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Role of Soil Microbes and their Cell Components on Stabilization of Soil Organic Carbon

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ABSTRACT

Soil organic carbon (SOC) is one of the largest pools of organic carbon (OC) and plays a primary role in global C balance and also soil functioning. SOC stabilization can be termed as any action which slows down the decomposition of SOM by reducing the mineralization rate. In a soil ecosystem, organic carbon can be stabilized via three mechanisms: (1) its biochemical recalcitrance, (2) formation of organo-mineral complexes through chemical interactions with minerals and metal ions (3) physical protection owing to occlusion within soil aggregates. Soil microorganism (fauna & flora) and their cell component like polysaccharides, glomalin etc. directly or indirectly involved in all the mechanism Microorganism and their cell components increase recalcitrance by changes in chemical characteristics of SOM, microbial synthesis and extracellular condensation. Increase interaction by microbial polysaccharides & proteins, sorption & precipitation, complexation reactions; decrease accessibility mainly by soil aggregation. Effectiveness of microbes in SOC stabilization by improving aggregate stability in the order of: fungi > actinomycetes> bacteria, although there is much variation within each group. The organic carbon is positively correlated with the different fraction of glomalin and the aggregate stability (%) increased with the glomalin. The aggregate percentage increased with inoculation of Bacillus sp. and Pseudomonas sp., Lactobacillus sakie (CY1) in sandy soil through extracellular polysaccharides (EPS) production. As the number and type of microbes and their cell components changed with soil management, understanding the in-depth mechanisms of microbes-driven SOC stabilization is crucial for long-term C sequestration.

Key words: *Soil, Organic carbon, Microorganism.*

INTRODUCTION

Soil organic matter is regarded as all dead materials in or on top of the soil which contain organic carbon[7]. The global soil carbon (C) pool of 2500 (Gt) includes about 1550 Gt of soil organic carbon (SOC) and 950 Gt of soil inorganic carbon (SIC). The soil C pool is 3.3 times the size of the atmospheric pool (760 Gt) and 4.5 times the size of the biotic pool (560 Gt). The SOC pool to 1-m depth ranges from 30 tons/ha in arid climates to 800 tons/ha in organic soils in cold regions, and a predominant range of 50 to 150 tons/ha[4].

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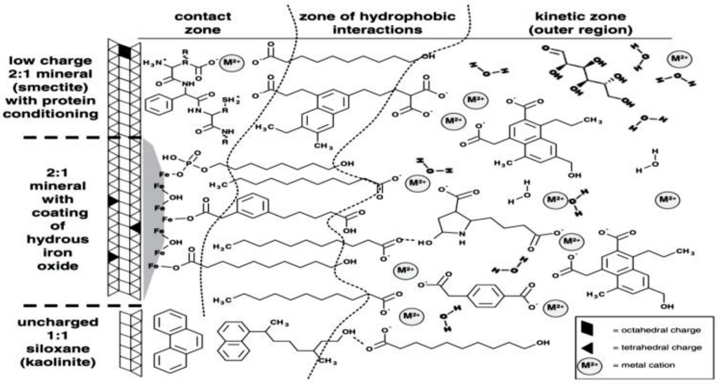
Soil C exists in two forms: inorganic and organic. Soil inorganic carbon (SIC) is the result of both weathering of the parent materials and carbonic acid in the soil, precipitating as C minerals such as calcite, aragonite, and dolomite. Formation of secondary or pedogenic carbonates is an important mechanism of SIC sequestration in arid and semi-arid climates. Soil organic carbon (SOC) is a complex of organic C compounds in the form of SOM. SOM includes everything in or on the soil that is of biological origin irrespective of origin or state of decomposition. It includes plants and animals in various states of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. SOC originally comes from atmospheric CO_2 that is captured by plants through the process of photosynthesis. The amount of SOC is a balance of C inputs and C losses of organic material. Soil carbon stabilization is a process which acts decrease in the potential for soil organic matter (SOM) loss by respiration, erosion or leaching[7]. Soil organic carbon stabilization can be termed as any action which slows down the decomposition of SOM by reducing the mineralization rate[6]. Stabilization (or protection) of SOM is a process which acts to slow the decomposition process. In 1992, the Kyoto Protocol on climate change demanded the fundamental understanding of the stabilization of carbon in soils. The reason for this lies in the fact that one of the largest sinks of organic carbon on the global scale is the organic matter stored in soils[2]. Changes in the size and the turnover rate of the soil carbon pools could possibly have an effect on the atmospheric CO2 concentration and the global climate[5]. Although the ability of the soil to store organic matter and to prevent it (partly) from mineralization to CO_2 has received growing interest in the last years, the mechanisms for carbon stabilization are still not entirely clear, and the potential of the soil for carbon stabilization is unknown[3].

Mechanisms of soil organic matter stabilization

A) Chemical stabilization

Chemical stabilization of SOM is the stabilization of SOM from microbial decomposition through chemical or physico-chemical binding between SOM and soil minerals (e.g. soil clay and silt particles). There is a close relationship between the proportion of primary particles (<20 µm) in the soils and the SOM associated with this fraction in the top 10 cm of soil profile. The amount of SOM in the >20 µm fraction was not correlated with texture, and cultivation decreased the amount of SOM in the >20 µm fraction more than in the <20 µm fraction, indicating SOM associated with the <20 µm is better protected against decomposition. The clay types (e.g. 2:1 versus 1:1 versus allophonic clay minerals) influence the stabilization of organic matter. Studies indicate there is a direct relationship between the silt plus clay content of soil and the amount of silt and clay-protected soil C, indicating a saturation level of silt and clay associated with C but this relationship was different between different types of land use, different clay types, and different silt plus clay size class.



Zonal model: The zonal model of organo-mineral interactions. The variety of surface types in soils is represented by a low charge smectite, a hydroxylated Fe-oxide coating, and a hydrophobic kaolinite siloxane surface. This selection is meant to illustrate major bonding mechanisms, and is not intended to represent the full range of mineral surface types that may be encountered in soils. In the contact zone, amphiphilic fragments accumulate on charged surfaces through electrostatic interactions, directing hydrophobic portions outwards toward the polar aqueous solution. Proteins serve as a surface conditioner that adds polar functionality to low-charge siloxane surfaces.

B) Physical stabilization

Physical stabilization of SOM is the stabilization of SOM from microbial decomposition through occlusion within macro- and/or micro-aggregates and adsorption onto minerals and 50% of organic matter is protected by this mechanism. The occlusion of SOM within aggregates contributes to inaccessibility of substrate to microbes and enzymes within soil, interactions of organic matter with minerals, metal ions and other organic substances. Physical inaccessibility of an organic substrate to microbes and extracellular enzymes is attributable to microorganisms and substrates are sparsely and heterogeneously distributed in the soil, and there are many physical and diffusion barriers to microbial movement in the soil due to the sparse and heterogeneous distribution of substrates in soil. Pore sizes less than 0.2 µm in diameter are too small for most bacterial and fungal hyphae to enter, and enzymes can also be inhibited from entering as pore sizes decrease to less than 0.5 nm. The hydrophobicity of numerous substrates, especially partially-oxidized materials, greatly reduces accessibility.

C) Biochemical stabilization

Biochemical stabilization of SOM is the protection of SOM from microbial decomposition due to the complex chemical composition of the organic matter (e.g. recalcitrant compounds such as lignin and polyphenols) and through chemical complexing processes (e.g. condensation reactions in soil) by the action of microbial populations (e.g. bacteria and fungi) and invertebrates, resulting in acquired stability. Biochemical protection of SOM occurs due to the complex chemical composition of the organic materials. This complex chemical composition can be an inherent property of plant residue, or be acquired during decomposition through the condensation and complexation of decomposition residues, rendering them more resistant to subsequent decomposition.

Microbes directly or indirectly involved in physical, chemical and Biochemical stabilization

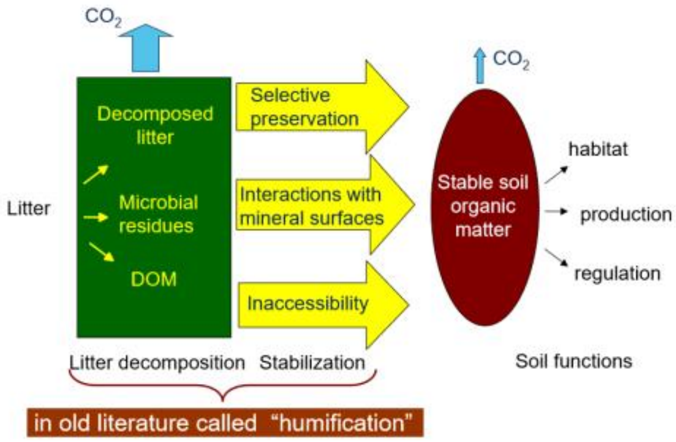
Carbon stabilization by microbes

The microbes will stabilize the soil carbon by following ways

a) Recalcitrance (selective preservation): Comprises molecular-level characteristics of organic substances, including elemental composition, presence of functional groups, and molecular conformation, that influence their degradation by microbes and enzymes.

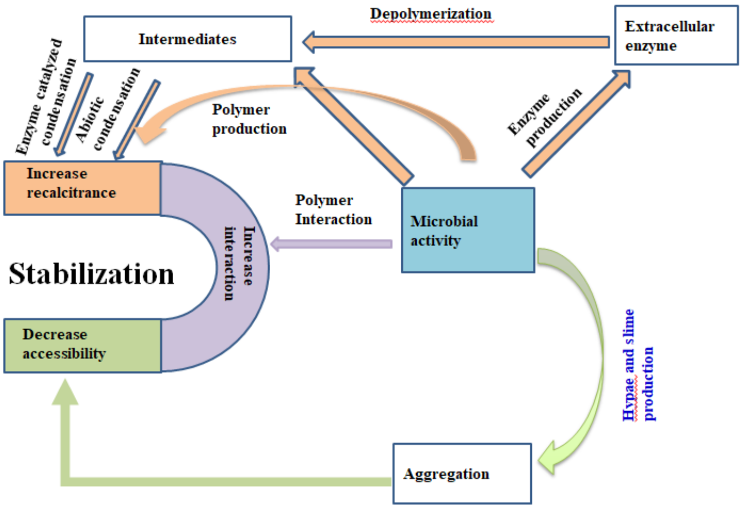
b) Interactions: It refers to the inter-molecular interactions between organics and either inorganic substances or other organic substances, that alter the rate of degradation of those organics or synthesis of new organics.

C) Inaccessibility: It refers to the location of organic substances as it influences their access by microbes and enzymes. Stability is the integrated effect of recalcitrance, interactions, and accessibility.



Types of stabilization of soil carbon

First the litter will decompose to various components like decomposed litter, microbial residues, dissolved organic matter and then this component are stabilized by microbes through recalictration, interaction and inaccessibility to stable organic matter which play important role in soil habitat production and regulation. In the old literature both decomposition and stabilization were called by single term- humification but now these two words are separate.



Stabilization of soil carbon by microbe potential controls on stabilization The microbial and their cell components help in aggregation of soil particle and decrease the organic carbon accessibility to microbes and with their polymer interaction protect the organic matter and through enzyme production, other intermediates and polymer production increases recalcitrance and decreases the organic carbon degradation.

Microbes involved in soil carbon stabilization

Mainly the fungi, bacteria algae and action mycetes are involved in the stabilization

Fungi: *Rhizophagus irregularis, Agaricus lilaceps, Paraglomus occultum, Glomusm osseae, Laccaria bicolor*

Bacteria: *Bacillus megaterium, Klebsiella, Enterobacter, Lactobcillus*

Algae: *Cyanobacteria, Nostoc, Chlorella, Oscilltaoria*

Actinomycetes: *Streptomyces, Nocardia asteroids, Actinomyces naeslundii*

Microbial cell components involve in carbon stabilization

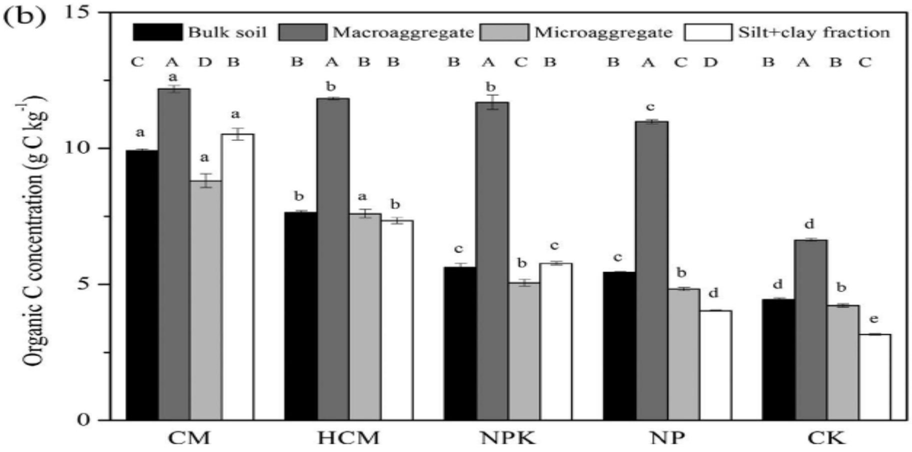
Glomalin: The characterization of arbuscular mycorrhizal fungi has shown the presence of a large quantity of an organic compound secreted by the hyphae[8]. Normally two fractions are there, one fraction is called easily extractable glomalin (EEG) and the fraction extracted with the highest concentration of solvent is called total glomalin (TG). Glomalin is a glycol protein having N-linked oligosaccharides and tightly bound iron. It is insoluble and possibly hydrophobic in its native state[8]. Glomalin can be detected in situ using immune fluorescence. The turnover of glomalin is between 6 and 42 years which is much longer than fort hyphae. This difference has been confirmed by a laboratory study showing that after 150-day incubation the concentration of glomalin was reduced by barely 25%, whereas the hyphae lost nearly 60% of their length after the host was removed. This difference could partly explain the seasonal variations of these two fungal factors in the aggregation.

Lipids: The role played by lipids in the aggregation processes is less well documented than for other compounds soil Aggregation is strongly correlated with the lipid concentration. The presence of lipids in the aggregates improves their resistance to slaking as lipids are hydrophobic.

Hydrophobins: Hydrophobins are a group of small (~100 amino acids) cysteine-rich proteins that are expressed only by filamentous fungi. They are known for their ability to form a hydrophobic (water-repellent) coating on the surface of an object. They were first discovered and separated in *Schizophyllum commune* in 1991.

Chaplins: These is Produced exclusively by gram positive bacterial domain streptomycetes (phylum Actinobacteria) these confer hydrophobic properties to surfaces. The chaplins share a hydrophobic domain of ∼40 residues (“chaplin domain”), and all have a secretion signal. Mass spectrometry of cell wall extracts confirmed that the short chaplins localized to the cell surface.

Soil organic carbon in bulk soils and aggregates under long-term fertilizer experiment



Organic C content in bulk soils and aggregates, as affected by long-term application of compost and mineral fertilizers

Yu, *et al.*,[9] reported mineral fertilizers did not significantly affect macro-aggregation. Long-term application of compost more effectively improved OC content in bulk soil than did long-term mineral fertilizer application; the percentage increase in OC compared with CK was as follows: CM (124%) > HCM (72%) > NPK (27%) > NP (23%). Compared with CK, compost application alone (CM) or in combination with NPK (HCM) increased the OC content in macro-aggregates, micro-aggregates and the silt +clay fractions. Mineral fertilizer amendment also increased the OC content in macro-aggregates and the silt + clay fractions but not in micro-aggregates. The ^{13}C-CPMAS-NMR spectra were slightly different among aggregates within the same treatment group or among treatment groups for the same aggregate, which was clearly revealed by the variation in the relative content and content of C functional groups. According to the content of C functional groups, the increase in phenolic C, carboxyl C and methoxyl/N-alkyl C content (88.8–156.6%) was higher than that of O-alkyl C, di-O-alkyl C, alkyl C (67.3–87.0%) and aromatic C (40.5–48.0%) in macro-aggregates in compost- or NPK-amended soils. Moreover, irrespective of the nature of the amendments, all amendments preferentially promoted the accumulation of carboxyl C in micro-aggregates (46.0–194.1% vs. − 22.9–156.1% for other C functional groups), as well as the accumulation of phenolic C and di-O-alkyl C in the silt + clay fractions (93.5–520.0% vs. − 21.4–314.7% for other C functional groups).

SOC protection in soil aggregates against mineralization in a vertisol

Location	**Carbon content (g/Ckg soil)**	**Mineralised carbon (unprotected) (g/Ckgsoil) ***	**Amount of protected C (g C /kgsoil)**	**Protected C (g/100g C total)**
MG(market garden soil)	12.5	7.2	0.50	4
Pr(soil with organic residues)	20.6	12.5	1.6	7.7
P(soil without organic residues)	38.2	16.8	0.10	0.26

Soil carbon content amount of carbon mineralized and amount of protected carbon from long-term incubations (325days)[1] showed the amount of C-CO_2 evolved from a sample, when the sample is a clod soil, was considered to be the amount of unprotected SOC in this sample. The extra amount of C-CO_2 evolved after crushing the clod soil was considered as the amount of protected SOC in the sample. The considered an amount of protected SOC between clod and 5000m size aggregate and an amount of protected SOC between 5000 and 200m size aggregate. The total amount of C-CO_2 evolved after crushing and sieving the sample at 200m was considered as a pool of total mineralisable SOC in the time of the incubation. The C-CO_2 evolved from the clod samples in 325 days increased with the SOC content from MG, to Pr and to P. The amount of C-CO_2 evolved was 1–1.8 times higher when the samples were crushed at 5000m and to 1–1.6 times when they were crushed at 200m. In general the extra amount of C-CO2 evolved after crushing samples was less in long-term incubation than in short-term incubations. In P plot and one Pr area, this extra amount of C-CO_2 was even null (P) or negative (Pr). In MG, the extra amount of C-CO_2 was significant only when the sample was crushed at 200m. In Pr, it was significant when the sample was crushed at 5000m improve the crushing to 200m did not increase the C-CO_2 evolved more. The fraction of SOC unprotected in clod samples ranged from 2.3 to 6.0gC/100g C soil. It increased to 4.3–10.4gC/100g C soil when the samples were crushed to 200m. This increase was much more important in Pr (from 1.7 to 3.5 times more) than in P and MG samples (only 1.7 times more). The amounts of protected SOC ranged from 0.5to1.7g C/kg soil. These amounts represented a higher proportion of the mineralisable amount of SOC in the pasture in restoration Pr (≈30%) than in a market gardening, MG (19%), or in a pasture installed for a long period, P plot (2%). Nevertheless, the amounts of resistant SOC represented more than 90% of the SOC content in all treatments. This amount of resistant SOC increased with the content of SOC from MG to Pr and to P.

CONCLUSION

- ✓ Among different microbial groups, fungus having higher carbon stabilization capacity followed by bacteria and actinomycetes by making aggregation.
- ✓ Polysaccharide and glomalin contribute more for stabilization compare to other microbial cell component.
- ✓ Meso and Macro Aggregate contain more carbon than micro aggregate.

- ✓ Sucrose as substrate is more efficient in inducing extracellular polysaccharide (EPS) production and aggregation than other substrates.
- ✓ *Lactobacillus sakei*'s (CY1) is more efficient in aggregation formation than the commercial stabilizers like xanthan and chitosan.

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