Soil Organic Matter Accumulation

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1. General Types of Organic Materials
2. Specific Types of SOM Substances and Pools
3. SOM Decomposition
4. Soils and Soil Forming Processes
5. Factors and Processes that affect SOM Content

1. General Types of Organic Materials

- Organic Matter
- Soil Organic Matter
- Soil Organic Carbon
- Total Soil Carbon

Organic Matter (OM) versus Soil Organic Matter (SOM)

- Organic Matter – (OM) the material of which organisms are composed. The material may be alive or dead, and may be found in the atmosphere, in organisms, or in the water and soil.
- OM may be from plant or animal tissues that contain C. There are many types of organic matter, and the C content varies widely.
- Soil Organic Matter - (SOM) includes all OM fixed in place on the soil, or already incorporated into the soil. SOM excludes living plant and animal tissues.
- SOM inputs to the soil are from decomposing plants, vertebrates, invertebrates and microbes. Leachates from leaves (through rainfall) and exudates from plants and animals also add to SOM.
- SOM exists in some stage of decomposition. Decomposition begins as soon as a plant part dies or a leachate or exudate is released into the soil. In fact, some leaching of substances from plant parts begin before plant death, and some roots decompose while the plant is still alive (grasses).

SOM versus Soil Organic Carbon (SOC)

- OM in not made up entirely of OC, there are other substances that make up about 40% of the weight.
- % SOC x 1.724 = % SOM
- % SOM x 0.58 = % SOC
- The Van Bemmelen conversion factor is an average: The actual range in nature is between 0.2 and 3.0.

Total Soil C versus SOC

- Total Soil C = Soil Inorganic C + Soil Organic Carbon
- Soil inorganic carbon is most common in semiarid and arid regions, but is also found in the eastern USA.
- The main sources of inorganic C is from $CaCO_3$ (a.k.a. calcite or lime) as calcareous dustfall, from weathering of limestone and concrete, agricultural application, construction in cities, traffic on gravel roads, exposure of unweathered clacareous rock in mine spoil and pits, and from marl formation in wetland soils by periphyton algae in/under calcium-rich waters.
- We directly measure total C by combustion at 550°C, then subtract the content of inorganic C measured by CO_2 evolution to get the organic carbon portion.

2. Specific Types of SOM Substances and Pools

- Nonhumic Substances
- Humic Substances (humus)
- SOM Pools (Partitions)
- SOM Decomposition Rates

Nonhumic Substances (NHS) versus Humic Substances (HS = Humus)

- Nonhumic substances (most easily-decomposed)
  - Make up about 10 - 15% of the total SOM
  - NHS have variable resistance to chemical and biological degradation in soil, and can be broken down further. They exist mainly in labile SOM pools and are not a component of humus.

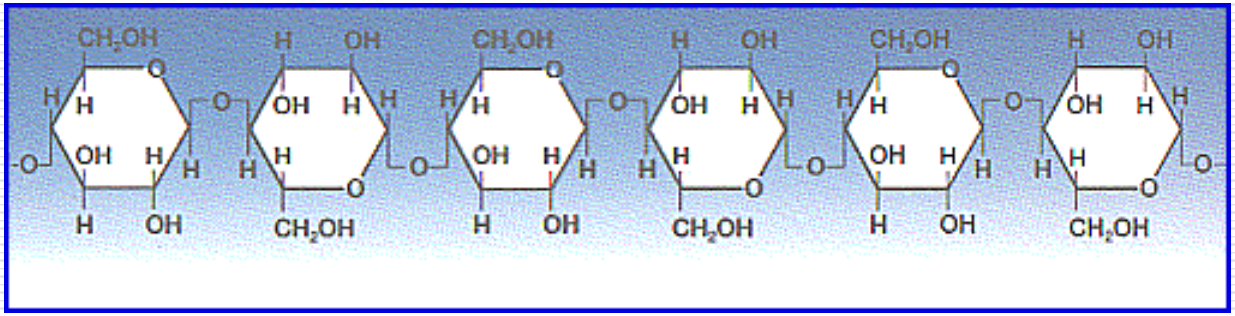
- Humic substances (stable, resistant to decomposition)
  - Make up about 85 - 90 % of the total SOM
  - HS are very resistant to chemical and biological degradation in soil and persist mainly in long-term SOM pools because they do not break down further. They are a component of humus.

Nonhumic Substances

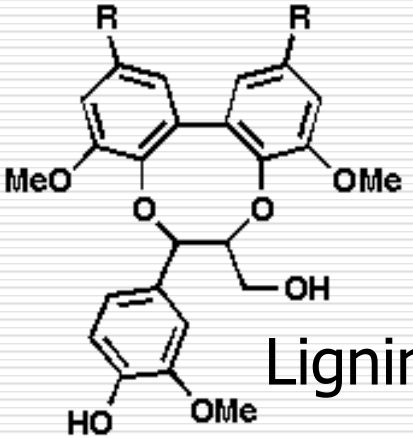
- Nonhumic substances are easily recognizable organic compounds with well-defined structures, such as sugars, amino acids, carbohydrates, fatty acids, pigments, proteins, lignin, resins, and waxes. All of these may exist in the SOM, but we will focus on sugars, carbohydrates, and lignin.

Examples of Nonhumic Substances

- Cellulose is a carbohydrate and is probably the single most abundant organic molecule in the biosphere. About 70% of plant structural material is made of cellulose. Wood is largely cellulose plus lignin, while cotton and paper are almost pure cellulose. Rings are held by O-H bonds.
- Lignin is found in plant structural material and provides high strength to cell walls. Rings are held by complex 0–0-OH bonds and have metals attached.



Cellulose



Lignin

Variable Rates of NHS Decomposition

NOTE: within the NHS, there are large differences in decomposition rates. For example:

Substance	Decomposition rate
Sugars, starch, proteins	rapid
Hemicellulose	↓
Cellulose	
Fats, waxes	
Lignin and phenols	very slow

Humic Substances

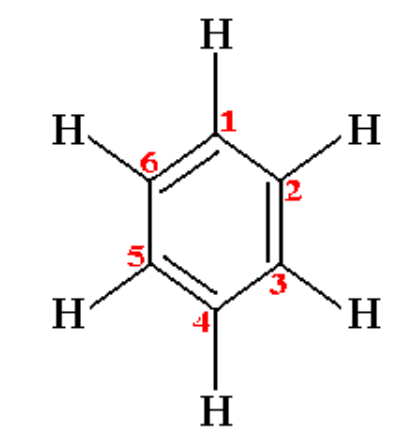
- Humic acids – The humic substances are extracted by dilute bases, but are insoluble in dilute acids like those found in the soil solution (thus they are stable in acid wetland soils). Humic acids are the dominant HS in the fine roots of grasses and grass-like plants.

- Fulvic acids – The fulvic substances are soluble in both acids and bases like those found in the soil solution (thus they are the most easily decomposed HS in wetland soils). Fulvic acids are the dominant HS in tree leaves, leachates, and exudates.

- Humin – Humin is insoluble in alkaline solutions (thus it is stable in alkaline wetland soils).

Example of Humic Substances

- HS are made up of thousands of different organic compounds, mainly amorphous, dark-colored, and partly aromatic (i.e., contain benzene and phenol rings).



Benzene (C_6H_6)

Soil Organic Matter Pools

POOL	KIND	TYPE	RESISTANCE	AGE
Labile	NHS*1	sugar	low	days - years
Long-term	HS*2	humic acid	high	centuries
Occluded	NHS*1 HS*2	any	low to high	millennia

*1 - NHS = nonhumic substances
*2 - HS = humic substances

3. Variable of SOM Decomposition

- Detritivore Decomposition
- Microbial Decomposition
- Optimal Conditions for Detritivores and Primary Decomposers
- Soil Moisture and Temperature Factors that Affect SOM Decomposition Rate
- SOM Decomposition Rates over Time

Detritivore Decomposition

- Detritivores decrease the size of OM parts and thus increase the surface area exposed to microbial decomposition.
- Detritivores include invertebrates such as ants, worms, termites, and grubs that chew or cut plant tissues and excrete them or store them below the soil surface. Examples are caterpillars that eat leaves and leaf-cutter ants that carry leaves them into their dens.
- Detritivores also include vertebrates that chew up and excrete plant or animal tissues or transport and store them below the soil surface. Examples include squirrels that bury acorns, and pack rats that store twigs and leaves in their burrows or nests. Animal excretement (manure) quickly decomposes into SOM because many of the complex bonds are already broken down by internal microbes and chemical actions in the animal.

Microbial Decomposition

- Primary microbial decomposition of OM begins with fungi and bacteria. Microbes may begin to decompose NHS before detritivore activity, but the rate increases after detritivore activity.

- Fungi are the only microbes that can break the strong bonds between lignin rings.

- Bacteria can break the simple bonds of NHS substances such as sugars, starches, carbohydrates (cellulose) and fats, but not lignin.

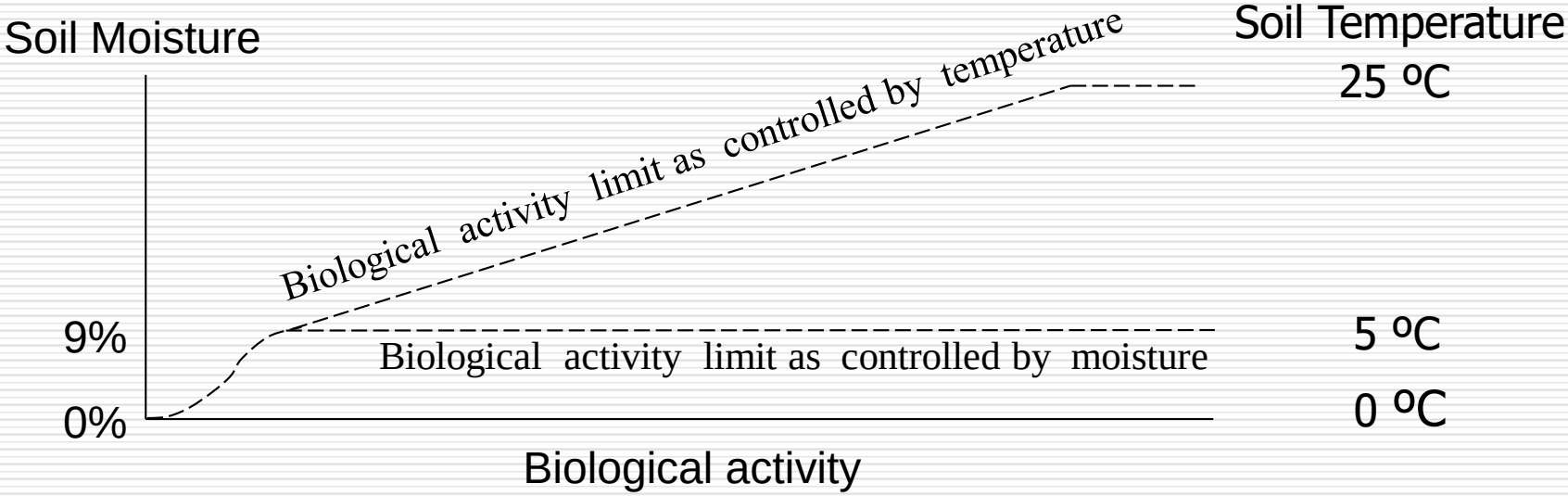
- Because all fungi and 70% of soil bacteria are aerobes, microbial decomposition is inhibited when the soil is devoid of oxygen (anaerobic).

Optimal Conditions for Detritivores and Decomposers

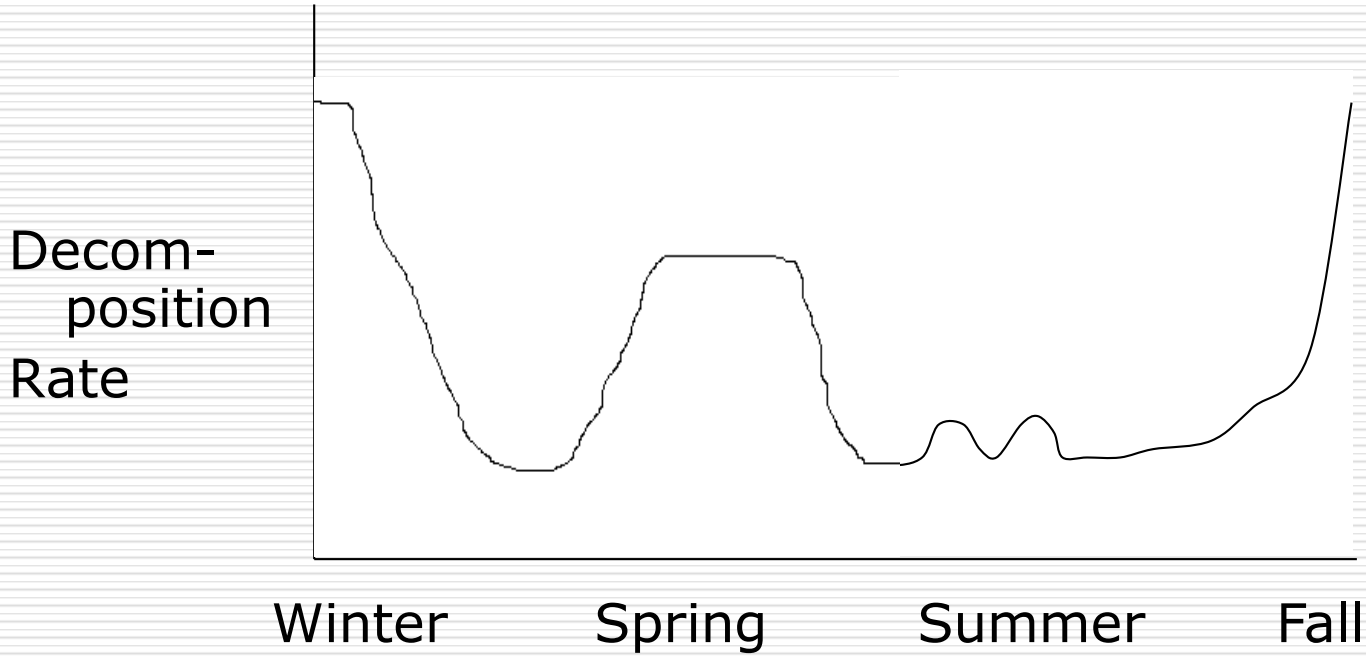
- Presence of gaseous O_2 (periodic aerobic conditions)*
- Steady supply of available, easily-digestible OM or OC*
- Soil properties
  - Adequate N, P and essential nutrients for microbes
  - Normal soil temperature range (5° to 25° C)*
  - Soil moisture of 9% or higher*
  - Slightly acidic pH
  - Low amounts of toxins, heavy metals, salinity
  - Low bulk density
  - Granular structure
  - 10:1 C:N ratio for microbes

* These increase the rate of decomposition

Temperature and Moisture Factors That Affect SOM Decomposition Rate



SOM Decomposition Rate over Time



4. Soils and Soil Forming Processes

- The Pedon
- Four Categories of Soil Forming Processes

Pedon

- A pedon is the basic sampling unit of a natural, human-transported or human-altered soil body on the landscape.
- A pedon is a discrete 3-D landscape unit, although pedons have a gradual lateral gradation into one another.
- A pedon is 1 to 20 m^2 in area and it contains the range of properties allowed for the soil series represented.
- Wetland pedons are typically 2-m deep and so the volume of the 3-D pedons is about 2 to 40 m^3.

Categories of Soil Forming Processes

- Soil formation is the product of specific processes that can be grouped into these four broad categories.
  - Additions (gains from outside of the pedon)
  - Transformations (changes within the pedon)
  - Translocations (relocation within the pedon)
  - Losses (losses from the pedon)

From: Simonson, R.W. 1958. Outline of a general theory of soil genesis. Soil Sci. Soc. Am. Proc. 22:152-156.

5. Processes and Factors that Affect SOM Content

A. Additions (accumulations)
B. Transformations
C. Translocations and Transformations
D. Losses

A. SOM Additions (accumulation)

- Activities and Factors that Increase SOM
- Processes of SOM Accumulation on the Soil Surface

Activities and Factors that Increase SOM Content

- Either limiting conditions for decomposers and detritivores or a surplus of OM inputs.
- Rapid burial of OM by soil transported by flooding or human activity, or OM covered by water after ponding caused by beavers or humans.
- Occlusion of easily-decomposed SOM within granular aggregates by natural aggregate-building processes.
- Excess additions of OM by humans such as biosolids, mulches, composts.

Processes that Describe OM Accumulation on the Soil Surface

- Littering - The accumulation of less than 30 cm of organic matter deposits on top of the mineral soil surface. Accumulations of 20-30 cm thick are called a *Histic epipedon*.

- Paludization – The accumulation of 30 cm or more organic matter deposits on top of the mineral soil surface. 30-40 cm of accumulation form a *Histic epipedon o*n mineral soils, and 40 cm or more form organic soils (*Histosols*). Frozen organic soils are found in the *Histels suborder*.

- Cumulization – Additions of mineral particles to the surface of a soil that have stable organic compounds (HS) attached. Cumulization usually occurs on footslope positions or in depressions containing mineral soils.

B. Processes Involving Transformation of SOM (1)

- Decomposition – The breakdown of OM bonds in organic tissues, leachates and exudates (explained in Section 3).
- Humification - The enrichment of C and loss of H and O content in the by-products of OM decomposition. Remember that 40% of the OM is not C.
- Melanization – The darkening of the soil color as the HS (humus) content increases.

B. Processes Involving Transformation of SOM (2)

- Synthesis - The chemical formation of new compounds from separate elements. In the soil, an example is the (Al-OC, Al-OC-Fe) found in *spodic horizons* and *ortstein*.

- Immobilization - The uptake of inorganic nutrients by microbes and detritivores and incorporation into organic substances within their bodies.

- Mineralization - The release of inorganic minerals during microbial decomposition of organic substances. This process is the opposite of immobilization.

C. A Combination of Translocation and Transformation of SOM

- Podzolization – the combination of several processes resulting in unique soil morphology. Intense decomposition of SOM and *chelation* (chemical adsorption) of soil nutrients and organic substances in the surface soil is followed by percolation of the soil solution into the subsoil. This results in the formation of an acid, ashy-colored horizon (*albic horizon*) near the surface.
- The translocated organic materials along with translocated Al are transformed in the subsoil by synthesis into new complex mineral-organic compounds (Al-OC, Al-OC-Fe), forming a *spodic horizon* or *orstein* (*spodic material* cemented by very high concentrations of mineral-organic compounds). Excess soluble organic substances leach into the groundwater. See the following slide for an example.

Podzolization

Albic horizon – strongly leached horizon

Spodic horizon – accumulation of Al-OC or Al-OC-Fe

D. Factors Affecting SOM Losses

- Human Disturbances that Decrease SOM
- Natural Losses from the Pedon
- Natural Activities and Factors that Decrease SOM

Human Disturbances that Decrease SOM

- Artificial drainage increases soil temperature and aerobic decomposition
- Leaching following artificial drainage
- Logging or conversion to agriculture or pasturing decreases OM inputs and increases removals, and increases soil compaction
- Plowing destroys aggregates and exposes occluded pools of SOM to microbial activity
- Wind erosion of fine particles in plowed organic and mineral soils
- Water erosion on uplands
- Human-caused fires

Natural Losses from the Pedon

- Leaching – The extreme translocation of soluble organic substances results in losses of SOM from the pedon through leaching. Rivers in humid sandy areas are often called "Blackwater Rivers" because the dark-colored substances such as tannins and other HS end up in solution in the stream water.
- Carbon Dioxide Efflux – The loss of CO_2 from the aerobic soil following respiration of microbes and higher plants and exhaling by vertebrates and invertebrates.
- Methane Efflux - The loss of CH_4 from the anaerobic soil following fermentation of microbes and flatulence by vertebrates and invertebrates.

Natural Activities and Factors That Decrease SOM

- Natural Disturbances
  - Fire (removal of OM - trees, stumps, roots, and litter layers) and some oxidation or burning of SOM

- Natural Factors
  - Seasonal leaching following water table fluctuation