# soil Organic Matter

Soil Health – Guides for Educators

United States Department of Agriculture
Natural Resources Conservation Service

Soil organic matter (SOM) is necessary for all soil functions, and it is the most important indicator of soil health. It is the organic component of soil. It consists of varying proportions of small plant residue (fresh), small living soil organisms, decomposing (active) organic matter, and stable organic matter (humus) in varying stages (fig. 1). SOM is a mineralizable source of nutrients for crops. It increases the availability of most nutrients, buffers the effects of high acidity, increases the available water capacity and moisture retention of the soil, helps to minimize compaction and surface crusting, increases water infiltration, provides food for micro-organisms that facilitate the availability of nutrients, holds soil aggregates together, decomposes pesticides, and acts as a carbon sink.

The content of SOM can be estimated in the field and/or in a lab. The results can be used to estimate the amount of mineralized nitrogen, phosphorus, and sulfur available for crop production, which is needed to determine the appropriate application of fertilizers. As SOM increases, the buffering capacity of the soil also increases. Thus, the amount of surface-applied herbicides needed to effectively control weeds increases, the potential for herbicide carryover for future crops decreases, and the amount of lime needed to raise pH increases.

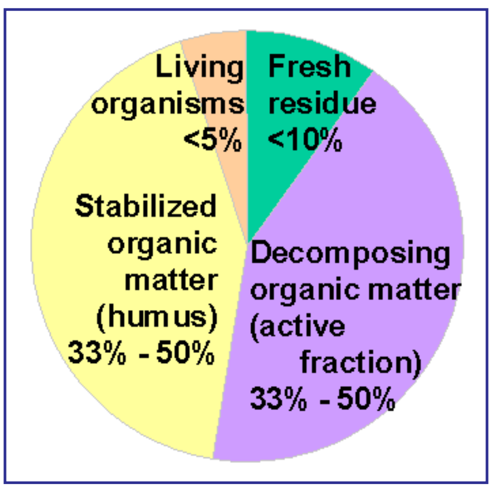


Figure 1.—Major components of soil organic matter (Source: Soil Food Web; USDA, NRCS).

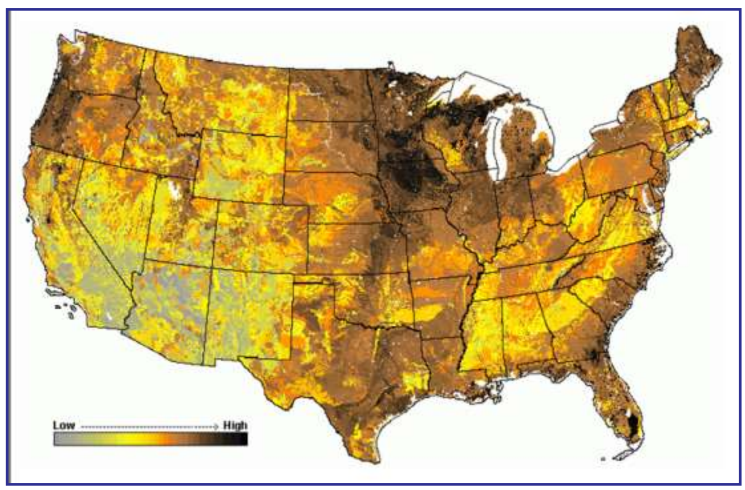


Figure 2.—Soil organic matter content (from the SSURGO database [USDA, NRCS]).

## Inherent Factors Affecting Soil Organic Matter

Inherent factors affecting soil organic matter include climate and soil texture and clay mineralogy. Climatic conditions, such as rainfall and temperature, and soil moisture and aeration (oxygen levels) affect the rate of organic matter decomposition. Organic matter decomposes faster in warm, humid climates and slower in cool, dry climates. It also decomposes faster when the soil is well aerated (higher oxygen level) and much slower when the soil is saturated (lower oxygen level). Decomposition is maximized when the soil is tilled, providing optimal oxygen for microbial activity. For more information, refer to figure 2 in the "Soil Respiration" guide for educators.

Soils that support grass vegetation (prairie) commonly have at least twice as much organic matter as those that support forest vegetation. Both the top growth and roots of grass vegetation dies continually each growing season, adding organic matter to the upper part of the soil. Soils that support forest vegetation commonly have relatively low organic matter content as a result of the following:

1. Trees produce a much smaller root mass per acre than do grasses.
2. Trees do not die back and decompose annually. Much of the organic matter in a forest is tied up in the wood of the trees and thus is not returned to the soil.

Figure 2 (page 1) is a general map of the soil organic matter distribution across the United States. The darker the area, the higher the organic matter content.

## Soil Organic Matter Management

Under a given set of site conditions, SOM generally is highest in areas where soil disturbance is minimized, biomass production is higher, and organic material is added to the soil. Plant residue that has a low C:N ratio (high nitrogen content) decomposes more quickly than residue with a high C:N ratio, and it does not increase the content of SOM as quickly. Excessive tillage destroys soil aggregates, increasing the rate of decomposition of SOM. Stable soil aggregates have a higher content of active organic matter with less rapid microbial decomposition. Measures that increase soil moisture and temperature and optimize aeration accelerate the decomposition of SOM.

Management practices can either degrade or increase SOM. Some key practices that can help to increase or maintain the content of SOM are:

- *Using cropping systems* that incorporate continuous no-till, cover crops, solid manure or other organic material, and diverse rotations that include high-residue crops and perennial legumes or grasses.
- *Minimizing or eliminating tillage* that results in microbial activity, increasing the rate of organic matter decomposition and the risk of erosion.
- *Minimizing erosion*, which helps to maintain the content of SOM. Most SOM is in the upper part of the soil; thus, the content is reduced when the soil erodes.
- *Properly fertilizing* according to results of soil tests. Proper fertilization encourages the growth of plants. Root and top growth can help to increase or maintain the content of SOM, even if much of the top growth is removed.
- *Using perennial forage plants* to provide for annual dieback and regrowth of perennial grasses. The fibrous root systems of perennial grasses are particularly effective as a binding agent in soil aggregation. The extensive root systems and biomass of perennial forage plants also contribute organic matter to the soil.

# Relationship of Soil Organic Matter to Soil Functions

Under average conditions in temperate regions, approximately 1.5 percent of SOM mineralizes annually (2 percent for spring-planted row crops, 1 percent for small grain, and 0.5 percent for perennial grass; Ray Ward, 2012) and the content of SOM can be maintained at current levels in soils that have 2 to 5 percent SOM (Doran, 2012). Mineralization rates and loss of SOM can increase dramatically under certain temperature, aeration, and moisture conditions.

**Key soil functions for which SOM is needed include:**

- *Nutrient supply.*—When SOM decomposes, nutrients are released and are available for plant use. Each percentage of SOM in the upper 6 inches (15.2 cm) of a medium textured soil (silt or loam with a bulk density of 1.2) releases about 10 to 20 pounds of nitrogen, 1 to 2 pounds of phosphorus, and 0.4 to 0.8 pounds of sulfur per acre per year. SOM maintains a supply of many nutrients for plant use (if the soil is not too acid), minimizes leaching of nutrients, and increases the availability of some nutrients.
- *Available water capacity*.—Organic matter acts similarly to a sponge. It can absorb and hold as much as 90 percent of its weight in water. Organic matter also releases nearly all of its stored water for plant use. In contrast, clay holds high quantities of water but much of it is unavailable to plants.
- *Soil aggregation*.—Organic matter contributes to soil aggregation, which improves soil structure. Better soil structure increases the infiltration of water through the soil and improves the ability of the soil to take in and hold water.
- *Erosion*.—Because SOM increases water infiltration and stabilizes soil aggregates, the risk of erosion is minimized.
- *Soil carbon retention*.—Stabilized SOM sequesters atmospheric carbon. If continued SOM-enhancing management practices are used, the amount of $CO_2$ released in the atmosphere is minimized.

**Estimating the amount of organic material needed to increase SOM:**

The term **steady state** refers to the condition in which the amount of organic matter added from crop residue, roots, and manure or other organic material equals the rate of decomposition. If the amount of organic matter added is less than the rate of decomposition, the content of SOM will decline. Conversely, if the amount of organic matter added is higher than the rate of decomposition, the content of SOM will increase.

An acre of soil 6 inches (15.2 cm) thick weighs approximately 2,000,000 pounds. One percent SOM, therefore, weighs about 20,000 pounds (dry). Under normal conditions, 10 pounds of organic material decompose into about 1 pound of organic matter. Thus, at least 200,000 pounds (100 tons) of organic material must be applied or returned to the acre of soil to produce 1 percent stable organic matter. ("What Does Organic Matter Do In Soil?"; Funderburg, 2001; Samuel Roberts Noble Foundation).

## Interpretations

Obtain % SOM content from a standard soil test. Estimate the amount of organic material, carbon (C), nitrogen (N), phosphorus (P), and sulfur (S) in the SOM. Estimate the average annual mineralization of N, P, and S. Using the information in tables 1 and 2 and the example calculations that follow, complete table 3. Compare management systems.

Table 1.—Ratio of carbon, nitrogen, phosphorus, and sulfur and average mineralization factor in soil organic matter (Doran, 2012). (Values displayed may vary based on local conditions.)

| Ratio, percentage, and factor | Carbon | Nitrogen | Phosphorus | Sulfur |
|---|---|---|---|---|
| Ratio in soil organic matter | 100 | 10 | 1 | 0.25-0.50 |
| Ratio of carbon to element | 1:1 | 10:1 | 100:1 | 200-400:1 (average 300:1) |
| Percentage of soil organic matter | 58 percent | 5.8 percent | 0.58 percent | 0.15-0.29 percent (average 0.22 percent) |
| Annual mineralization factor (may need to be adjusted for local conditions) | 1.5 percent under normal temperate conditions (0.015 factor) | | | |

Table 2.—Average bulk density for organic matter and soil textures (Rawls, 1983).

| Organic matter and textures | Average bulk density ($g/cm^3$) |
|---|---|
| Organic matter | 0.22 |
| Sand | 1.56 |
| Loamy sand | 1.54 |
| Sandy loam | 1.50 |
| Loam | 1.45 |
| Silt loam | 1.20 |
| Sandy clay loam | 1.63 |
| Silty clay | 1.55 |
| Clay loam | 1.45 |
| Silty clay loam | 1.40 |
| Red clayey soils | 1.10 |
| Soils that formed in volcanic ash | 0.80 |

**Soil organic matter calculations** (depth in metric units converted to depth in pounds/acre):

Follow example to complete table 3. Estimate total C, N, P and S, and average annual nutrient (N, P, and S) release from a standard soil sample report of percent soil organic matter (% OM) (dominantly stable and active SOM fractions). Adjust sampling depth as appropriate.

*Example—*

Silty clay loam, 8-inch (8 in. * 2.54 cm/in. = 20.3-centimeter) sample depth; 2 percent organic matter (2% OM) from soil test; bulk density (BD) from field measurement or (BD based on average values given in table 2).

**Sampling depth conversion**:

Sampling depth in centimeters (cm) = inches (in) x (2.54). For example, 8 in (sampling depth) x 2.54 = 20.3 cm sampling depth

**Estimated bulk density calculation** (refer to "Bulk Density" guide for educators for determining actual bulk density in field or use estimates from table 2 in this guide):

$$\text{Estimated bulk density (table 2)} = \frac{100}{(\%\ OM \div OM\ BD) + (100 - \%\ OM \div \text{average soil BD table 2})}$$

$$\frac{100}{(2 \div 0.22\ g/cm3) + ([100 - 2] \div 1.40\ g/cm3)} = 1.26 \text{ grams per cubic centimeter (g/cm3)}$$

**Soil organic matter (SOM) (lbs/ac-depth):** (% OM x 10,000 parts per million [ppm]) x (bulk density) x (sample depth [cm] ÷ 10) x (0.893 [conversion factor])

*For example, (2 % x 10,000 ppm) x (1.26) x (20.3 cm ÷ 10) x (0.893)* = 45,682 lbs SOM/ac-8 in.

**Soil organic carbon (C) (lbs/ac-8 in):** 45,682 lbs SOM/ac-8 in x 0.58 (58 percent organic C) = 26,496 lbs organic C/ac-8 in. Note: 2,000 lbs. per ton = (26,496 lbs./2,000) = 13.2 Tons/Ac.

**Soil organic nitrogen (N) (lbs/ac-8 in):** 45,682 lbs SOM/ac-8 in x 0.058 (5.8 percent organic N) = 2,650 lbs organic N/ac-8 in.

**Mineralized organic nitrogen (N) (lbs/ac-8 in/yr):** 2,650 lbs organic N x 0.015 (mineralization factor) = 39.8 lbs mineralized organic N/ac-8 in.

**Soil organic phosphorus (P) (lbs/ac-8 in):** 45,682 lbs SOM/ac-8 in x 0.0058 (0.58 percent organic P) = 265 lbs organic P/ac-8 in.

**Mineralized organic phosphorus (P) (lbs/ac-8 in/yr):** 265 lbs organic P x 0.015 (mineralization factor) = 4.0 lbs mineralized organic P/ac-8 in.

**Soil organic sulfur (S) (lbs/ac-8 in):** 45,682 lbs SOM/ac-8 in x 0.0022 (0.22 percent organic S) = 100.5 lbs organic S/ac-8 in.

**Mineralized organic sulfur (S) (lbs/ac-8 in/yr):** 100.5 lbs organic S/ac-8 in x 0.015 (mineralization factor) = 1.5 lbs mineralized organic S/ac-8 in.

Table 3.- Calculations if % OM is known. (Calculations based on sample depth, Ex. = 8" = 20.3 cm (8" *2.54cm/in)). Refer to Page 5 for equations to complete each calculation in table below. Again, the values calculated in the table below are for the depth of soil, in the example, values are for the top 8" of soil.

| Site | (a) Sample depth (cm) | (b) Bulk density (g/cm3) | (c) Soil OM (%) From Soil Test | (d) Soil organic matter (lbs/ac) | (e) Soil organic C (lbs/ac) | (f) Soil organic N (lbs/ac) | (g) Miner-alized organic N (lbs/ac/yr) (excludes N flush from wetting of dry soil)* | (h) Soil organic P (lbs/ac) | (i) Miner-alized organic P (lbs/ac/yr) | (j) Soil organic S (lbs/ac) | (k) Miner-alized organic S (lbs/ac/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ex. | 20.3 | 1.26 | 2 | 45,682 | 26,496 (13.2 t/a) | 2,650 | 39.8* | 265 | 4.0 | 100.5 | 1.5 |
| | | | | | | | | | | | |
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*More accurate estimates of yearly organic N release can be estimated by measuring N released from active and microbial organic matter in soil because of rewetting of dry soils. In the example, an additional 20 to 30 lbs/ac of N can be released from micro-organisms (N flush) as a result of soil wetting and drying. Additional N flush can be estimated using the Solvita® test (see "Soil Respiration" guide for educators) or with a biological respiration and nitrification test, available at soil testing laboratories.

## *Carbon Calculations (based on known Soil % Carbon using Dry Combustion method)*

Table 4.- The above table (3) uses book value conversion, Soil OM% x 0.58 = % Soil Carbon. Table 4. (below) calculations are based on actual soil testing for % Carbon using the Dry Combustion method. Typically topsoil samples will result in % Carbon values near 58% of OM. Sub soil samples show greater variation. Calculations below prepared specifically for NSAS Conference 2019 and not part of the original Guide for Educators. Conversion factors derived from "Measuring soil carbon change", Peter Donovan and other metric to U.S. conversion tables.

| Site | (m) Sample depth (cm) | (n) Bulk density (g/cm3) | (o) Carbon (%) Dry Combustion method | (p) Metric Tons Carbon per hectare for depth sampled [(m) x (n) x (o)] | (q) Metric Tons CO2 per hectare for depth sampled [(p) x 3.67] | * Metric Tons Carbon per acre for depth sampled [(p) / 2.47] | * Metric Tons CO2 per acre for depth sampled [(q) / 2.47] |
|---|---|---|---|---|---|---|---|
| Ex. | 20.3 | 1.26 | 1.16 | 29.67 | 108.89 | 12.0 | 44.1 |
| | | | | | | | |
| | | | | | | | |
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* Data reporting for CO2 will often be in Metric Tons. To convert from Metric Tons / Hectare to US Tons / Acre use a conversion factor of 0.4461. Example: 29.67 Metric Tons Carbon/Ha * 0.4461 = 13.2 US Tons/Ac. 108.89 Metric Tons CO2 per Ha * 0.4461 = 48.4 US Tons/Ac.