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Effect Of Organic Matter Application On Physical Properties Of Soil: A Review

Narender Kumar
Associate Professor (Physics), Dayanand College, Hisar, narenderdnc@gmail.com

Abstract
Organic matter has a significant impact on the physical properties of soil, which in turn affect the soil health and quality. This review critically examines the impact of various types and rates of organic matter application such as compost, manure, crop residue and wool waste on key soil physical parameters including bulk density, porosity, soil moisture content, soil moisture retention, soil hydraulic conductivity, infiltration rate, soil temperature, specific heat and soil thermal conductivity etc. In current agricultural scenario, organic matter of various type is integrated with inorganic fertilizers to meet the nutrient requirement of plants. Organic matter has low density and high specific surface area than soil particles, which are most contributing attributes to have a significant effect on soil properties. Application of organic amendments has been shown to improve soil structure, reduce compaction, and enhance moisture infiltration and retention. These changes not only foster healthier root environments but also mitigate erosion risks and increase resilience against drought stress. This review synthesizes findings from fields across the diverse soil types and climatic conditions, highlighting interaction of organic matter with mineral components of soil to modify its physical properties. Additionally, the paper explored the long-term effects of organic matter on soil. By consolidating current research, this work provides a comprehensive understanding of how organic inputs contribute in improving soil physical properties and hence soil health & agricultural productivity.

INTRODUCTION

Soil is the fundamental component of terrestrial ecosystems and plays a critical role in sustaining agricultural productivity. Its physical properties, including texture, structure, bulk density, porosity, water-holding capacity and aggregate stability, directly influence plant growth, root development, microbial activity and nutrient transport. These properties also affect physical processes such as aeration, infiltration, erosion, and compaction, ultimately shaping crop productivity and environmental quality. However, intensive agricultural practices after green revolution, deforestation, and climate variability have led to widespread soil degradation, compromising its physical integrity and resilience. In this context, the application of organic matter has garnered significant attention as a regenerative strategy for improving soil physical characteristics and enhancing soil health.

Organic matter encompasses a diverse range of inputs such as compost, farmyard manure, crop residues, green manure, biochar and wool waste etc. These materials not only enrich the soil with essential nutrients but also play a crucial role in modifying its physical framework. By serving as binding agents, organic matter enhances soil aggregation, promotes porosity, and lowers bulk density, thereby fostering better aeration and moisture retention. It helps in the development of stable macroaggregates, which protect soil from erosion and improve water infiltration. Additionally, organic amendments can buffer temperature fluctuations and reduce crusting in surface layers, which are essential features for maintaining plant health during adverse weather conditions.

Numerous studies have demonstrated that regular incorporation of organic matter significantly improves soil aggregates and hence soil structure over time. For instance, compost and manure applications have been shown to reduce compaction in clay-heavy soils while increasing water-holding capacity in sandy soils. The transformation is not merely physical; organic amendments also stimulate microbial activity that further contributes to soil aggregation and pore connectivity. These biological processes serve as feedback mechanisms, reinforcing the physical changes induced by organic inputs. The interactions between organic matter, soil particles, and biological agents are complex yet pivotal in re-engineering the soil matrix for enhanced functionality.

Moreover, the influence of organic matter on soil physical properties varies according to the source of the amendment, its decomposition rate, climatic conditions, and soil type. While compost provides relatively stable humic substances that improve long-term structure, rapidly decomposing materials like green manure may offer short-term benefits. Biochar, with its porous architecture, contributes uniquely to enhancing water retention and reducing bulk density. Understanding these distinctions is vital for selecting appropriate organic amendments tailored to specific agronomic goals and environmental conditions.

Despite the demonstrated benefits, adoption of organic matter application faces practical challenges including availability, labor, cost, and integration with conventional farming systems. There is also a need to quantify optimal application rates and understand the temporal dynamics of physical improvements. Recent advances in soil physics and organic matter characterization offer new tools for evaluating amendment efficacy and predicting long-term outcomes. Furthermore, synergistic practices such as reduced tillage, cover cropping, and crop rotation can amplify the effects of organic matter on physical properties, offering holistic soil management solutions.

Given the increasing global emphasis on sustainable agriculture, climate-smart practices, and soil carbon sequestration, this review aims to provide an in-depth synthesis of how organic matter application affects soil physical properties. By collating empirical evidence and theoretical frameworks, the paper seeks to bridge the gap between research and practice, guiding farmers, researchers, and policymakers toward informed decision-making. Special attention will be given to comparative analysis across amendment types, soil classifications, and agroecological zones to develop actionable insights for region-specific soil management.

In summary, the addition of manures plays significant role in increasing soil organic carbon and contributes in improving the soil physical condition by improving soil structure, decreasing soil bulk density and increasing soil water retention which ultimately results in increase in crop productivity. Therefore, long-term application of manures such as farmyard manure shows beneficial effects on physical, chemical, hydraulic and thermal properties of soils. The long-term application of both manures and fertilizers were observed to improve soil quality (Kumara *et al.*, 2014). Now in upcoming sections, we will discuss, findings of research work done in the recent past years in the field of effect of long- term application of manures with and without fertilizers on soil physico-chemical, hydraulic and thermal properties in different cropping systems under different heads.

Effect of organic matter on soil bulk density

Bulk density is defined as the mass of dry soil solids per unit of bulk volume, encompassing both the volume occupied by solids and that by pore spaces. It serves as a key parameter in evaluating soil compaction, porosity, and aeration. Coarse-textured soils generally exhibit higher bulk densities than fine-textured soils due to lower total porosity. As soil texture becomes finer, bulk density tends to decrease, with clayey soils presenting lower values than loamy or sandy counterparts.

Organic matter plays a crucial role in modifying soil bulk density. An increase in organic content generally results in a reduction in bulk density, attributed to enhanced aggregation and reduced particle packing. Moreover, surface soils typically contain more organic residues and biological activity than subsoils, resulting in lower bulk density values near the surface. Pant and Ram (2019) reported a marked decrease in soil bulk density following the application of balanced fertilization with farmyard manure (FYM) after rice cultivation. Their study noted bulk density values ranging from 1.53 to 1.26 g cm^{-3} in surface soil and from 1.61 to 1.34 g cm^{-3} (15–30 cm), 1.63 to 1.44 g cm^{-3} (30–45 cm), and 1.73 to 1.54 g cm^{-3} (45–60 cm) in subsoil layers. The lowest densities across the 0–60 cm profile were recorded under the 100% NPK + FYM treatment, surpassing other fertilizer regimes. The observed reductions were attributed to increased root and crop residue inputs and improved aggregate formation due to the binding effects of organic acids and polysaccharides generated during decomposition. Similar findings were documented by Tripathi et al. (2014) and Pant et al. (2017), who also observed that the combined use of FYM and fertilizers led to reduced bulk density. Khan et al. (2018) demonstrated a decline in bulk density with the application of FYM at varying rates—reporting mean values of 1.47 Mg m^{-3} under control conditions, 1.39 Mg m^{-3} with 20 t ha^{-1}, and 1.24 Mg m^{-3} with 40 t ha^{-1} of FYM. Shirani et al. (2002) similarly reported significant reductions in bulk density following manure application. Furthermore, Meena et al. (2018) found a notable decrease in bulk density within the 0–15 cm soil layer under FYM treatments, with a strong correlation to soil organic carbon levels.

Soil water retention curve

The soil water retention curve illustrates the relationship between soil moisture content and matric suction, reflecting how much water is retained in the soil under varying tension levels. This curve is strongly influenced by factors such as soil texture, type of clay minerals, structure, organic matter content, and pore geometry. Water held at suctions between 0.1 to 0.3 bar is considered field capacity, representing the maximum moisture content after excess water has drained—typically achieved within two to three days following irrigation under field conditions. Conversely, water retained at 15 bar suction corresponds to the permanent wilting point, where most plants fail to regain turgor after wilting. The difference between field capacity and wilting point defines the plant-available water range critical for crop performance.

Organic amendments, particularly biochar, have been shown to significantly affect the soil water retention behavior. Lei and Zhang (2013) reported that biochar application increased moisture retention at field capacity, enhancing plant growth in clay loam soils. This was attributed to the development of fine-scale pores induced by added organic matter. Similarly, Eusufzai et al. (2012) emphasized that biochar contributes to the formation of nanometer-scale pores in fine-textured soils, improving water retention characteristics. Studies on coarse-textured soils further support these findings. Hansen et al. (2016) found that biochar amendments improved the volume of plant-available water, while Obia et al. (2016) demonstrated that biochar modifies soil water retention by increasing overall porosity and altering the pore-size distribution. Depth-dependent variations were highlighted by Zhang et al. (2013), who observed a decline in water-holding capacity with increasing soil depth. In addition to biochar, other organic materials like sewage sludge also show positive effects. Awang et al. (2009) reported enhanced water retention at 1 bar suction following sewage sludge application, indicating the potential of various organic sources in improving soil moisture dynamics.

Soil Moisture

The incorporation of organic manures into soil management practices has been widely recognized for its capacity to enhance soil organic carbon levels. This increase in organic carbon contributes to improved soil aggregation and the formation of water-retaining pore structures, ultimately enhancing soil moisture retention. Organic inputs not only modify the physical properties of soil but also play a vital role in improving its water-holding capacity through better pore connectivity.

Supporting this, Ghosh et al. (2010) reported that conservation tillage practices, facilitated by the inclusion of organic matter, significantly increased soil moisture levels compared to conventional tillage systems. Similarly, Ouattara et al. (2006) demonstrated that the application of organic amendments markedly improved soil water content under field conditions. In addition to amendments directly applied to the soil, surface management strategies such as mulching also contribute to soil moisture conservation. According to Sarkar et al. (2007), the use of surface mulch helped reduce evaporation and preserved moisture content more effectively than unmulched treatments.

Saturated hydraulic conductivity

Saturated hydraulic conductivity refers to the soil's ability to transmit water when all its pores are completely filled with water. This property is governed by several factors including soil texture, structural arrangement, pore size distribution, and organic matter content.

The role of organic amendments in enhancing this hydraulic property has been well-documented. Katkar et al. (2012) demonstrated that the application of farmyard manure (FYM) improved saturated hydraulic conductivity by promoting the formation of stable soil aggregates through increased organic matter input. Likewise, Selvi et al. (2005) reported a significant rise in hydraulic conductivity with increasing levels of fertilizers, especially under combined applications of FYM and NPK. Notably, the highest conductivity was observed with the treatment of NPK + $ZnSO_4$ (1.99 cm h^{-1}), while the control recorded the lowest value (1.44 cm h^{-1}). Are et al. (2017) corroborated these findings, revealing that organic amendments considerably enhanced saturated hydraulic conductivity, likely due to improved soil structure. Mbagwu (1992) further emphasized this effect, noting that the incorporation of poultry manure, cattle manure, and vermicompost boosted both soil porosity and conductivity, attributed to elevated soil organic carbon levels. Integrated nutrient management strategies also showed promising results. According to Hati et al. (2006), the combination of NPK and FYM increased saturated hydraulic conductivity by 21.4% compared to NPK alone, and by 95.8% relative to the control treatment. These observations collectively highlight the crucial influence of organic inputs and balanced fertilization in enhancing water movement through soil under saturated conditions.

Infiltration rate

Infiltration refers to the process by which water enters the soil surface, while the infiltration rate quantifies this movement—defined as the volume of water penetrating the soil per unit area per unit time. This rate is a critical indicator of soil physical properties and hydrological behavior, and it generally decreases as the soil moisture content increases.

Numerous studies have highlighted the influence of organic and inorganic amendments on enhancing soil infiltration capacity. Mubarak et al. (2014) reported that a combined application of organic manure and chemical fertilizers substantially improved the infiltration rate, suggesting synergistic effects on soil structure and water dynamics. Focusing on cereal-based systems, Bajpai et al. (2006) investigated infiltration in a rice–wheat cropping sequence and found significantly higher infiltration rates (1.30 cm h^{-1}) under 100% NPK fertilization in both crops compared to the control (0.85 cm h^{-1}). Similarly, Sharma (2005) observed increased infiltration with the incorporation of green manure or green gram residues alongside 120 kg N ha^{-1}, attributing the improvement to enhanced organic matter integration into the soil profile. Harne (2001) also documented a rise in infiltration rates in Vertisols when organic matter was applied in conjunction with chemical fertilizers, noting that higher porosity induced by these inputs facilitated faster water entry. Furthermore, Brar et al. (2015) emphasized the fundamental role of soil organic matter in controlling infiltration behavior across various soil types. These findings collectively underscore the positive effects of integrated nutrient management practices, especially those combining organic and inorganic inputs, in improving infiltration rates and promoting sustainable soil-water relations.

Soil temperature

Soil temperature plays a pivotal role in influencing soil productivity, both directly through its impact on biological and chemical processes and indirectly via its effects on soil moisture and structure. Organic amendments such as manures have been shown to alter the soil's thermal properties significantly.

According to Liang et al. (2018), soil temperature exhibits a negative correlation with soil moisture content, as wet soils require more thermal energy to increase in temperature due to higher heat capacity. Similarly, Chen et al. (2014) reported that soil temperature measured at a depth of 5 cm undergoes more frequent and pronounced fluctuations than at 10 cm, highlighting greater exposure of surface layers to ambient conditions. Surface mulching has been widely used as a strategy to moderate soil temperature fluctuations. Ramakrishna et al. (2006) and Pang et al. (2010) observed that mulches help buffer temperature changes by shielding the soil from direct solar radiation. Earlier findings by Van et al. (1959) further reinforced this concept, noting that surface residues can reduce soil warming rates by acting as insulators and reflecting incoming solar energy. These studies collectively underscore the importance of organic matter and surface management in regulating soil thermal regimes, thereby contributing to sustained soil productivity under variable environmental conditions.

Volumetric specific heat capacity

The specific heat capacity of soil refers to the amount of heat required to raise the temperature of a unit mass of soil by 1°C. This property plays a critical role in regulating the thermal behavior of soils and is influenced by various factors, most notably soil moisture. As water content increases, the specific heat capacity also rises due to water's inherently high thermal capacity.

According to Abu-Hamdeh (2003), volumetric specific heat capacity is positively correlated with both soil bulk density and moisture content. Their findings indicated that clay soils exhibited higher specific heat compared to sandy soils, primarily due to finer particle size and greater water-holding potential. Amendments such as biochar also affect the thermal properties of soils. Ren et al. (2016) reported that the integration of biochar into soil significantly increased the specific heat capacity of the solid phase, suggesting a beneficial modification of soil thermal buffering capacity. In a similar context, Ahn et al. (2009) found that volumetric heat capacity of substrates like sawdust and soil enriched with compost reached peak values when maintained at 80% of the water-holding capacity, demonstrating the combined influence of organic material and moisture availability. Together, these studies underline the intricate relationship between soil composition, organic amendments, and moisture content in shaping the soil's thermal behavior, an essential consideration for managing soil temperature and optimizing crop performance.

Thermal conductivity

Thermal conductivity refers to the coefficient that relates the temperature gradient to the rate of heat transfer via conduction, expressed as the amount of heat energy transmitted across a unit area per unit time. This property is crucial in understanding soil heat flow, which influences processes such as seed germination, root development, and microbial activity.

Several physical and compositional factors affect the thermal conductivity of soil, including mineral composition, structural arrangement, bulk density, water content, and organic carbon. For instance, Nayyeri et al. (2009) found that application of dairy cattle manure enhanced soil thermal conductivity, likely due to improved moisture retention and altered pore structure. Conversely, Edet et al. (2017) demonstrated that loamy soils treated with inorganic fertilizers exhibited higher thermal conductivity than those amended with cow manure or poultry waste, suggesting that the chemical nature of amendments can markedly influence heat transfer characteristics. The integration of biochar presents a different effect. According to Usowicz et al. (2006), biochar application reduced the thermal conductivity of soil, potentially resulting from a decrease in bulk density and enhanced porosity. In support of this, Dec et al. (2009) noted that tillage practices and soil compaction significantly impact soil thermal behavior. Conservation tillage, in particular, was shown to modify thermal conductivity due to its influence on soil moisture preservation. Further, Abu-Hamdeh et al. (2003) reported a positive relationship between soil bulk density and moisture content with thermal conductivity. Their study also highlighted a decrease in conductivity with increasing levels of soil organic matter, which functions as a natural insulator. These findings underscore the multifaceted influences of organic and inorganic amendments, soil structure, and moisture dynamics on soil thermal conductivity—offering valuable insights for optimizing soil thermal regimes under different management practices.

Thermal diffusivity

Thermal diffusivity of soil is defined as the ratio of thermal conductivity to volumetric specific heat capacity. This parameter reflects not only the soil's ability to conduct heat but also its capacity to change temperature in response to thermal energy input or loss. It is crucial in understanding the thermal response of soil systems, particularly in agricultural and environmental contexts.

Several studies have explored how organic amendments influence this property. Usowicz et al. (2014) reported that the incorporation of biochar and other organic materials into soil led to a reduction in thermal diffusivity, with the effect being more pronounced in mineral soils due to their distinct physical characteristics. Similarly, Chishala et al. (2019) observed that the addition of chicken manure decreased the thermal diffusivity of soil, suggesting that organic amendments can act as thermal insulators by altering soil structure and moisture dynamics.Soil moisture plays a key role in modulating thermal diffusivity. Danelichen et al. (2013) found a strong correlation between soil water content and thermal diffusivity, indicating that water is a dominant factor in heat transmission within the soil matrix. Supporting this, Gnatowski (2009) documented that the thermal diffusivity of organic topsoil varied between 1.3×10^{-7} to 2.5×10^{-7} $m^2 s^{-1}$ across a moisture range of 0–90%, underscoring the dynamic influence of moisture on thermal behavior. These findings collectively highlight that both organic matter content and moisture levels are critical determinants of soil thermal diffusivity, with implications for managing heat flow in soil and optimizing temperature-sensitive agronomic processes.

CONCLUSION

Organic matter application has emerged as a pivotal strategy for enhancing the physical properties of soil, contributing significantly to sustainable agriculture and soil health. Across various studies, organic amendments such as farmyard manure, biochar, compost, and crop residues have been shown to improve bulk density, porosity, infiltration rate, saturated hydraulic conductivity, and water retention capacity. These enhancements are primarily attributed to increased soil aggregation, improved pore connectivity, and enriched organic carbon levels.

Thermal properties, such as thermal conductivity, specific heat capacity, and thermal diffusivity, are also notably influenced by organic inputs. The incorporation of biochar and manures has been found to modulate heat transfer dynamics, often reducing thermal diffusivity and conductivity while increasing specific heat capacity, especially in moisture-rich soils. These changes contribute to more stable thermal regimes, which support optimal root development and microbial activity.

Overall, organic matter fosters a synergistic improvement in both hydrological and thermal behavior of soils, particularly when integrated with conservation tillage and balanced fertilization. The evidence reviewed highlights the necessity of tailoring organic amendments to soil type, texture, and climate conditions for maximum benefit. Continued research into the long-term impacts and mechanisms of organic matter incorporation will be essential for developing region-specific recommendations and enhancing soil resilience in the face of climatic variability.

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