



SOIL CARBON STABILIZATION: AN AVENUE FOR CARBON SEQUESTRATION

RAJI MOL R P¹, PRABHA SUSAN PHILIP^{2*}, GREENA P G¹

¹Department of Soil science and Agricultural Chemistry, University of Agricultural Sciences, GKVK Bengaluru

²ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Delhi

*Corresponding author, E-mail: prabha0825@gmail.com

Man kind in 21st century faces a series of concerns such as over-population and food shortage, degradation of agricultural land, accumulation of greenhouse gases (GHGs) and climate change, air and water pollution, loss of biodiversity, and genetically modified organisms which are intimately linked to soils. Soil carbon has been recognized as one of the major sources of GHGs in the atmosphere. The atmospheric concentration of carbon dioxide (CO₂) is increasing at an alarming rate. The current atmospheric CO₂ concentration is 410 ppm which alone accounts for 82 percent of GHGs present in the atmosphere. Carbon sequestration and storage in soils provide an important means of reducing GHGs in the atmosphere to mitigate predicted climate change.

Soil is the largest sink for carbon (C) capture and storage. For long term carbon sequestration, stabilization of carbon in soil is a prerequisite process. The fundamental understanding of the stabilization of carbon in soils was emphasized by the Kyoto Protocol in 1992. “Carbon stabilization” is the collective term for mechanisms or processes for maintaining carbon sequestration and storage in an area. Stabilization of carbon means decrease in the potential loss of organic C by microbial respiration, erosion or leaching.

FACTORS AFFECTING CARBON STABILIZATION

Soil texture: The soil with finer fraction stabilizes more organic carbon than that of coarser soil. Chemically stabilized organic carbon mainly occurs through organo-mineral interaction with clay minerals and organic matter. The following figure (figure 1) depicts the relation between carbon stabilization and texture of the soil.

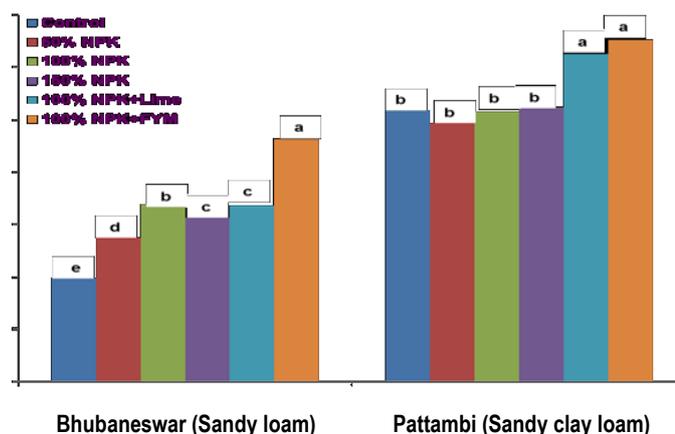


Figure 1: Long-term effect of manuring and fertilization on clay+silt protected C in two Alfisols with different texture (Meena *et al.*, 2017)

Type of clay mineral: Organic carbon accumulation and C stabilization will be more in smectite than kaolinite.

Presence of amorphous oxide: The sorption capacity of kaolinitic clay increases significantly with goethite coating. Presence of goethite reduces desorption of dissolved organic carbon (DOC) from kaolinitic clays but does not influence desorption from illitic and smectitic clays. The interactions of hydrous iron oxides and phyllosilicate clays can modify DOC sorption and desorption, probably by affecting the specific surface area (SSA) and charge (Kleber *et al.*, 2005).



Land use: The type of land use affect C stabilization. In grasslands, physical protection of C by macro and micro aggregates prevails whereas in forest soils clay particles facilitate higher organic C stabilization.

Type of organic matter added: Stabilization of decomposed organic matter is more than that of fresh organic matter (Karsten et al., 2005).

MECHANISMS OF CARBON STABILIZATION

Current proposed mechanisms of soil C stabilization are grouped into physical, chemical and chemical/bio-chemical protection mechanisms or their combinations.

Physical stabilization: These mechanisms are largely arose from the interactions of soil organic carbon (SOC) with soil mineral matrix forming strong chemical bonds or making soil C inaccessible to decomposer organisms or their enzymes. As much as half of the total soil organic matter (SOM) is maintained and protected in soils by these mechanisms (Elliott et al., 1996). Stevenson (1994) ascribed two major groups of mechanisms responsible for the retention of organic substances (e.g. pesticides) and soil C by clay minerals. These are (1) physico-chemical stabilization by sorption of organic matter to clay surfaces (e.g. cation and anion exchange, polyvalent cation bridging, H-bonding) forming organo mineral complexes and (2) physical stabilization by the penetration of organic matter into interlayer spaces of expanding clay minerals thereby encapsulate and shield the organic matter, inhibiting its accessibility to degrading soil micro-organisms or their enzymes.

Chemical stabilization: Soil organic matter (OM) can be stabilized against decomposition by association with minerals, by its inherent recalcitrance and by occlusion in aggregates. These mechanisms are attributed to the production of charcoal (or black C) by fires and biologically inert or recalcitrant and refractory compounds, and very slowly decomposable humic substances (HS) and organic compounds such as lipids (e.g. waxes, cutins, subelins) and chitin by plants, soil fauna, and soil micro-organisms.

Biological stabilization: Though several biological mechanisms and processes have been proposed the extent and relative significance of these mechanisms

are still unclear. Mechanisms through which SOC can be biologically stabilized depend on the decomposition of soil mineral phase and the chemical structure of organic residues added to the soil. These include the classical model of aggregate formation and organization in which micro-aggregates are bound together by roots and fungal hyphae and transient (polysaccharides) agents. Among these methods, C stabilization through organo-mineral complexes deserves special attention as it contributes too much of the C stabilization in the soil. Organo-mineral complexes are the complexes formed between organic and mineral matter by certain linkages. The association of organic matter leads to the formation of secondary organo-mineral complexes. The various bonding mechanisms present in organo-mineral complexes can be H bonding, ligand exchange, bridges of polyvalent cations, Van der Waals forces, hydrophobic interactions etc.

MODELS FOR ORGANO-MINERAL INTERACTION

Popular models for the organo-mineral associations are presented below

Wershaw Bilayer Model: The soluble mixtures of organic molecules representing a significant fraction of SOM can form organized structures called micelles within aqueous solution, structures that consist of hydrophilic exterior regions that shield hydrophobic interiors from contact with water molecules. Because amphiphilic molecules are requisite to the formation of micelles, the ability of SOM components to form these structures suggests that many of these molecules are amphiphilic. Significant to this insight, Wershaw et al. (1996) previously developed a bilayer model of organo-mineral interactions (Figure 2) that sharply contrasted with the traditional view of organo-mineral interactions, which were visualized as associations of large, multifunctional polymers with mineral surfaces via a broad range of bonding mechanisms.

Zonal model: The zonal structure of organo-mineral associations (Figure 3), based on the amphiphilicity of SOM fragments, and the intimate involvement of proteinaceous compounds in stable organo-mineral associations, defined here as a structure formed when the organic matter attached to a mineral surface



is segregated into more than one layer or zone of molecules, such that not all adsorbed molecules are in contact with the mineral surface. Assuming such a zonal structure, the scientists are able to account simultaneously for a number of phenomena observed in soils and sediments.

Micro aggregate model: Organo-mineral interactions manifest themselves primarily as organic surface coatings on clay particles, which can be considered an aggregate when sandwiched between two clay particles (Fig. 5). From that perspective, the interaction with mineral surfaces or the protection by its location between minerals confers more stability to the organic matter.

CONCLUSION

Carbon stabilization can combat climate change since the process helps to sequester and store the carbon in soil and thereby prevents the mineralization of carbon. Even though the mechanisms underlying the carbon stabilization still remain unclear, more than half of the total soil carbon is protected by physical stabilization. Organo-mineral complexes play a major role in carbon stabilization. Physical stabilization and protection mechanisms such as occlusion to the surface of microaggregates and incorporation into organo-mineral complexes are prevailing mechanisms for long term carbon storage. The complex formed between

short range order Fe -oxides and C contribute to major stabilization of C in the terrestrial ecosystem.

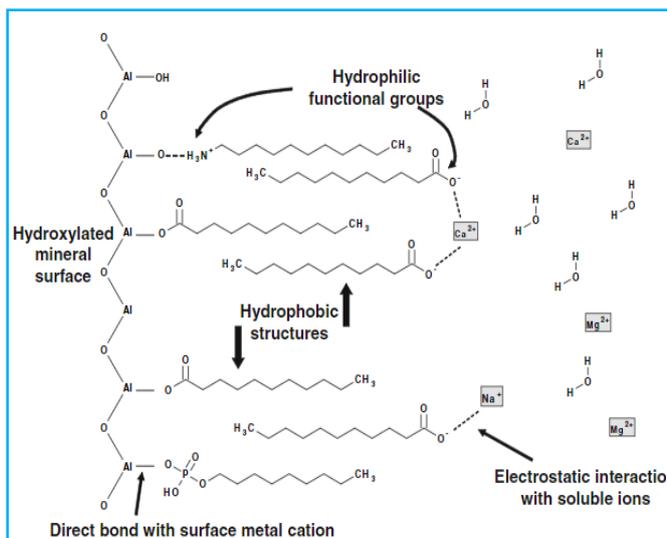


Figure 2. Wershaw bilayer model (Wershaw *et al.*, 1996)

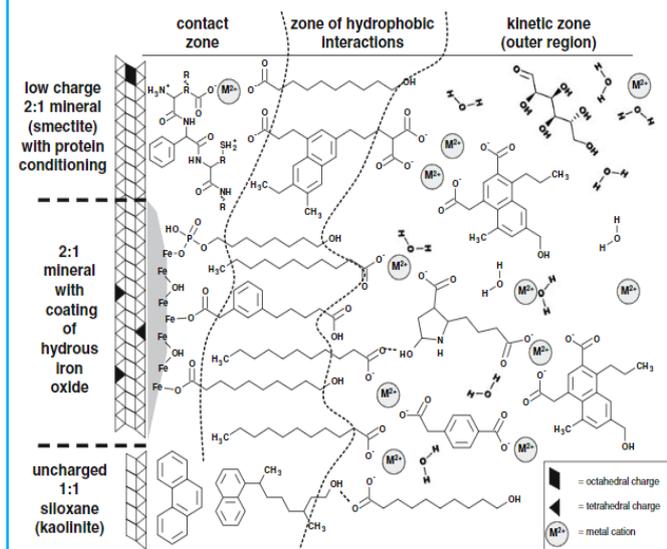


Figure 3. Zonal model (Kleber *et al.*, 2007)

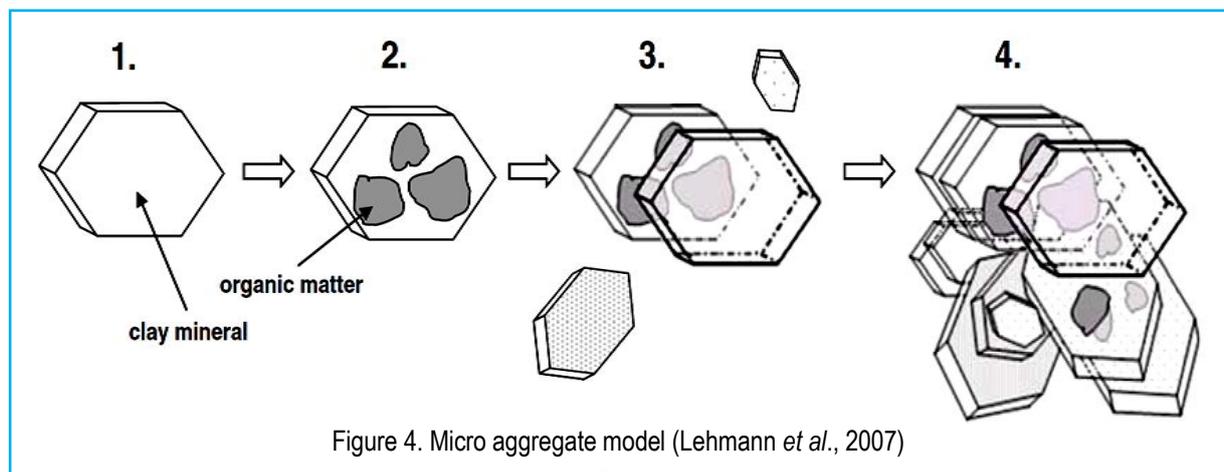


Figure 4. Micro aggregate model (Lehmann *et al.*, 2007)



REFERENCES

- Elliott, E.T., Paustian, K. and Frey, S.D., 1996, Modeling the measurable or measuring the modelable: Hierarchical approach to isolating meaningful soil organic matter fractions. *In* Evaluation of Soil Organic Matter Models, Ed. DS Powlson, P Smith, and JU Smith, p. 161-179, Springer-Verlag, Berlin.
- Kartson, R., Mikutta, C., Kalbitz, K., Scheel, T., Kaiser, K., and Jahn, R., 2007. Biodegradation of forest floor organic matter bound to minerals via different binding mechanisms. *Geochimica et Cosmochimica Acta*, 71(10): 2569-2590.
- Kleber, M., Sollins, P., and Sutton, R., 2007. A conceptual model of organo-mineral interactions in soils: self-assembly of organic molecular fragments into zonal structures on mineral surfaces. *Biogeochem.*, 85(1): 9-24.
- Lehmann, J., Kinyangi, J. and Solomon., D., 2007, Organic matter stabilization in soil microaggregates: Implications from spatial heterogeneity of organic carbon contents and carbon forms. *Biogeochem.*, 85(1): 45-57.
- Meena, R. K., Verma, A. K., Kumawat, C., Yadav, B., Pawar, A. B. and Trivedi, V. K., 2017, Impact of clay mineralogy on stabilization of soil organic carbon for long-term carbon sequestration. *Int. J. Curr. Microbiol. Appl. Sci.*, 6(5): 2157-2167.
- Stevenson, F.J., 1994, Humus chemistry, genesis, composition, reactions, p. 429-471, John Wiley, New York.
- Wershwa. R.L., Liaguno, E.C., Leenheer, J.A., Sperline, R.P., Song, Y., 1996, Mechanism of formation of humus coatings on mineral surfaces 1. Evidence for multi dentate binding of organic acids from compost leachate on alumina. *Coll. Surf A: Physiochem Eng Aspects* 96: 93- 104.
