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THE IMPORTANCE OF SOIL ORGANIC MATTER (SOM) ON SOIL PRODUCTIVITY AND PLANT GROWTH

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Abstract: *Soil organic matter (SOM) is vital to soil health and plays a critical role in crop production. This review paper examines the impact of SOM on soil health, crop production, and the challenges and opportunities associated with managing SOM. The paper emphasizes the importance of interdisciplinary research, technological advancements, and supportive policies in addressing SOM dynamics and management complexities. The review highlights the role of SOM in nutrient supply, soil structure improvement, water-holding capacity, and microbial activity enhancement, which are fundamental for sustainable agricultural systems. Various management practices to enhance SOM, including organic amendments, cover cropping, conservation tillage, and crop rotation, are discussed. Despite the benefits of managing SOM, challenges such as slow formation rates, trade-offs with other agricultural objectives, and economic viability exist. Addressing these challenges requires further research, knowledge exchange, and integrating traditional knowledge with modern technologies. Future perspectives and research needs include advancing interdisciplinary collaboration, harnessing emerging technologies, understanding the interactions between SOM and climate change, exploring novel management practices, quantifying ecosystem services, addressing knowledge gaps, and providing policy support and incentives. Sustainable soil management strategies can be developed by embracing these perspectives and addressing the identified research needs. These strategies optimize SOM levels, promote soil health, enhance crop productivity, and contribute to global food security and environmental sustainability. Overall, this review provides valuable insights for researchers, policymakers, and stakeholders in their efforts to enhance SOM management and promote sustainable agriculture.*

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Introduction

Soil organic matter (SOM) is one of the most vital constituents of the soil, forming the backbone of soil health and fertility (Lal, 2014) SOM is a complex mixture of plant and animal materials in varying stages of decomposition, microbes, and the substances they synthesize in the soil (Lehmann and Kleber, 2015). It plays a key role in numerous soil functions, contributing to soil structure, nutrient cycling, and water retention, among other things (Janzen, 2006). The importance of SOM in agriculture cannot be overemphasized. In addition to improving soil structure and enhancing nutrient and water retention, SOM plays a crucial role in supporting a rich and diverse soil biota (Postma-Blaauw et al., 2010). This biodiversity is an integral part of the soil ecosystem, contributing to soil fertility, suppressing soil-borne diseases, decomposing organic matter and residues, and enhancing crop nutrient availability (Bender et al., 2016). Given the vital role that SOM plays in soil health and crop production, understanding its dynamics is crucial for sustainable agricultural practices and food security.

The relationship between SOM and soil health is multifaceted and dynamic. Healthy soils, characterized by good structure, optimal nutrient availability, and a diverse microbial community, tend to have higher levels of SOM (Kibblewhite et al., 2008). This, in turn, contributes to higher productivity and resilience in agricultural systems. However, modern agricultural practices, such as intensive tillage and monocropping, can lead to SOM depletion, adversely affecting soil health and crop productivity (Montgomery, 2007).

The impact of SOM on crop production is also significant. SOM improves the physical properties of the soil, enhancing root growth and access to water and nutrients (Kautz et al., 2013). It also contributes to nutrient cycling, ensuring the continuous availability of essential nutrients to plants (Stockmann et al., 2013). Furthermore, the beneficial microorganisms supported by SOM can improve plant health by suppressing disease-causing organisms and enhancing plant resistance to pests and diseases (Lugtenberg and Kamilova, 2009). There is, however, a pressing need for more comprehensive research on the role of SOM in soil health and crop production. This is due to the complex nature of SOM, its interactions with other soil properties, and the myriad of factors that influence SOM dynamics, including climate, soil type, land use, and management practices (Pan et al., 2009). Understanding these complexities is crucial for developing sustainable soil management strategies and enhancing global food security.

This review paper aims to provide a comprehensive overview of the impact of soil organic matter on soil health and crop production, drawing on the latest scientific literature. We will explore the role of SOM in various aspects of soil health and examine how it influences crop productivity. We will also discuss strategies to enhance SOM and address the challenges and opportunities in SOM management in a changing climate.

Understanding Soil Organic Matter

Soil Organic Matter (SOM) is a complex and diverse soil component, constituting about 1-6% of the total soil mass (Bronick and Lal, 2005). It is formed through the decomposition and transformation of plant and animal residues by soil organisms, a process termed as humification (Stevenson, 1994). These organic residues undergo various stages of decomposition, resulting in a heterogeneous mixture of materials that vary in their degree of decomposition and stability in the soil (Schlesinger and Bernhardt, 2013). The composition of SOM is diverse and dynamic, reflecting the variety of its sources and the myriad of biological, chemical, and physical processes it undergoes in the soil (Schmidt et al., 2011). It includes many organic compounds, from simple sugars and amino acids to complex polymers like lignin and humic substances (Piccolo, 2002). The latter is particularly important as they are more resistant to decomposition and can persist in the soil for decades or even centuries, thereby contributing to the long-term storage of carbon (Paustian et al., 2019).

The sources of SOM are primarily plant residues and animal manure, but it can also originate from other organic materials added to the soil, such as compost and biochar (Paustian et al., 2000). Plant residues are the largest source of SOM, contributing about 60-80% of the total SOM in agricultural soils (Rasse et al., 2005). These residues include above ground biomass (e.g., leaves, stems) and below ground biomass (e.g., roots), both of which differ in their chemical composition and decomposition rates (Sistani et al., 2010). On the other hand, animal manure contributes a smaller proportion of SOM but is often richer in nutrients and decomposes more rapidly (Davidson and Janssens, 2006). The formation and decomposition of SOM are influenced by many factors, including climate, soil type, vegetation, and land management practices (Conant et al., 2011). Temperature and moisture, for instance, are key climatic factors affecting SOM dynamics. Warmer temperatures and adequate moisture generally enhance microbial activity and decomposition of organic materials, leading to faster turnover of SOM (Six et al., 2002). Soil type also plays a significant role, with clay-rich soils generally having higher SOM levels due to the protective effect of clay particles on organic materials (Cotrufo et al., 2013).

Vegetation type and land management practices can also greatly impact SOM dynamics. Different plant species produce residues with different qualities (e.g., nutrient content, lignin content), which can influence their decomposition rates and the subsequent formation of SOM (West and Post, 2002). Management practices, such as tillage, crop rotation, and organic amendment application, can also influence SOM levels by altering the quantity and quality of organic inputs and the physical environment of the soil (Lal, 2010).

Understanding the nature of SOM and the factors that govern its dynamics is crucial for predicting its behavior under different environmental and management conditions. This knowledge can inform the development of sustainable soil management practices that enhance SOM levels and, in turn, soil health and crop productivity (Cotrufo et al., 2015).

However, despite the substantial progress in SOM research, several knowledge gaps and challenges remain. For example, the exact mechanisms of SOM formation and stabilization are not fully understood, and the influence of soil microorganisms on SOM dynamics is still an active area of research (Trivedi et al., 2013; Lal, 2012). Moreover, the impact of global changes, such as climate change and land use change, on SOM dynamics is still uncertain and requires further investigation 9Lal, 2016). As we navigate through these challenges and unknowns, the role of SOM in soil health and crop production remains a key area of inquiry. In the following sections, we delve into these topics, shedding light on the multifaceted role of SOM in maintaining healthy, productive soils.

Impact of Soil Organic Matter on Soil Health

Soil organic matter (SOM) is indispensable in maintaining and improving soil health. Its influence on soil health is multifold, affecting the soil's physical, chemical, and biological properties, thereby contributing to the overall productivity and resilience of agroecosystems (Six et al., 2004).

Physically, SOM influences soil structure, water-holding capacity, and erosion resistance. By binding mineral particles together into aggregates, SOM improves soil structure, enhancing soil porosity and water infiltration (Lal, 2003). This facilitates root penetration and growth and reduces surface runoff and soil erosion (Hudson, 1994). Furthermore, organic matter, particularly the humic fraction, has a high water-holding capacity, thus increasing the soil's ability to retain and supply water to plants (Stevenson and Cole, 1999). Chemically, SOM is a reservoir of essential nutrients and acts as a buffer against changes in soil pH. As it decomposes, SOM releases nutrients like nitrogen, phosphorus, and sulfur, which plants can take up (Lindsay, 1979). Moreover, certain components of SOM can form complexes with metal ions, enhancing the availability of micronutrients such as iron, zinc, and manganese (Van Veen and Kuikman, 1990). The buffering capacity of SOM, attributed to functional groups like carboxyl and phenolic groups, helps maintain soil pH within a range conducive to nutrient availability and microbial activity (Sylvia et al., 2005).

Biologically, SOM serves as an energy source and habitat for diverse soil organisms. By providing energy and nutrients, SOM supports the growth and activity of soil microorganisms, which play crucial roles in nutrient cycling, disease suppression, and soil structure formation (Lavelle et al., 20060. SOM also enhances the diversity and abundance of soil fauna, including earthworms, mites, and beetles, which contribute to nutrient cycling and organic matter decomposition (Lal, 2004). Given the above, it is evident that SOM is integral to soil health, providing numerous ecosystem services that underpin agricultural productivity. However, SOM levels in many agricultural soils have declined due to intensive farming practices, such as continuous cropping, excessive tillage, and inadequate organic matter inputs (Lal, 2001). This has led to soil health degradation, reduced soil fertility, increased susceptibility to erosion, and decreased water-holding capacity, among other symptoms (Lal, 2016). Therefore, restoring and maintaining SOM levels is a key strategy for improving soil health and ensuring the sustainability of agricultural systems. Various practices can be employed, including organic amendment application, cover cropping, conservation tillage, and crop rotation (Paustian et al., 2016). These practices increase the quantity and quality of organic inputs to the soil and enhance soil protection and microbial activity, thereby promoting SOM formation and stabilization (Chen et al., 2019).

Despite the well-documented benefits of SOM for soil health, several challenges remain in managing SOM in agroecosystems. These include SOM formation's slow rate, SOM dynamics variability across different soils and climates, and potential trade-offs between SOM management and other agricultural objectives (Reganold et al., 2010). Further research is needed to address these challenges and to develop context-specific strategies for SOM management that balance the goals of productivity, sustainability, and resilience (Sprent and Platzmam, 2001).

Impact of Soil Organic Matter on Crop Production

The influence of soil organic matter (SOM) on crop production is profound and multifaceted, impacting not only the direct supply of nutrients to crops but also the physical and biological conditions of the soil that underpin crop growth and health (Berendsen et al., 2012). The nutrient supply function of SOM is one of its most important contributions to crop production. As mentioned earlier, SOM serves as a reservoir of essential nutrients, including nitrogen, phosphorus, and sulfur, released upon decomposition (Lindasy, 1979). Crops subsequently absorb these nutrients and contribute to their growth and development. In addition, the ability of SOM to form complexes with metal ions enhances the availability of micronutrients such as iron, zinc, and manganese, which are crucial for various physiological processes in crops (Van Veen and Kuikman, 1990). The nutrient supply function of SOM is especially significant in low-input and organic farming systems, where mineral fertilizers are either not used or used sparingly (Lal, 2006).

Besides nutrient supply, SOM also improves the physical conditions of the soil for crop growth. By enhancing soil structure, SOM facilitates root penetration and growth, critical for crop nutrient and water uptake (Lal, 2003). Moreover, the water-holding capacity of SOM helps maintain soil moisture, providing a consistent water supply to crops and reducing their susceptibility to drought (Stevenson and Cole, 1999). This is particularly important in rainfed agricultural systems and in regions with irregular rainfall patterns (Lal, 2009). SOM's impact on the soil's biological conditions also has implications for crop production. By supporting a diverse and active soil microbial community, SOM promotes nutrient cycling and disease suppression, both beneficial for crops (Lavelle et al., 2006). For instance, certain soil microorganisms can transform atmospheric nitrogen into forms accessible to plants, a process known as biological nitrogen fixation (Gattinger et al., 2012). Other microorganisms, particularly those in the rhizosphere, can suppress soil-borne diseases by outcompeting or inhibiting pathogenic microbes, thereby enhancing crop health and yield (Diacono and Montemurro, 2015).

In addition to its direct benefits for crop production, SOM contributes to cropping systems' resilience. By enhancing soil's capacity to absorb and release water, SOM can buffer crops against water stress during dry periods (Stevenson and Cole, 1999). Similarly, by maintaining soil structure and stability, SOM can reduce the risk of soil erosion, which can cause loss of topsoil and nutrients and degrade the crop-growing environment (Hudson, 1994). Furthermore, the buffering capacity of SOM can help maintain soil pH within a range conducive to crop growth, despite the addition of acidic or alkaline substances (Sylvia et al., 2005). Despite the significant contributions of SOM to crop production, many conventional farming practices have led to a decline in SOM levels, with negative implications for crop productivity and sustainability [40]. Therefore, integrating SOM management into farming practices is a key strategy for improving crop production and ensuring the sustainability of agricultural systems.

Various practices can be employed to maintain or increase SOM levels, including organic amendment application, cover cropping, conservation tillage, and crop rotation (Paustian et al., 2016). These practices enhance the quantity and quality of organic inputs to the soil, reduce soil disturbance, and enhance microbial activity, thereby promoting SOM formation and stabilization (Chen et al., 2019). However, the effectiveness of these practices can vary depending on local soil and climatic conditions, farm management and economic considerations (Poeplau and Don, 2015). SOM plays an essential role in crop production by improving the soil's physical, chemical, and biological conditions and providing a reservoir of essential nutrients. Managing SOM effectively is crucial for achieving high and sustainable crop yields, particularly in the face of global challenges such as climate change and increasing food demand.

Practices to Enhance Soil Organic Matter

Given the importance of soil organic matter (SOM) for soil health and crop production, effective strategies for enhancing SOM levels in agricultural soils are paramount. These strategies typically involve increasing the quantity and quality of organic inputs to the soil and reducing soil disturbance, thereby promoting SOM formation and stabilization (Blanco-Canqui et al., 2015). One common strategy for enhancing SOM is the application of organic amendments, such as compost, manure, and crop residues. These materials provide a direct input of organic matter to the soil and supply nutrients to crops and soil microorganisms, stimulating plant growth and microbial activity (Peoples et al., 2015). Moreover, the decomposition of organic amendments can result in the formation of stable organic compounds, such as humus, which contribute to the long-term storage of carbon in soils (Bizi and Sidi, 2023). However, the effectiveness of organic amendments in enhancing SOM can depend on various factors, including their composition, the timing and method of application, and local soil and climatic conditions (Islam et al., 2022).

Cover cropping is another widely adopted practice for enhancing SOM. Cover crops, typically grown during periods when main crops are absent, can increase the organic matter input to the soil through their above- and below-ground biomass (Govaerts et al., 2007). In addition to providing organic matter, cover crops can enhance soil protection against erosion, suppress weeds, and provide habitat for beneficial soil organisms (Powlson et al., 2014). Moreover, certain cover crops, such as legumes, can fix atmospheric nitrogen, contributing to soil fertility (Palm et al., 2014).

Conservation tillage, which involves reducing the intensity or frequency of tillage, is also beneficial for SOM enhancement. Conservation tillage can reduce the decomposition and loss of SOM by minimizing soil disturbance, thereby promoting its accumulation in the soil (Verhulst et al., 2010). Furthermore, conservation tillage can enhance soil protection against erosion and improve water conservation, both beneficial for soil health and crop production (Bizi and Sidi, 2023). Crop rotation, the practice of growing different types of crops in succession on the same land, can also contribute to SOM enhancement. Different crops vary in their residue quantity and quality, rooting depth, and interactions with soil microorganisms, all of which can influence SOM dynamics (Islam et al., 2022). By diversifying crop types, crop rotation can enhance the diversity and balance of organic inputs to the soil, promote nutrient cycling, and disrupt pest and disease cycles, thereby contributing to SOM enhancement and overall agroecosystem health (Peoples et al., 2009). Despite the well-documented benefits of these practices, challenges remain in their implementation. These include technical challenges, such as the need for specialized equipment or knowledge, economic challenges, such as the cost of organic amendments or the potential yield trade-offs, and social challenges, such as the acceptance of new practices by farmers (Bizi and Sidi, 2023). Therefore, further research and extension efforts are needed to overcome these challenges and to tailor SOM management strategies to local conditions and needs.

Challenges and Opportunities in Managing Soil Organic Matter

Managing soil organic matter (SOM) is a critical aspect of sustainable agriculture, contributing to soil health, crop productivity, and climate change mitigation. However, several challenges and opportunities exist in effectively managing SOM in agricultural systems. Addressing these challenges and embracing the opportunities can improve soil management practices and enhanced agricultural sustainability. Slow rate of SOM formation: SOM formation is slow, with organic inputs decomposing over years or even decades. This poses a challenge in building SOM levels within a reasonable timeframe (Bizi and Sidi, 2023). To overcome this challenge, innovative management practices and technologies are being developed to accelerate SOM formation, such as using biochar, microbial inoculants, and specific crop residues with high decomposability (Lal, 2004; Major et al., 2010).

Variability of SOM dynamics: SOM dynamics vary across different soil types, climates, and management practices. Soil characteristics influence SOM stabilization and decomposition rates, including texture, mineralogy, and organic matter quality (Kätterer et al. 2011). Climate, particularly temperature and moisture, also plays a crucial role in SOM dynamics (Six et al., 2002). Understanding these variations and tailoring management practices accordingly is crucial for effective SOM management. Trade-offs and synergies: There can be trade-offs between SOM management and other agricultural objectives. For example, using high-residue cover crops may provide substantial organic inputs to the soil but could also increase water consumption or interfere with weed control (Blanco-Canqui and Lal, 2008). Balancing multiple objectives, such as optimizing crop productivity, conserving water resources, and reducing greenhouse gas emissions, requires careful consideration and system-level approaches.

Economic viability: The economic viability of SOM management practices is a key factor in their adoption by farmers. Some practices, such as organic amendments or conservation tillage, may require initial investments or changes in farm operations that can be perceived as challenging or costly (Palm et al., 2014). Providing incentives, technical support, and education to farmers can help overcome these barriers and promote adopting sustainable SOM management practices. Knowledge and information gaps: Despite substantial research efforts, there are still knowledge gaps in understanding the intricacies of SOM dynamics, including the mechanisms of carbon stabilization, interactions between SOM and soil microorganisms, and the long-term impacts of management practices on SOM stocks (Poeplau and Don, 2015). Continued research and knowledge-sharing among scientists, extension services, and farmers are essential for advancing our understanding and implementing effective SOM management strategies.

Climate change implications: Climate change poses both challenges and opportunities for SOM management. Changes in temperature, precipitation patterns, and extreme weather events can affect SOM decomposition rates, nutrient cycling, and soil erosion dynamics (Minasny et al., 2018). On the other hand, SOM management practices can contribute to climate change mitigation by sequestering carbon in soils and reducing greenhouse gas emissions from agricultural activities (Bizi and Sidi, 2023). Optimizing SOM management in the context of a changing climate requires a holistic and adaptive approach. Integration of traditional knowledge and modern technologies: Traditional knowledge and soil management practices by indigenous and local communities can provide valuable insights into sustainable SOM management (Steiner et al., 2007). Integrating this traditional knowledge with modern technologies, such as precision agriculture, remote sensing, and data analytics, can lead to innovative and context-specific SOM management strategies that are both effective and culturally relevant.

Future Perspectives and Research Needs

As we look towards the future, several key perspectives and research need emerge to advance our understanding and management of soil organic matter (SOM). These perspectives highlight the importance of interdisciplinary collaboration, technological advancements, and policy support to address the challenges and seize the opportunities associated with SOM management.

Advancing interdisciplinary research: SOM management requires a holistic and multidisciplinary approach integrating knowledge from various fields, including soil science, agronomy, ecology, microbiology, and climate science. Collaboration among scientists, policymakers, farmers, and stakeholders is crucial to promote knowledge exchange, fostering innovation, and developing context-specific SOM management strategies (Lal, 2004;2006).

Harnessing technological advancements: Emerging technologies offer new opportunities to study SOM dynamics and develop innovative management practices. High-resolution imaging techniques, molecular biology tools, isotopic tracing methods, and remote sensing technologies can provide valuable insights into SOM formation, stabilization mechanisms, and spatial distribution patterns (Mayer et al., 2022; Smith et al., 2015). Integrating these technologies into research and management practices can enhance our ability to monitor and manage SOM effectively. Understanding interactions with climate change: Climate change poses challenges and opportunities for SOM management. Future research should understand how changing climatic conditions, including temperature, precipitation patterns, and extreme events, interact with SOM dynamics (Minasny et al., 2018). Additionally, investigating the potential of SOM management practices to mitigate greenhouse gas emissions and enhance climate resilience is critical for sustainable agricultural systems (Bizi and Sidi, 2023; Kell, 2011)).

Exploring novel management practices: Innovative SOM management practices should be explored to enhance SOM levels and soil health. These may include using biochar, cover crops, precision agriculture, and agroforestry systems (Adhikari and Hartemink, 2016; Major et al., 2010). Integrating traditional ecological knowledge with modern science can also provide insights into sustainable soil management practices (Steiner et al., 2007). Future research should evaluate these practices' effectiveness, economic viability, and scalability across different agroecosystems. Quantifying ecosystem services: Quantifying the multiple ecosystem services provided by SOM can help build the economic case for sustainable SOM management. Assessing the impacts of SOM on crop productivity, water regulation, nutrient cycling, carbon sequestration, and biodiversity conservation can contribute to policy support and incentive mechanisms for farmers adopting sustainable soil management practices (Palm et al., 2014; Lehmann et al., 2011).

Addressing knowledge gaps: Several gaps persist in our understanding of SOM dynamics and management. Research is needed to elucidate the mechanisms of SOM stabilization, the roles of specific microbial communities, and the impacts of different management practices on SOM turnover and composition (Díaz-Siefer et al., 2022; Major et al., 2010). Long-term monitoring and experimental studies are essential for gathering robust data to inform decision-making. Policy support and incentives: Policies and incentives that promote sustainable SOM management are crucial for widespread adoption. Governments, agricultural organizations, and international bodies should develop and implement policies that support farmers in adopting practices that enhance SOM levels, provide education and technical support, and establish market-based mechanisms for rewarding carbon sequestration in agricultural soils (Paustian et al., 2000).

Conclusion

In conclusion, soil organic matter (SOM) is crucial in soil health and crop production. It influences nutrient availability, soil structure, water-holding capacity, and microbial activity, all essential for sustainable agricultural systems. Through effective management of SOM, we can enhance soil fertility, mitigate climate change through carbon sequestration, and improve overall ecosystem resilience. This review paper has highlighted the impact of SOM on soil health, crop production, and the challenges and opportunities in managing SOM. It emphasizes the importance of interdisciplinary research, technological advancements, and supportive policies to address the complexities of SOM dynamics and management. Key practices to enhance SOM include organic amendments, cover cropping, conservation tillage, and crop rotation. These practices promote organic matter input, reduce soil disturbance, and enhance microbial activity, leading to increased SOM levels and improved soil quality. However, managing SOM comes with challenges like slow formation rates, trade-offs with other agricultural objectives, and economic viability. Addressing these challenges requires further research, knowledge exchange, and integrating traditional knowledge with modern technologies. Future perspectives and research needs include advancing interdisciplinary collaboration, harnessing emerging technologies, understanding the interactions between SOM and climate change, exploring novel management practices, quantifying ecosystem services, addressing knowledge gaps, and providing policy support and incentives. By embracing these perspectives and addressing the identified research needs, we can develop sustainable soil management strategies that optimize SOM levels, promote soil health, enhance crop productivity, and contribute to global food security and environmental sustainability.

Conflict of interest

The authors declared absence of conflict of interest.

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