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Review article

INFLUENCE OF SOIL ORGANIC MATTER CONTENT ON SOIL PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES

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ABSTRACT: Soil organic matter (SOM) is composed of microorganisms, fresh residues and humus fractions. Measurement of soil microbial activity, in conjunction with other soil physical and chemical properties and processes, can be a valuable tool for developing a complete profile for soil fertility and may be used to increase the efficiency of fertilizer recommendations. Soil microorganisms are the centerpiece of biogeochemical cycling of nutrients in soil. Soil fertility is directly related to, and defined by, the heterotrophic activity of soil microbes as a whole. The breakdown of added residues and of SOM is affected by their physical and chemical characteristics, as well as by temperature, moisture, nutrition, and other factors that affect biological activity directly. Investigation about soil organic matter is continues by researchers and this review indicated the positive effects of soil organic matters on soil structure, soil porous, and soil electro conductivity, microorganisms, carbon and nitrogen rate. Knowledge about soil microorganisms and soil biological processes may improve the scientific basis of management decisions, e.g., determination of the type of species to be used for planting and cropping in agricultural areas.
Key words: Biological properties, CEC, Microorganisms, Physico-chemical properties, SOM

INTRODUCTION

What Is Soil Organic Matter (SOM)?

Soil organic matter (SOM) is the organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms [5,50]. Soil organic matter (SOM) is the foundation for productive soil. It promotes healthy crops, supplies resources for microbes and other soil organisms, and regulates the supply of water, air and nutrients to plants [75]. SOM can deliver over half of the nitrogen and a quarter of the phosphorous crops require, thus strongly influencing fertilizer requirements. [21] The amount and type of organic matter varies from soil to soil, but generally SOM can be divided up into three pools with different turnover times. SOM management should focus on strategies that build all three pools. This is the key to simultaneously building SOM and deriving benefits from its decomposition, including nutrient turnover, aggregate formation and water storage [1].

Soil organic matter (SOM) pools

Active SOM: The active SOM pool has a turnover time of months to years, and it includes constituents such as soil microorganisms that are involved in even faster turnover times. It is primarily composed of recent plant residues that are in the early stages of decomposition and of soil organisms. This active SOM pool is very important for nutrient release, and helps develop a soil's slow SOM pool [Fig 1].

Slow SOM: The slow SOM pool has a turnover time that varies from years to decades. A soil's physical condition and nutrient buffering capacity are both strongly influenced by this slow turnover pool of organic matter. Different from the stable SOM pool, the slow pool is also a source of nutrients including nitrogen and phosphorous. It includes decomposed materials, residues and microbial products that are protected through physical (for example, interior of soil aggregates) and biochemical processes [Fig 1].

Stable SOM: The stable SOM pool consists of material that is hundreds to thousands of years old. Sometimes this pool is called the passive pool, or humus. It is a highly recalcitrant pool (resistant to decomposition) that influences the cation exchange capacity of the soil, and is important in soil physical processes such as aggregation. The amount of stable SOM is not strongly influenced by recent management practices and tends to increase with increasing clay concentration in the soil. However, management practices such as residue removal, burning, tillage and cover-cropping can have long-term effects on the relative and absolute amounts of stable SOM [Fig 1].

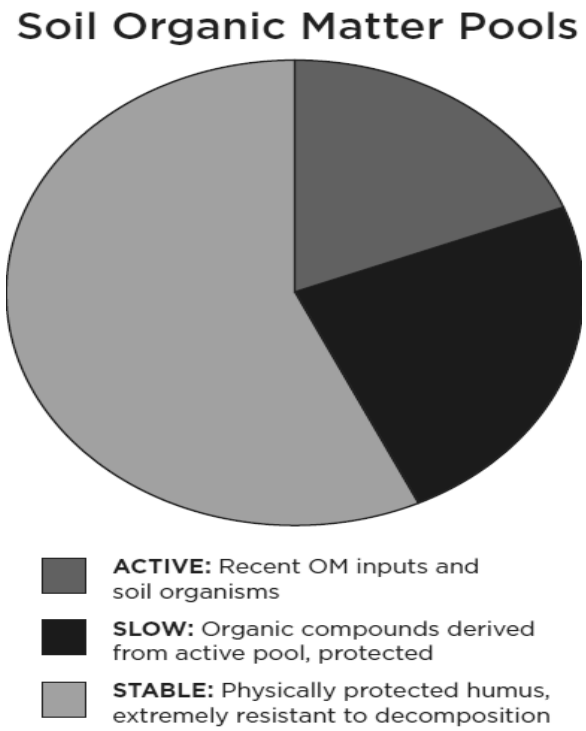

Fig1. Soil organic matter pools [71]

Soil Physical Properties

It is often difficult to clearly separate soil functions into chemical, physical, and biological processes because of the dynamic, interactive nature of these processes [2, 74]. Soil physical properties, including texture, structure, and porosity, the fraction of pore space in a soil.

Soil Texture: Soil texture can have a profound effect on many other properties and is considered among the most important physical properties [76]. Texture is the proportion of three mineral particles, sand, silt and clay, in a soil. These particles are distinguished by size, and make up the fine mineral fraction Particles over 2 mm in diameter (the 'coarse mineral fraction') are not considered in texture, though in certain cases they may affect water retention and other properties [69]. The relative amount of various particle sizes in a soil defines its texture, i.e., whether it is a clay, loam, sandy loam or other textural category [26].Texture is the result of 'weathering,' the physical and chemical breakdown of rocks and minerals. Because of differences in composition and structure, materials will weather at different rates, affecting a soil's texture. For example, shale, an easily weathered rock, forms clay-rich soils, whereas granite, a slow weathering rock, usually forms sandy, coarse soils [20]. Since weathering is a relatively slow process, texture remains fairly constant and is not altered by management practices.

Soil Structure: Soil structure is the arrangement and binding together of soil particles into larger clusters. Aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil [51, 73]. 'Granular' structure consists of loosely packed spheroidal peds that are glued together mostly by organic substances Granular structure is characteristic of many A horizons, particularly those with high SOM content and biological activity [27]. Larger peds, in the form of plates, blocks, or prisms, are commonly associated with the B horizon and are formed via shrink-swell processes and adhesive substances [24].

Peds are held together and in place through the adhesion of organic substances, iron oxides, clays or carbonates. Cracks and channels between peds are important for water, air, and solute transport and deep water drainage [46] . Finer soils usually have a stronger, more defined structure than coarser soils due to shrink/swell processes predominating in clay-rich soils and more cohesive strength between particles [57].

Soil Porosity: Many important soil processes take place in soil pores (the air or water-filled spaces between particles) [44]. Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Coarse-textured soils have many large (macro) pores because of the loose arrangement of larger particles with one another. Macropores in fine-textured soils exist between aggregates [68]. Because fine-textured soils have both macro- and micropores, they generally have a greater total porosity, or sum of all pores, than coarse-textured soils [68]. Long-term cultivation tends to lower total porosity because of a decrease in SOM and large peds [14]. Surface crusting and compaction decrease porosity and inhibit water entry into the soil, possibly increasing surface runoff and erosion [33, 34]. Calcareous and salt-affected soils can also alter porosity and structure [56]. In general, increasing SOM levels, reducing the extent of soil disturbance, and minimizing compaction and erosion will increase soil porosity and improve structure [33].

Chemical Properties

Exchange Capacity: Most chemical interactions in the soil occur on colloid surfaces because of their charged surfaces. Due to their chemical make-up and large surface area, colloids have charged surfaces that are able to sorb, or attract, 'ions' (charged particles) within the soil solution [40]. Depending on the ion's charge, size and concentration in the soil, it can be sorbed and held to the colloid surface or exchanged with other ions and released to the soil solution. The soil's ability to sorb and exchange ions is its 'exchange capacity' [50]. Although both positive and negative charges are present on colloid surfaces, soils of this region are dominated. Therefore, more cations (positive ions) are attracted to exchange sites than anions (negative ions), and soils tend to have greater cation exchange capacities (CEC) than anion exchange capacities (AEC). Fine-textured soils usually have a greater exchange capacity than coarse soils because of a higher proportion of colloids [38, 43]. Soil pH: Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H^+) in the soil. A high amount of H^+ corresponds to a low pH value and vice versa [3]. Soil pH can affect CEC and AEC by altering the surface charge of colloids [66]. A higher concentration of H^+ (lower pH) will neutralize the negative charge on colloids, thereby decreasing CEC and increasing AEC [38].

Salt-Affected Soils: The presence and concentration of salts in soil can have adverse effects on soil function and management [42]. Salt-affected soils are most common in arid and semiarid regions where evaporation exceeds precipitation and dissolved salts are left behind to accumulate, or in areas where vegetation or irrigation changes have caused salts to leach and accumulate in low-lying places [36]. The three main types of salt-affected soils are saline, sodic and saline-sodic (Q&A #1). Saline soils contain a high amount of soluble salts, primarily calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+), whereas sodic soils are dominated by sodium (Na^+). Saline-sodic soils have both high salt and Na^+ content. Salts in soil can affect structure, porosity and plant/water relations that can ultimately lead to decreased productivity [38].

Calcareous Soils: Calcareous soils often form from the weathering of carbonate-rich parent material, such as limestone or lime-enriched glacial till, and generally occur in areas where precipitation is too low to leach the minerals from the soil [59]. Carbonates can be found throughout a soil profile or concentrated in the lower horizons due to downward leaching. The subhorizon letter 'k' denotes a calcareous horizon layer [38]. Calcareous soils can be distinguished in the field by an effervescence reaction that occurs when a drop of dilute acid (10% hydrochloric acid or strong vinegar) is applied [14,38].

Benefits of Stable Soil Organic Matter

Physical Benefits: Enhances aggregate stability, improving water infiltration and soil aeration, reducing runoff, Improves water holding capacity, Reduces the stickiness of clay soils making them easier to till and Reduces surface crusting, facilitating seedbed preparation [38].

Soil structure and aggregate stability: Soil structural stability refers to the resistance of soil to structural rearrangement of pores and particles when exposed to different stresses (e.g. cultivation, trampling/compaction, and irrigation) [33]. The interrelationship between SOC and soil structure and other physical properties has been extensively studied, and excellent reviews can be found in Tisdall and Oades [70], Oades [52], and Carter [17] and Stewart [39].

It is well established that addition of SOM can not only reduce bulk density (Db) and increase water holding capacity, but also effectively increase soil aggregate stability [48]. Carter et al. [16] noted that the amount of water-stable aggregates (WSA) was often associated with SOC content, and that particularly labile carbon was often positively related to macro-aggregate stability. Kay and Angers [31] reported that a minimum of 2% SOC was necessary to maintain structural stability and observed that if SOC content was between 1.2-1.5%, stability declined rapidly. Boix-Fayos et al. [13] showed that a threshold of 3-3.5% SOC had to be attained to achieve increases in aggregate stability; no effects on aggregate stability were observed in soils below this threshold. Haynes [28] found that the mean weight diameter (MWD) of aggregates exhibited a curvilinear increase with carbon content, suggesting an upper limit of influence of SOC [33]. Water-Holding Capacity: An important indicator of soil physical fertility is the capacity of soil to store and supply water and air for plant growth [10, 47]. The ability of soil to retain water is termed water holding capacity (WHC) [8]. In particular, the amount of plant-available water in relation to air-filled porosity at field capacity is often used to assess soil physical fertility [38, 58]. Total plant available water (PAW) is the amount of water held between the wettest drained condition (field capacity FC, at matric suction of -10 kPa) and the water content at which plants are unable to extract water (permanent wilting point PWP, at matric suction of -1500 kPa [9]. WHC of soils is controlled primarily by the number of pores and pore-size distribution of soils, and by the specific surface area of soils. In turn, this means that with an increase in SOC content, there is increased aggregation and decreased Db, which tend to increase the total pore space as well as the number of small pore sizes [28, 35]. These relationships highlight the interconnectivity between soil structure, Db and WHC [62]. The effect of organic carbon on the WHC of soil is generally assumed to be positive but the types of carbon responsible for this effect and synergistic behavior with other soil properties is not well understood [38]. Hudson [29] and Kern [34] found an increase in water content with increasing SOC content and Pachepsky [53] stated that an increase of 1% SOM can add 1.5% additional moisture by volume at FC. Garambois et al. [22] showed that per gram of additional carbon at -10 kPa suction, a 50% increase in water content was achieved. They suggest that the organic carbon from exudates ('gel') from ectotrophicmycrorhiza would bond soil particles, which would result in a change in the size of the pores and a change in water retention at -10 kPa.

Soil Colour: Soil colour is often used as the highest categorical level in many soil classification systems, e.g. the concept of the Russian chernozem was centered around the thick dark soils of the Russian steppe and the Mollisol order of the US soil taxonomy is specifically defined to include most soils with relatively thick, dark surface horizons [37]. Generally good soil conditions are associated with dark brown colours near the soil surface, which is associated with relatively high organic matter levels, good soil aggregation and high nutrient levels [58]. The effect of usually dark brown or black SOM on soil colour is important not only for soil classification purposes, but also for ensuring good thermal properties, which in turn contribute to soil warming and promote biological processes [5]. Only about 10% of the solar energy reaching the earth's surface is actually absorbed by the soil, which can be in turn used to warm the soil. Naturally, dark-coloured soils absorb more energy than light-coloured ones.

The physical deterioration often associated with a decline in organic matter content is manifested by a decline in wet aggregate stability, an increase in bulk and clod densities, an increase in modulus of rupture, and a decline in large pore space [38].

Soil organic matter and soil chemical properties

The cycle of carbon on Earth is the story of life on this planet. Soils are the largest carbon reservoir of the terrestrial carbon cycle. The quantity of C stored in soils is highly significant; soils contain about three times more C than vegetation and twice as much as that which is present in the atmosphere [19].The content of soil organic carbon (SOC) is universal soil quality indicator with significant influence on soil properties. Soil organic carbon today is in the center of interest because of international conventions on climate change (UNFCC), biodiversity (CBD) and desertification (UNCCD). Therefore, it is very important to understand the processes that influence changes in soil organic carbon particularly in Pannonian and Mediterranean region [49].

It is being recognized that another important role for SOM is as a critical component of the global C balance, being a much larger C pool than the atmosphere and the biota, but less than that in fossil fuels and the predominant marine C pool [39]. Soil respiration is a key component of the C cycle in terrestrial ecosystems and small changes may strongly affect soil C sequestration [61]. While Wang and Wang [60] study results indicated that Soil microbial biomass C and N and respiration were on average 100%, 104% and 75%, respectively higher in the (Secondary broadleaved forest) SBF than in the pure Cunninghamialanceolata plantation (PC).

Variations of the C:N ratios of different pools of organic matter and variations of the C and N assimilation efficiency of the microbial biomass may also confound the usefulness of the soil C:N ratio to predict gross N transformation rates [25].High soil microbial activity does not always lead to high N mineralization due to immobilization that can occur; however, determining the C:N ratio from a much smaller more active pool of C and N to soil microbial activity could increase the accuracy of predicting the net mineralization/immobilization. A more sensitive and effective approach may be to assess the much smaller fractions of water-extractable organic C and N, which are highly related to soil microbial activity [64].The breakdown of organic residues by microbes is dependent upon the carbon to nitrogen (C:N) ratio [30].For good composting, a C:N ratio less than 20 allows the organic materials to decompose quickly (4 to 8 weeks) while a C:N ratio greater than 20 requires additional N and slows down decomposition. A low nitrogen content or a wide C:N ratio is associated with slow SOM decay. Immature or young plants have a higher nitrogen content, lower C:N ratios and faster SOM decay.The C:N ratio of most soils is around 10:1 indicating that N is available to the plant. The C:N ratio of most plant residues tends to decrease with time as the SOM decays [30]. Bouajila and Sanaa [32] results showed that the application of 120 t/ha household wastes and manure improved an organic carbon (1.74 % and 1.09 %, respectively) when compared with control (0.69 %). They have shown that the potential release of CO2 shows variations between the control soil and soil amended with compost or manure, the value of higher is recorded for the soil amended with 120 T / ha of compost (35.8 mg CO2 / kg).

Mineralization is biological decomposition, the availability of N for crop plants is controlled by the chemical composition of OM, and the physical, chemical, and biological characteristics of the soil [55].Excessive and inappropriate use of OMs can cause intensive mineralization and drastically increase mineral N in the soil and plants [15], which triggers various disturbances in the biological equilibrium of the ecosystem, and excessive and harmful accumulation of nitrates in the plants [4].As such, it is necessary, when using organic sources of N, to estimate the mineralization potential of OMs so that by selecting a fertilizer with an appropriate content and by applying it at different times, the needs of the crops can be synchronized with the release of nutrients [11,54].Microbial mineralization/immobilization of soil N can be broadly estimated using soil organic C:N [18].Microbial biomass C and microbial biomass N were closely interrelated and also showed significant correlations with soil organic C and total N [63].in other studythe use of OMs increased the concentration of mineral N in the soil and increased the yield of fresh lettuce [45].

Soil organic matter has a net negative charge and nutrients such as calcium, magnesium, potassium and ammonium (i.e. cations) have a positive charge [6]. The capacity of a soil to hold plant nutrients so that they are easily released or "exchanged" into the soil solution is measured by the cation exchange capacity (CEC) as the sum of exchangeable cations in the soil. The application of organic matter with a high C:N ratio (> 30:1) such as wood and sawdust, may immobilise nitrogen as microbes consume nitrogen in the soil in order to decompose the organic matter. On the contrary, organic matter with a low C:N ratio (< 30:1) such as manure, may lead to excess nitrogen release from the organic matter into the soil [7].The highest EC that obtained by the manure treatments could be attributed to the addition of organic fertilizers that supplied soil with soluble compounds [72]. Moisture, pH, soil depth, and particle size affect SOM decomposition [30]. While soils that are neutral to slightly alkaline in pH decompose SOM quicker than acid soils; therefore, liming the soil enhances SOM decomposition and carbon dioxide evolution [30].

Soil organic matter and soil biological properties

Agricultural management, such as crop rotation, tillage, compost, manure, herbicide and synthetic fertilizer application, and water regime, are key determinants of microbial community structure in soil. Vegetation is also an important factor since plants are providing microorganisms with specific carbon sources [23]. Microbes need regular supplies of active SOM in the soil to survive in the soil. Long-term no-tilled soils have significantly greater levels of microbes, more active carbon, more SOM, and more stored carbon than conventional tilled soils. A majority of the microbes in the soil exist under starvation conditions and thus they tend to be in a dormant state, especially in tilled soils [30].Bacteria are the first microbes to digest new organic plant and animal residues in the soil. Aerobic bacteria assimilate about 5 to 10 percent of the carbon while anaerobic bacteria only assimilate 2 to 5 percent, leaving behind many waste carbon compounds and inefficiently using energy stored in the SOM. The fungus generally captures more energy from the SOM as they decompose it, assimilating 40 to 55 percent of the carbon. Microorganism populations change rapidly in the soil as SOM products are added, consumed, and recycled. The microbes in turn build SOM and store soil nutrients. Building SOM requires soil nutrients like N-P-K-S to be tied up in the soil.

Several investigations show long term positive influence of organic farming on soil quality and microbial activity in comparison with conventional farming, due to regular crop rotation, and absence of synthetic nutrients and pesticides [67].Significantly higher numbers of all groups of analyzed cultivable microorganisms were observed inorganic agriculture fields in comparison to conventional fields, e.g., the number of bacteria had increased by 70%, actinobacteria by 290%, cultivable filamentous fungi by 110%, yeasts and maltose fermenting bacteria by 190% [41]. The microbial biomass in soil/compost mixtures increased within 10 days after the addition of compost to the soil (except for sterilized soil amended with a high level of compost where the maximum value was observed after 22 days) [65]. In an investigation in the semiarid Canadian prairie comparing annual legumes as green manure (green fallow) with tilled fallow-wheat and continuing wheat cultivation it was estimated that after six years of green fallow practices significant improvements were detected in several microbial characteristics such as colony counts of aerobic bacteria and filamentous fungi [12].

CONCLUSION

During the past three decades, there has been increased awareness of soil degradation and its negative impact on its productivity. Such agricultural practices have led to progressive impoverishment in the organic matter contents in the A horizon and hence, a remarkable decrease of the initial productivity of these soils, derived from their unsuitable chemical properties. Soil microbial biomass has been suggested to be a sensitive indicator of changes in total SOM given that it more readily responds to alterations in plant vegetation or land use. Soil organic matter encompasses the soil biota, and plant and animal tissues at varying stages of decomposition. To circumvent the loss of the organic matter, amendment using solid wastes has been attempted. Of particular interest, manure and composts have received much interest and their positive impact on soil structure, stability, nitrogen and carbon content have been reported. The biological component of the soil is responsible for soil humus formation, cycling of nutrients and building soil structure along with many other functions. Knowledge about soil microorganisms and soil biological processes may improve the scientific basis of management decisions, e.g., determination of the type of species to be used for planting and cropping in agricultural areas.

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