Soil Organic Matter

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Introduction

Soil organic matter (SOM) is a complex mixture of plant and animal tissues in various stages of breakdown (decomposition). SOM is one of the primary indicators of overall soil health as it plays an important role in the physical, chemical, and biological processes in the soil. SOM often represents a small portion of the overall weight of a soil, ranging from less than 0.5% to over 5%, but it contributes greatly to the ability of the soil to retain and supply water and nutrients to plants. The goal of this publication is to briefly describe how SOM contributes to overall soil fertility, factors controlling SOM abundance, and what cultivation practices growers can use to increase SOM in their soils.

What is Soil Organic Matter?

Soil organic matter is composed of living organisms, including bacteria, fungi, plant roots, insects, earthworms, and other animals that reside in the soil; nonliving materials, including plant and animal residues that can be decomposed by the living components; and ***humus***, which is the stable portion of remaining organic material that resists decomposition.

Roles of Soil Organic Matter

Supplies Essential Plant Nutrients

SOM consists of approximately 58% carbon, which serves as an energy source for soil microbes. Having an abundant and diverse community of soil microorganisms plays an important role in overall soil health and fertility. During the breakdown of SOM, critical plant nutrients are released and become available for plant uptake. The main nutrients provided through this mechanism are the essential plant macronutrients nitrogen, phosphorus, and sulfur. Soil microbes can increase soil fertility in other ways as well, such as making phosphorus more available to the plants or converting (fixing) nitrogen from the atmosphere into a plant-available form.

The ability and speed at which a residue releases plant-available nutrients largely depends on the ratio of carbon (C) and nitrogen (N) within the residue itself (Table 1). As microorganisms break down organic matter, they need a fraction of the carbon released for their own growth, typically around 30%, with the remaining 70% being released as carbon dioxide (CO_2). Thus, a residue with a carbon to nitrogen ratio (C:N) of 20:1 can provide microorganisms with six units of C (30% of 20 = 6) per unit of N, which is a typical C:N ratio of soil bacteria. In that case, no N becomes available for the plant as the net 6:1 C:N ratio matches the needs of the bacteria, and all the released N is used by the microorganism (see Table 2).

Residues containing a lower C:N ratio (≤ 10:1) have more nitrogen per unit of carbon than the microbes need themselves, and therefore decomposition proceeds quickly and results in the release of nitrogen. This process is known as ***mineralization***. On the other hand, when the organic residues contains a C:N ratio greater than 20, say 50:1, decomposition will proceed very slowly and the microbes will require an additional nitrogen source to completely break down the residue. This normally results in the microorganisms taking up nitrogen from the soil, thereby decreasing the amount of plant-available nitrogen. This process is known as ***immobilization***.

Table 1. Normal Carbon to Nitrogen Ratios for Many Common Plant and Animal Residues.

Material	C:N Ratio
Sawdust	100–500:1
Wheat, rye, or oat straw	80:1
Leaves	60:1
Mature cereal rye	40:1
Crimson clover	28:1
Grass clippings	15–25:1
Dairy manure	17:1
Food waste	15–20:1
Poultry litter	14:1
Alfalfa hay	12:1

Note. See references for more information and sources for these values.

Table 2. Comparison of Nitrogen Resulting From the Microbial Breakdown of Common Residues.

Residue material	C:N ratio	Units of C available to the microorganisms[1]	Net units of N from decomposition[2]	Mineralization or immobilization of N
Poultry litter	14:1	4.2	0.3	Mineralization
Food waste	20:1	6	0	Equilibrium
Leaves	60:1	18	-2	Immobilization
Wheat hay	80:1	24	-3	Immobilization

Note.
[1] Assumes a microbial efficiency of 30%, where the remaining 70% is evolved as CO_2.
[2] Assumes a microorganism C:N requirement of 6:1.

Improves Soil Chemical Properties

In addition to improving soil fertility by releasing plant nutrients during decomposition, SOM contributes substantially to soil ***cation exchange capacity*** (CEC; which is the relative ability of a soil to retain and supply positively charged cations), which is related to the ability of a soil to retain and supply nutrients to plant roots. The CEC associated with SOM originates from the negative charges commonly associated with organic materials. Just like a magnet where opposite charges attract, these negative charges are capable of loosely holding positively charged plant nutrients (***cations***) like K^+, Mg^{2+}, NH^{4+}, and Ca^{2+}.

As plants take up cations from the soil solution, some of the cations retained by the negative charges are released and become available for plant uptake (see Figure 1). However, because the CEC of SOM comes from the negative charges on the particle surface, soil pH must be closely monitored—under acidic soil conditions, hydrogen ions (H+) available in the soil solution can bind with the negative charges on the organic material, eliminating some of the CEC.

The negative charges associated with SOM also increases the pH-buffer capacity of the soil. These binding sites serve as a reservoir to release H^+ at a high soil pH and a sink for excess H+ in the soil at a low pH, which allows the soil to resist sudden changes in pH.

Additionally, some of the organic compounds contained within SOM are able to form ***chelates*** (pronounced key-lates; when ions or molecules combine with metal ions) with certain essential plant nutrients, like iron, zinc, and

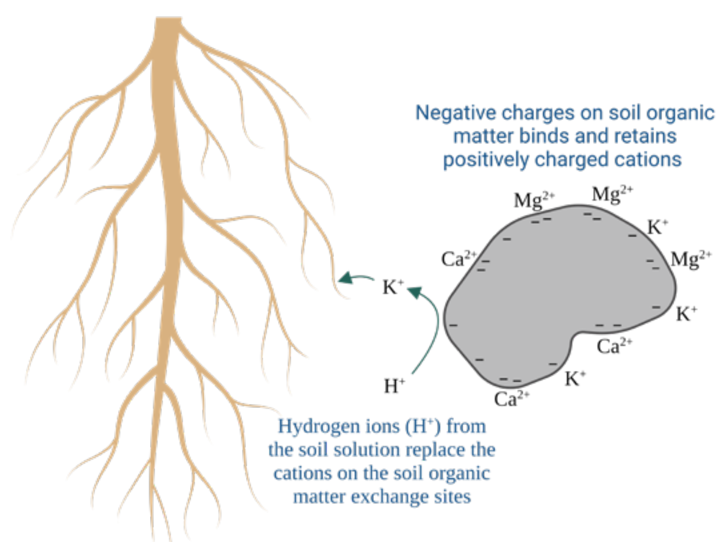

Figure 1. Cation Exchange Between Hydrogen Ions and Soil Organic Matter.

manganese. This chelation process retains these critical nutrients in the soil solution, where they are accessible for plant uptake. In soils with low SOM, these critical micronutrients can be bound up by soil particles or be leached out of the soil solution, which may lead to plant deficiencies.

Improves Soil Physical Properties

Soil organic matter also serves an important role in soil aggregate stability, as humus, microbes, and plant residues help to bind soil particles into larger, more structured aggregates. These aggregates increase the soil porosity, which improves the movement of air and water into the soil. Additionally, SOM reduces bulk density and improves the overall water-holding capacity of the soil, making crops grown in high SOM soils more resilient under drought conditions. In fact, increasing the SOM from 0.5–3% more than doubles the available water capacity of the soil.

Factors Controlling the Amount of Soil Organic Matter

The amount of SOM contained in soil is dependent not only on the amount of inputs from plant residues, manures, and composted materials, but also on losses through decomposition and soil erosion. In order for organic matter to accumulate in soil, the inputs must exceed the losses. Because soil organic matter comes from crop and root residue additions to the soil surface, the concentration of SOM is generally greater near the soil surface and declines deeper into the soil profile.

The rate of organic matter loss in soils is determined by the rate of decomposition by microorganisms. Microbes thrive in climates with warm, wet conditions. Because of this, SOM tends to be lower in the warmer southern states, like Georgia, compared with soils from more northern areas of the United States. While these conditions are also conducive to plant growth (and thus sources of organic matter), as long as the microbial activity remains high throughout the year, the losses will always exceed the inputs.

Climates that are favorable for SOM accumulation have warm wet periods and extremely cold periods. Water availability limits plant production in drier regions, and therefore reduces the amount of organic matter being returned to the soil in the form of plant residues. As water becomes more available, plant production increases, which results in higher organic matter inputs to the soil. Additionally, soil microbes require oxygen to decompose SOM, so when precipitation rates continue increasing to the point of soil saturation, the rate of decomposition slows. Consequently, in swampy areas where plant productivity is relatively high and oxygen in the soil remains quite low because of saturation, SOM tends to accumulate.

Soil particle size, known as soil texture, is involved in many of the physical and chemical properties of the soil, including the decomposition rate of SOM. Soil particles are classified based on size as either sand, silt, or clay, with sand (0.05–2 mm) being the largest particle and clay particles the smallest (less than 0.0002 mm). The small size of clay allows these particles to encase organic matter in a

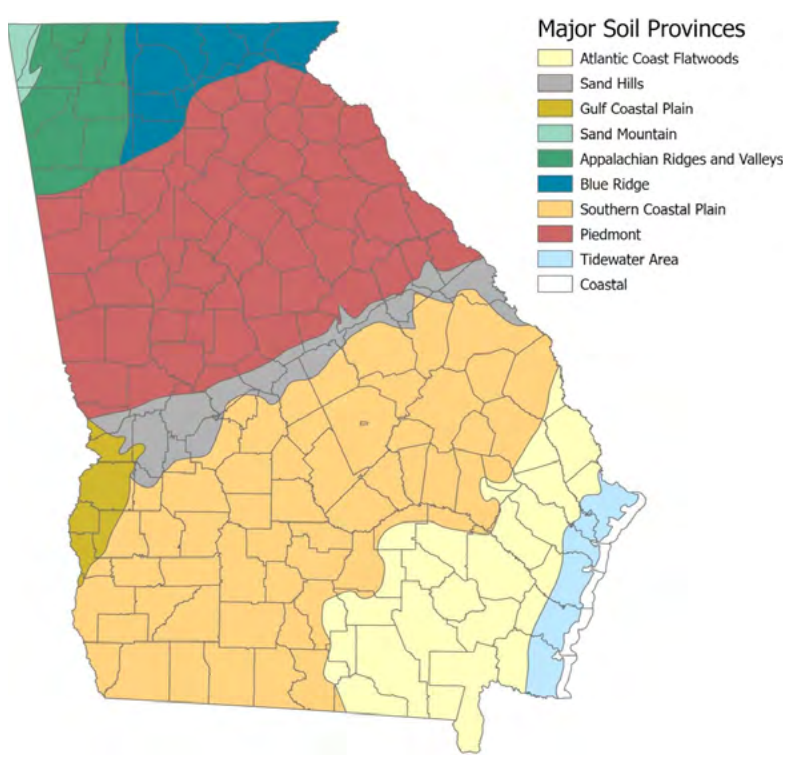

Figure 2. Map Showing the Distribution of the Major Soil Provinces in Georgia.

protective film, which slows microbial decomposition. Meanwhile, SOM in sandy soils remains unprotected and freely exposed to microbial decomposition, and therefore sandy soils generally have lower SOM content.

As a result of the warm, humid climate, cultivated surface soils in Georgia generally contain relatively low SOM, ranging from 0.5–2%. Soils in the northern part of Georgia, which are generally classified as the Piedmont, Blue Ridge, or Appalachian Ridges and Valleys (Figure 2), contain more clay and have slightly cooler climates than the southern areas of the state and therefore generally contain higher SOM.

Soils in the Atlantic Coast Flatwoods, Sand Hills, and Southern Coastal Plain regions are characterized by very high sand content in the surface soil horizons and often contain very low (≤ 1%) SOM, especially in fields managed using conventional tillage practices.

Table 3 compares the median SOM content from soils analyzed by the UGA Agricultural and Environmental Services Laboratories between 2015–2023. Peanuts and cotton, which are mainly grown in the southern portion of the state under conventional tillage, had a median SOM of 1.2%. Meanwhile, median SOM content from perennial fescue and Bermuda pastures, which are grown under systems where soils remain covered year-round and do not undergo tillage, were 3.8 and 4.2, respectively.

Table 3. Soil Organic Matter (SOM) Content Based on Crop, 2015–2023.

Crop	Number of Samples	Median SOM Content (%)
Peanut	156	1.2
Cotton	101	1.2
Fescue pasture	135	3.8
Bermuda pasture	96	4.2

Note. Median data based on soils analyzed by the UGA Agricultural and Environmental Services Laboratories.

Cultivation Practices to Increase Soil Organic Matter Content

1. Minimize soil structure disturbance by practicing no-till or conservation tillage practice. Soil structure is disturbed during tilling which allows SOM that was previously protected within soil aggregates to become accessible to decomposition by soil microbes (see Figure 3).
2. Use cover crops to reduce erosion and evaporation and ensure that a continual supply of root material and plant residues enter the soil.
3. Use manures and composts to provide needed plant nutrients and supply organic matter.
4. Add nitrogen-fixing legumes and deep-rooted crops in crop rotations.
5. Avoid running equipment over wet soils to prevent soil compaction.
6. Maintain good soil fertility and diverse soil microbiological communities through proper pH and nutrient management.

Figure 3. Common Practices That Increase Soil Organic Matter.

Adding poultry litter (left), crimson clover cover crop (middle), no-till soybeans planted in previous crop residue (right).

Photos: (left) David Dickens, University of Georgia, Bugwood.org; (middle) Rebekah D. Wallace, University of Georgia, Bugwood.com; (right) Gerald Holmes, Strawberry Center, Cal Poly San Luis Obispo, Bugwood.org.

Testing Soil Organic Matter

SOM is determined by heating a soil sample to a very high temperature (~1,000 °F), which burns off all carbon contained in the sample. The sample weight is then compared to the original weight prior to heating, with the proportion of weight lost being attributed to soil carbon.

Many commercial soil testing labs offer SOM analysis services, including the UGA Agricultural and Environmental Services Laboratories (AESL). Soil samples can be submitted to AESL through your local county Extension office (https://extension.uga.edu/county-offices.html).

Samples should include a completed sample submission form, which can be found on the AESL website (https://aesl.ces.uga.edu/forms; click on Soil Submission Form to download it). Write "organic matter (S6)" in the space provided for specifying requested tests.

Conclusions

Soil organic matter contributes significantly to the overall health and fertility of the soil. While soils in Georgia are generally low in SOM, even moderate increases in SOM can have dramatic economic and ecological benefits. However, making meaningful increases to SOM takes years, if not decades, so strategic planning and a commitment to improving SOM are needed for success. Nevertheless, by understanding the importance of SOM for soil fertility and incorporating a few of the management practices outlined here (e.g., increasing plant residue inputs, reducing tillage, rotating crops, and using cover crops), producers can begin a path towards healthier, more productive soils.

Glossary

Cation exchange capacity: the relative ability of soil to retain and supply positively charged cations.

Chelate: a compound that has a ring structure and usually contains a metal ion held by coordinate bonds.

Conservation tillage: any tillage and planting practice that results in greater than or equal to 30% of soil coverage in crop residue.

Humus: the portion of soil organic matter that remains after microbial decomposition.

Immobilization: when the organic residues contains a C:N ratio greater than 20, decomposition proceeds very slowly and the microbes require an additional nitrogen source to completely break down the residue. This normally results in the microorganisms taking up nitrogen from the soil, thereby decreasing the amount of plant-available nitrogen.

Mineralization: when residues contain a lower C:N ratio and have more nitrogen per unit of carbon than the microbes need themselves, decomposition proceeds quickly and results in the release of nitrogen.

No-till: when less than or equal to one third of the row width is distribured during planitng; other wise, soil is left undisturbed by tillage for the entire year.

Soil aggregate stability: the ability to regulate movement and storage of water and air through the soil profile.

Soil texture: the relative proportion of the soil's mineral fraction made up of sand, silt, and clay particles.

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