al., 2017).

Physical, chemical and biological parameters of soil are determinants for soil health, but soil enzymes serve as a good indicator or marker to determine soil fertility (Bakshi and Varma, 2011). The origin of enzymes in soil can be attributed to a variety of sources, including plants, animals, and microorganisms (Tiwari et al., 2019). Enzymes are typically associated with living cells, but they can also be excreted into the soil solution by dead cells (Bandick and Dick, 1999). The enzyme in solution interacts with humic acid or clay substances (Bandick and Dick, 1999; Tiwari et al., 2019)., which are known for their ability to break down clays and participate in biochemical processes and nutrient recycling of soil (Bakshi and Varma, 2011). Given the important role of soil enzymes in these processes, they can be utilised to regulate ecosystem functioning (Makoi and Ndakidemi, 2008). Furthermore, enzymes serve as valuable indicators for monitoring soil contamination with heavy metals, pesticides or hydrocarbons (Baran et al., 2004).

In this review, a brief overview of potential physical, chemical and biological indicators for soil health parameters is discussed and show in figure 1.

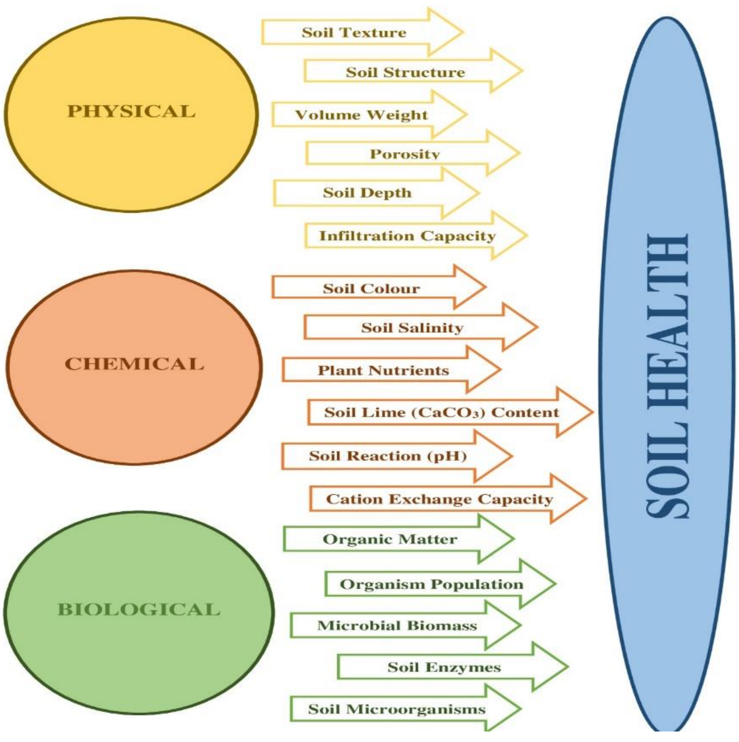

Figure 1. Soil health parameters

2. Physical Health Parameters

These are texture, volume weight, soil structure, porosity, soil depth and infiltration capacity. Soil texture is a very important soil health parameter that affects many critical soil functions. It governs water retention, drainage, nutrient availability, soil structure, root penetration and erosion susceptibility. Sandy soils with larger particles have good drainage but lower water retention, while clay soils with smaller particles exhibit higher water retention but poorer drainage. This dynamic directly influences plant growth as well as the availability of essential nutrients through its effect on cation exchange capacity and soil pH. Furthermore, soil texture plays a vital role in soil structure formation by influencing root penetration and soil aeration. Understanding soil structure enables specific management practices to optimise soil health, such as selecting appropriate crops, implementing conservation tillage and erosion control measures. By assessing soil texture as a soil health parameter, farmers and land managers can make informed decisions to increase agricultural productivity, maintain soil fertility and reduce environmental degradation. Soil texture plays an important role in determining the volume weight of soil (Martin et al., 2017) and in improving soil health as it provides isolated microhabitats for microorganisms, resulting in an increase in the diversity and abundance of microorganisms (Li et al., 2010; Rabot et al. 2018; Abraham et al., 2019). Microbial activity is influenced by soil texture as it directly affects soil moisture content and temperature (Chau et al. 2011; Vinhal-Freitas et al., 2017).

It should be noted that volume weight is not a natural property of soil and varies with a number of factors, including rainfall, root growth and normal field traffic (Casanova et al., 2016; Al-Shammary et al., 2018). It serves as an important indicator for assessing soil quality and is widely used in various prediction models for soil health assessment (Fernandez et al., 2019; Lema et al., 2019). Bulk weight is a fundamental soil health parameter with significant effects on soil structure, porosity, water holding capacity, nutrient availability and erosion risk. As a measure of soil mass per unit volume, it directly reflects soil compaction and its impact on various soil functions. High bulk weight indicates soil with pore spaces compacted, which inhibits water infiltration, air movement and root penetration. This adversely affects soil aeration, drainage and nutrient cycling, negatively affecting plant growth and microbial activity. Furthermore, compacted soils are more susceptible to erosion, accelerating soil degradation and loss of fertile topsoil. Therefore, bulk weight guides management practices aimed at improving soil health, productivity and sustainability. Li et al. (2002) reported that soil microbes and enzymatic activities also affect soil bulk density.

Soil structure affects soil porosity, which in turn affects the exchange of gases such as oxygen and carbon dioxide between the soil and the atmosphere. Adequate pore spaces between soil aggregates allow sufficient air movement, facilitating root respiration and microbial activity.

Soil porosity refers to the arrangement and distribution of pore spaces within the soil. These pore spaces are essential for the movement of air, water and nutrients through the soil, which are critical for plant growth and overall soil health. Of these, macropores are larger pores that allow the movement of air and water. Macropores promote root respiration by facilitating drainage and aeration within the soil. Micropores retain water and nutrients and make them available for uptake by plant roots. Micropores also provide habitat for microorganisms that play a vital role in soil fertility and nutrient cycling. Macro- and micropores facilitate gas exchange between soil and atmosphere, providing an adequate supply of oxygen for root respiration and microbial activity. Poorly aerated soils can become anaerobic, leading to the accumulation of harmful gases such as methane (CH_4) and hydrogen sulphide (H_2S). Soil porosity exerts a profound influence on microbial diversity and activity, which in turn affects nutrient cycling, organic matter decomposition and overall soil fertility. Factors such as soil texture, organic matter content, compaction and land use practices can affect soil porosity and can be considered when assessing soil health.

Soil depth refers to the thickness or depth of the soil layer covering the earth's surface. It is a very important parameter in assessing soil health as it directly affects the soil's ability to support plant growth and sustain ecosystems. Soil depth affects the diversity and activity of soil organisms. Deeper soils provide more habitat for a variety of soil organisms, including bacteria, fungi, earthworms and other microorganisms. These organisms play vital roles in nutrient cycling, organic matter decomposition and soil structure formation, contributing to overall soil health.

Evaluating soil depth as a soil health parameter involves measuring the thickness of the soil profile and assessing its effects on plant growth, water retention, nutrient availability, biological activity and erosion resistance. Understanding soil depth enables land managers to make informed decisions regarding land use, conservation practices and soil management strategies to maintain or improve soil health for sustainable agriculture and ecosystem functioning.

Infiltration capacity is an important aspect of soil health and refers to the rate at which water penetrates or infiltrates the soil surface. It is essentially a measure of how fast water can enter the soil rather than run off the surface. This parameter is important because it directly affects various aspects of soil health and ecosystem function. Soils with high water-holding capacity are ideal for plant growth and provide efficient use of water (Yan et al., 2015). This property is vital for maintaining soil moisture levels during dry periods, which in turn supports plant growth, sustains ecosystems and promotes the addition of organic matter to the soil. Adequate water retention facilitates nutrient cycling within the soil. Thus, it causes microbial community changes in the soil (Geisen et al., 2014). It helps the solubilisation of nutrients, making them available for plant roots and microbial communities.

3. Chemical Health Parameters

These are colour, pH, $CaCO_3$, salinity, KDK and plant nutrients. Soil colour is an important parameter of soil. The lightness or darkness of soil colour gives us some information about the soil. One of these information is the presence and amount of soil organic matter. Darker soils generally indicate higher organic matter content, which is beneficial for soil fertility and general health. Organic matter improves soil structure, water retention, nutrient availability and microbial activity. Soil colour serves as a valuable diagnostic tool to assess soil health and fertility. By understanding the importance of soil colour, farmers, land managers and scientists can better manage agricultural and natural ecosystems for sustainable productivity and environmental protection.

pH is an important soil property as it determines nutrient availability and the physical state of the soil and thus controls microbial diversity (Abraham et al., 2019). It also affects the buffering capacity and quality of soil organic matter (Usharani et al., 2019). It is well documented that a decrease in soil pH reduces microbial growth and activity (Geisseler and Scow, 2014). It plays an important role in determining the composition and activity of soil microbial communities. Many soil microorganisms have specific pH requirements for optimal growth and function. Maintaining a favourable pH level promotes a diverse and active microbial population, which is essential for nutrient cycling, organic matter decomposition and overall soil ecosystem health.

pH affects soil structure by influencing the aggregation of soil particles. Soils with good pH maintain soil structure, allowing adequate water infiltration, root penetration and air exchange. However, poor pH levels can lead to soil compaction, crusting or poor drainage, which can adversely affect soil health.

Assessing soil reaction or pH is crucial for the purpose of evaluating soil health as it directly affects nutrient availability, microbial activity, soil structure, toxicity risks and crop suitability. Maintaining an optimum pH range is key to promoting healthy soil and sustainable agricultural practices. Baath and Anderson (2003) showed that an increase in soil pH leads to an increase in microbial biomass.

Salinity is defined as the accumulation of soluble mineral salts in soil (Tanji, 2002). Assessment of soil salinity is critical in assessing soil health as it directly affects various aspects of soil and plant health. Soil salinity can affect soil pH and chemical properties. Saline soils often contain high levels of sodium (Na^+) and chloride (Cl^-) ions, which can increase soil pH and impair nutrient availability. High sodium levels can lead to soil alkalinity, affecting the solubility of essential nutrients and contributing to nutrient imbalances (Zhao and Xu., 2016). Salinity-induced changes in soil chemistry affect soil health parameters such as nutrient availability, microbial activity and soil structure. The presence of excessive amounts of salts increases the osmotic potential of soil water, causing water withdrawal from the cell, which can kill microorganisms present in the soil (Yan et al., 2015).

Soil salinity affects several soil health parameters, including nutrient availability, soil structure, water holding capacity, microbial activity, soil chemistry and erosion risk. Understanding the effects of soil salinity on these parameters is essential to implement effective management strategies to maintain soil health and sustain agricultural productivity in salt-affected areas.

Soil cation exchange capacity (CEC) is a very important parameter that affects various soil health parameters. CEC refers to the ability of soil to hold and exchange positively charged ions (cations) such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and hydrogen (H^+). CEC is a fundamental property of soil that affects nutrient availability, soil fertility, pH buffering capacity, soil structure and other critical soil functions.

Soil CEC affects the retention and stabilisation of soil organic matter (Rahal and Alhumairi, 2019). Cations retained on soil surfaces can form complexes with organic matter and help retain organic carbon in the soil (Xu et al., 2016). Increased organic matter content improves soil health and fertility by improving soil structure, nutrient cycling, microbial activity and water holding capacity. Soil health and CEC are closely interrelated; CEC plays a critical role in influencing nutrient availability, pH buffering capacity, soil structure, organic matter retention and heavy metal retention (Graber et al., 2017). Understanding and managing soil CEC is essential to improve soil health, sustain agricultural productivity and protect environmental quality. CEC increases with an increase in pH (Graber et al., 2017). Soils with high CEC have high organic matter, and microbial diversity and abundance are also higher in soils with high organic matter (Xu et al., 2016).

Plant nutrients are essential elements that plants need for their growth and development. These nutrients are usually obtained by plants from the soil but can also be supplied by other means such as soil fertilisation or foliar fertilisation. The availability of these nutrients in soil is a critical factor in determining soil health and the overall productivity of an ecosystem. According to Worthington (2001) and Woese et al. (1997), the nutrients N, P and K play important roles in various physiological processes within the plant such as photosynthesis, energy transfer and cell division, while Ca, Mg and S contribute to processes such as enzyme activation, cell structure and nutrient uptake. Microbial biomass is closely related to primary production in the ecosystem and is also associated with the functions and development of the soil system through nutrient circulation (Zak and Pregitzer, 1990). Therefore, microorganisms play a fundamental role in the shaping of soil structure and the realisation of biochemical cycles within the soil (Smith and Papendick, 1993).

Plants take up nitrogen in the form of ammonia and various soil microorganisms play an important role in the N cycle to convert atmospheric nitrogen to ammonia (Rice et al. 1997). Nitrogen plays a pivotal role in enhancing soil fertility and serves as a crucial indicator of soil fertility (Liu et al., 2013). Phosphorus plays a pivotal role in the conversion of carbon biomass into soil organic matter (Filippelli, 2017). Given that soil phosphorus affects a number of soil properties, plant growth, microbial activities and community structure, it can be considered an indicator of soil fertility in conjunction with nitrogen (Doolette and Smernik, 2011; Li et al., 2019b). Phosphorus is present in numerous forms within the soil, with the most readily available being that associated with organic matter. However, plants are unable to take up phosphorus in this organic form (Filippelli, 2017).

Potassium plays a pivotal role in the advancement of plant roots (Jaiswal et al., 2016), increasing crop yield and enabling plants to withstand various biotic and abiotic stresses. Additionally, it facilitates the activation of enzymes for metabolic processes in plants (Rao and Srinivas, 2017; Loka et al., 2018; Singh and Pathak, 2018; Sattar et al., 2019). Immobilisation of sulphur, which is the 4th macro element group after N, P and K, from soil is due to the soil microbial community and their metabolic activities (Kertesz and Mirleau, 2004; Bashri et al., 2017).

4. Biological Health Parameters

These are organic matter content (OM), organism population, microbial biomass, microorganisms, respiration rate, metabolic respiration coefficient and enzyme activity. Biological parameters are key indicators of soil health as they reflect the activity and diversity of organisms in the soil ecosystem.

Soil organic matter (SOM) is defined as the accumulation of plant and animal remains at various stages of decomposition. It serves as a source of energy and nutrients for soil organisms and contributes to the formation of soil structure and the retention of water. High organic matter content indicates fertile soils with good microbial activity and nutrient cycling. Soil organic matter is a mixture containing both decomposed and undecomposed microorganisms and plant residues (Arias et al., 2005), therefore OM is included in the group of biological parameters. The presence of organic matter has been demonstrated to enhance the biological activity and diversity of the soil (Norris et al., 2018). Consequently, SOM is a valuable indicator of soil fertility and health (Anikwe, 2006; Obalum et al., 2017).

Soil organisms include plant and animal organisms such as bacteria, fungi, protozoa, nematodes, actinomycetes, algae, and earthworms. The population density and diversity of these organisms reflect the biological activity and health of the soil. A diverse and abundant population of soil organisms indicates a well-functioning soil ecosystem capable of nutrient recycling and organic matter decomposition, and a factory whose wheels are constantly turning.

Microorganisms such as bacteria and fungi play an important role in nutrient cycling, decomposition and disease suppression (Hayat et al., 2010). Microbial biomass refers to the total mass of microorganisms present in a given volume or weight of soil. High microbial biomass indicates active soil biology and efficient nutrient cycling, contributing to soil fertility and productivity.

Soil respiration is the process by which soil organisms and plant roots respire and release carbon dioxide (CO_2) into the atmosphere. It refers to the release of carbon dioxide (CO_2) from the soil as a result of microbial activity breaking down organic matter. This organic matter includes dead plant roots, leaves and other plant and animal remains. Respiration rate can be considered as a measure of microbial activity and decomposition rates in soil. Often used as an indicator of soil health, higher respiration rates indicate greater microbial activity and decomposition of organic matter. This mechanism is a vital process in the carbon cycle and helps researchers as a basic indicator of soil health. Microbial indicators used in European countries are mainly microbial biomass and soil respiration (Nielsen and Winding, 2002).

Healthy soils are full of diverse microbial life, including bacteria, fungi and other microorganisms. These microorganisms decompose organic matter, releasing water, mineral matter and CO_2 as a by-product of their metabolic processes (Gardiner and Miller, 2008). Soil respiration rate reflects the level of microbial activity, which is an indicator of soil health. A more active microbial community generally indicates better soil health. Soil respiration rates are generally correlated with the amount of organic matter present in the soil. Higher organic matter content generally leads to higher respiration rates, which is due to the availability of more organic materials for microbial decomposition. The monitoring of soil respiration can provide valuable insights into the health of the soil, as organic matter plays a crucial role in soil structure, fertility and moisture retention.

Soil respiration is closely linked to nutrient cycling within the soil ecosystem. As microbes decompose organic matter, nutrients such as nitrogen, phosphorus and potassium, which are essential for plant growth, are released (Sparling et al., 2004). Monitoring soil respiration can help assess the efficiency of nutrient cycling processes in soil, which is crucial for maintaining plant productivity and overall ecosystem health. Soil respiration has wider environmental impacts, particularly in terms of its contribution to atmospheric CO_2 levels and climate change. Soils, especially terrestrial ecosystems, are important carbon pools that store large amounts of carbon. However, excessive soil respiration, especially from disturbances such as deforestation or intensive agriculture, leads to carbon loss from soils, resulting in CO_2 emissions. In this respect, monitoring soil respiration can help assess its impact on carbon storage and overall environmental sustainability.

Soil respiration serves as a valuable indicator of soil health by reflecting microbial activity, organic matter content, nutrient cycling and environmental impacts. Monitoring soil respiration can help inform land management practices aimed at improving soil health, increasing agricultural productivity and mitigating climate change. According to El-Ramady et al. (2014), soil management can improve soil quality by leading to reduced use of agrochemicals, reduced tillage and lower fuel consumption of farm equipment, and can also contribute to sequestering more CO_2 in the soil, which benefits the environment. Modern agricultural science has the ability to correct many of the wrong practices of the past and ensure the sustainable use of healthier soils.

The coefficient of metabolic respiration (qCO_2) is a biological parameter used to assess the productivity of microbial communities in soil. It is a ratio that compares the microbial respiration rate (CO_2 production) to the biomass of microorganisms present in the soil (Jenkinson and Powlson, 1976). Essentially, it provides information on microbial activity and carbon cycling in soil by measuring the amount of CO_2 produced per unit of microbial biomass. The coefficient of metabolic respiration (qCO_2) is calculated as the rate of microbial respiration (CO_2 production) divided by microbial biomass. It is usually expressed in units of μg CO_2-C g^{-1} microbial biomass h^{-1} or μg CO_2-C mg^{-1} microbial biomass h^{-1} (Anderson and Domsch, 1990).

A low qCO_2 value indicates that microbial communities are efficient in utilising organic matter for energy production, leading to a lower rate of CO_2 production than microbial biomass. This indicates a more stable and mature soil ecosystem with efficient nutrient cycling and carbon sequestration. A high qCO_2 value indicates that microbial communities are less efficient and produce more CO_2 than microbial biomass. This can occur in soils with high organic matter input or degradation, where microbial communities rapidly decompose organic matter but do not efficiently convert it into stable soil organic carbon. Monitoring changes in qCO_2 over time can provide information on soil health and the response of microbial communities to environmental conditions, management practices and disturbances. A decreasing qCO_2 value indicates improved soil health and increased microbial productivity, while an increasing qCO_2 value may indicate declining soil quality or microbial stress.

Sustainable soil management practices that promote microbial diversity, soil organic matter accumulation and reduce degradation can help optimise qCO_2 values and improve soil health and fertility. These practices include minimising tillage, encouraging cover cropping, diversifying crop rotations and reducing chemical inputs (Coleman and Crossley, 1995).

In general, metabolic quotient (qCO2) is a valuable tool for assessing soil microbial activity and carbon cycling and provides information on soil health and ecosystem functioning. Monitoring qCO_2, as well as other soil health parameters, can help inform management decisions aimed at improving soil health and sustainability.

Enzymes facilitate the mineralisation of soil organic matter (SOM), recycling nutrients, sequestering carbon and playing a role in waste management and gas emissions (Kang et al., 2013). Enzymes are biological catalysts produced by soil organisms to facilitate various biochemical reactions such as decomposition of organic matter and nutrient cycling. Enzyme activity in soil reflects the functional capacity of soil microbes and their ability to decompose complex organic compounds. High enzyme activity indicates healthy soil with active microbial communities that can efficiently cycle nutrients and decompose organic matter (Perez-Gumman, 2021). Enzyme activity is a valuable indicator of soil health, reflecting the functional diversity and activity of soil microbial communities. Monitoring changes in enzyme activity can provide information on soil fertility, nutrient cycling and the effectiveness of soil management practices.

Soil enzyme activity is subject to the influence of a number of environmental factors, including soil moisture, temperature, pH, organic matter content and substrate availability. Optimum enzyme activity typically occurs under conditions that favour microbial growth and activity, such as moist, aerated soils with sufficient organic matter (Dick et al., 1996). Enzyme activity can help assess the impact of land management practices on soil health and fertility. Sustainable land management practices that promote microbial diversity, organic matter accumulation and reduced disturbance tend to increase enzyme activity and soil biological function.

5. Conclusions

Porosity determines the movement of air and water, which is crucial for plant growth and soil aeration. Soil depth provides the basis for root development and access to nutrients. Infiltration capacity regulates water flow, reducing erosion and flood risks. Understanding and managing these physical parameters is essential to maintain soil health, promote resilient ecosystems and ensure long-term agricultural productivity in a changing climate.

Soil colour indicates organic matter content and drainage conditions, while pH levels affect nutrient availability and microbial activity. Calcium carbonate ($CaCO_3$) content affects soil alkalinity and buffering capacity. Salinity levels affect plant growth and microbial diversity. Cation exchange capacity governs nutrient retention and availability to plants. The growth and functioning of crops and ecosystems alike depend on the presence of essential plant nutrients, including nitrogen, phosphorus and potassium. Managing these chemical parameters is vital for maintaining soil fertility, supporting plant productivity and maintaining environmental quality.

Organic matter content acts as a source of nutrients and energy for soil organisms, affecting their populations and diversity. Microbial biomass plays a pivotal role in the cycling of nutrients and the formation of soil structure. Respiration rate and metabolic respiration coefficient reflect microbial activity and energy metabolism, respectively, indicating soil vitality. Enzyme activity governs various biochemical processes that are crucial for nutrient transformation and availability. Understanding and managing these biological parameters is essential to promote resilient soils, support sustainable agriculture and maintain ecosystem health amid evolving environmental challenges.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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