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Building Super Soil: The Contribution of Soil Organic Matter, Soil Organic Carbon, and Soil Organic Nitrogen

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Introduction

Soil organic matter (SOM) is an essential indicator (often regarded as the most important indicator) of soil health. As the organic fraction of the soil (usually ranging from 3-8% of the total soil mass), SOM comprises partially decomposed remains of plants, animals, insects, and microorganisms. Soil organic carbon (SOC) and soil organic nitrogen (SON) are the two major components of SOM, as most organic material consists of two primary elements, carbon (C) and nitrogen (N). The portion of SOM that consists of organic carbon molecules is considered SOC, while that consisting of organic nitrogen forms is regarded as SON. Therefore, not only SOM, but its components SOC and SON, should be monitored and maintained to create soil that is optimal for overall ecosystem health (Figure 1). In this context, it is worth noting that inorganic carbon (in the form of carbonates and bicarbonates) and nitrogen (in the form of nitrates) fractions are also essential to understand soil health.

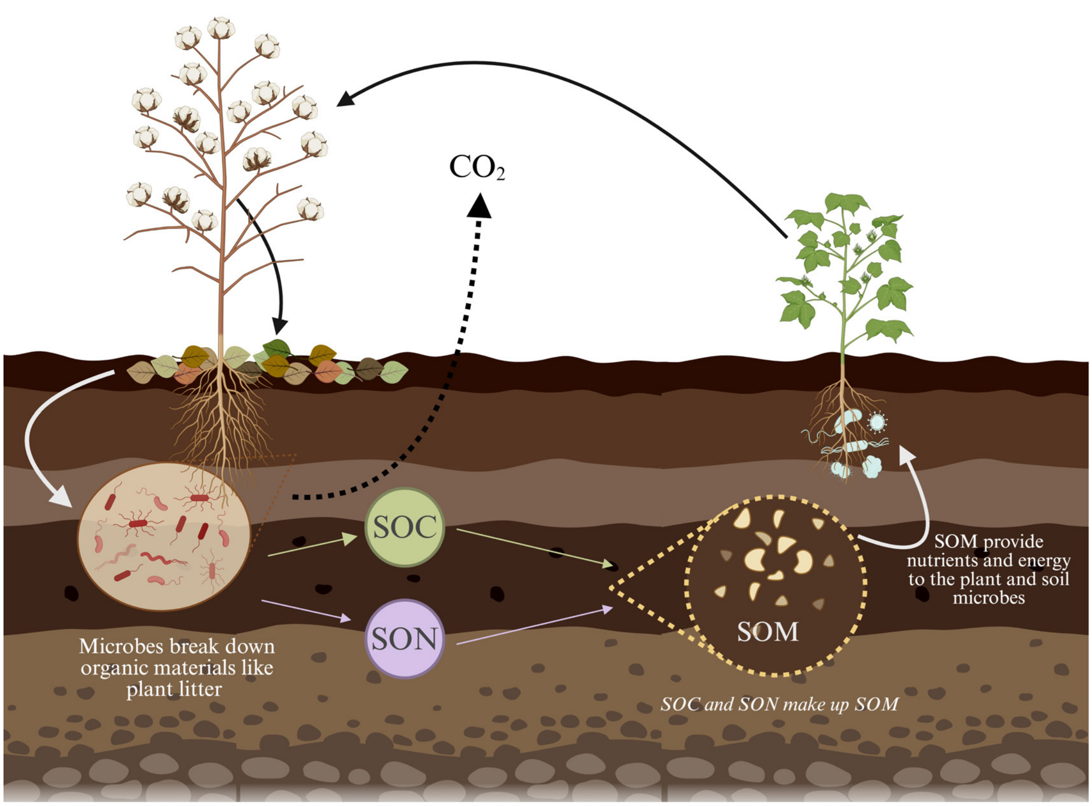

Figure 1. The conceptual diagram shows how soil microbes break down plant or animal debris into soil organic carbon (SOC) and nitrogen (SON) forms, which contribute to soil organic matter (SOM) storage. Microbes and plants access the nutrients available from the decomposition of SOM for nutrition and growth, allowing the cycle to continue (the illustrative diagram was developed in BioRender: https://BioRender.com/xt71p7x).

The Role of SOM, SOC, and SON in Soil Health

Soil microbes utilize SOM as a nutrient and energy source as required for their survival and growth, which leads to the decomposition of SOM and the release of carbon dioxide (CO_2). Partially decomposed SOM contains essential carbon molecules and plant-available nutrients as byproducts, which in turn serve as food for other soil organisms undergoing further decomposition. This process releases vital carbonaceous compounds that enhance soil aggregation, improve soil structure, and help in the retention of water and the availability of essential plant nutrients, which provide ideal conditions for plant growth. Besides soil microbes and plants, other soil organisms, such as earthworms and burrowing animals, also depend directly or indirectly on SOM to thrive in the soil ecosystems. Many of these organisms are crucial for maintaining a healthy ecosystem.

Soil Organic Carbon plays a significant role in carbon sequestration. Carbon sequestration is the process of capturing and storing CO_2 from the atmosphere or industrial sources, thus reducing it in the atmosphere. Plants contribute to this process through photosynthesis, by converting sunlight, water, and CO_2 into glucose which is the primary source of energy used in plant growth. When plants or other organisms die, the biomass gets incorporated into the soil, and the carbon within the biomass is transferred to the soil as SOC. Microbes convert carbon into a stable form which may be stored long-term helping lower atmospheric CO_2. Even small increases in SOC over agricultural fields could assist in reducing atmospheric carbon dioxide (Lal, 2009).

Soil Organic Nitrogen is an environmentally friendly source of plant-available nitrogen and, therefore, is essential for nutrient cycling. Nitrogen is the most crucial nutrient for plant growth and crop production. SON undergoes a cycle of microbial transformations within the soil. As microbes decompose SOM, nitrate is produced as a byproduct, which is the primary nitrogen form that can be utilized by plants. Many plants can also uptake ammonium-nitrogen also. So, plants take up nitrogen from the soil, animals eat plants, and finally, nitrogen is returned to the soil in waste and when animals and plants die and decompose. The combination of SOM, SOC, and SON forms a continuous loop that cycles carbon, nitrogen, and other nutrients in the soil-plant/animal-atmosphere continuum creating a resilient ecosystem. Most commercial laboratories recommend testing soil nitrate levels to support making informed decisions about nitrogen fertilization needs.

Assessing SOM, SOC, and SON

Several assessment methods can be used to determine whether SOM, SOC, and SON levels are improving or declining. We will discuss several key soil health indicators in the following sections.

a. **Soil Testing:** Regular soil testing is the most direct way to measure SOM, SOC, and SON levels. The Cornell Cooperative Extension (2023) resource emphasizes that soil tests should include measurements of SOC, as it is a key indicator of soil health and productivity. Laboratories can analyze soil samples to determine percentages of organic matter, soil organic and inorganic carbon, and soil organic and inorganic nitrogen forms. These types of tests usually provide the baseline information for soil health and determine if other tests are required, such as:

   - **Permanganate Oxidizable Carbon (POXC):** POXC is a soil health test that measures a microbially available portion of SOC. It is a highly sensitive indicator of changes in SOC and can help assess management practices on soil health (Culman et al., 2012). Refer to the article on POXC found in the link below:

     https://extension.arizona.edu/publication/understanding-pox-c-carbon-catalyst-soil-biological-health

   - **Potentially Mineralizable Nitrogen (PMN):** PMN measures the amount of SON that can be transformed into plant-available soil nitrate form by soil microbes. It also provides information about the soil's capacity to provide nitrate-nitrogen to plants, which is important to understand the nutrient cycling within the soil (Haney et al., 2018).

b. **Field Observations:** Farmers can observe changes in soil color, texture, and plant health. Dark, crumbly soil with good soil structure (Figure 2) is often an indicator of high SOM, while pale, compacted soil likely indicates low SOM. The presence of earthworms and other beneficial organisms indicates a healthy soil ecosystem.

Figure 2. Dark, rich soil containing earth worms is a great visual indicator of healthy soil organic matter, which typically correlates with good levels of soil organic carbon and nitrogen. Lab tests will help confirm these visual observations (Image credit: Debankur Sanyal).

Well-drained or well-aerated soils where water can infiltrate quickly are also considered healthy soils. Another important factor is soil erosion, especially in the southwest. An eroded soil where wind easily blows topsoil also indicates poor or unhealthy soil conditions.

Practices to Improve and Manage SOM, SOC, and SON

Maintaining and enhancing SOM, SOC, and SON requires adopting sustainable soil management practices:

a. **Conservation Tillage:** Tilling is the process of preparing the soil for subsequent crops by plowing. This also clears the field of prior crop residues and weeds and helps prepare a fine seedbed for improved seed germination and crop stand. Conservation tillage is a practice of tilling the soil with minimal disturbance. This is mainly done by reducing the depth of tillage or keeping a section of the soil untilled. The extreme form of conservation tillage is known as 'zero tillage' or 'no tillage', where tillage operation is completely avoided and the next crop is seeded and grown on the residues of the previous crop, soon after the harvest. While conventional tillage breaks down soil aggregates and soil structure in the process, and delays soil organic matter buildup, conservation tillage minimizes soil disturbance, preserves soil structure, and reduces soil carbon loss. Incorporation of previous crop residues in the soil during conservation tillage can increase organic matter levels, which in turn enhances SOC levels (Blanco-Canqui & Lal, 2008).

b. **Cover Cropping:** Planting cover crops in a rotation to avoid fallow periods helps protect the soil from erosion, improves water retention, and adds organic matter. Legume cover crop species convert the gaseous form of nitrogen from the atmosphere into nitrogen compounds that are more readily available to plants, increasing SON levels (Snapp et al., 2005). Cover crops can improve soil structure and increase SOM, particularly in organic farming systems. Additionally, cover crops can help in carbon sequestration as well; more information available in the following article:https://extension.arizona.edu/publication/cover-crops-and-carbon-sequestration-perspective-desert-soils.

Conclusion

Soil organic matter, soil organic carbon, and soil organic nitrogen are fundamental to soil health and overall ecosystem sustainability. By consistently assessing SOM, SOC, and SON levels by utilizing soil health tests and adopting sustainable agricultural practices, farmers can improve soil health, facilitate carbon sequestration, and support more productive agricultural systems. All these efforts contribute to more widespread environmental goals like mitigating climate change and preserving essential biodiversity.

Additional reading

Cornell Cooperative Extension. (2008). Soil organic matter fact sheet. Franklin County CCE. https://franklin.cce.cornell.edu/resources/soil-organic-matter-fact-sheet

Oklahoma State University Extension. (2017). Building soil organic matter for a sustainable organic crop production. https://extension.okstate.edu/fact-sheets/building-soil-organic-matter-for-a-sustainable-organic-crop-production.html

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This information has been reviewed by University faculty.
extension.arizona.edu/pubs/az2151-2025.pdf

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extension.arizona.edu/pubs