Organic Matter and Organic Soils

ESS 210

Chapter 12
p. 498-542

Global Organic Carbon in Soil (1,576 Pg)

<table>
<thead>
<tr>
<th>Soil Order</th>
<th>Median g C kg⁻¹</th>
<th>Range g C kg⁻¹</th>
<th>Global mass Pg (10¹⁵ g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histosols</td>
<td>419</td>
<td>366 – 724</td>
<td>357</td>
</tr>
<tr>
<td>Inceptisols</td>
<td>10.5</td>
<td>0.3 – 114</td>
<td>352</td>
</tr>
<tr>
<td>Entisols</td>
<td>6.6</td>
<td>0.3 – 94.2</td>
<td>148</td>
</tr>
<tr>
<td>Alfisols</td>
<td>3.8</td>
<td>0.2 – 50.0</td>
<td>127</td>
</tr>
<tr>
<td>Oxisols</td>
<td>7.8</td>
<td>0.6 – 117</td>
<td>119</td>
</tr>
<tr>
<td>Aridisols</td>
<td>5.4</td>
<td>1.6 – 33.1</td>
<td>110</td>
</tr>
<tr>
<td>Ultisols</td>
<td>4.6</td>
<td>0.3 – 72.0</td>
<td>105</td>
</tr>
<tr>
<td>Andisols</td>
<td>38.3</td>
<td>0.9 – 308</td>
<td>78</td>
</tr>
<tr>
<td>Mollisols</td>
<td>8.4</td>
<td>0.4 – 54.5</td>
<td>72</td>
</tr>
<tr>
<td>Spodosols</td>
<td>27.9</td>
<td>0.6 – 331</td>
<td>71</td>
</tr>
<tr>
<td>Vertisols</td>
<td>8.4</td>
<td>1.5 – 46.7</td>
<td>19</td>
</tr>
</tbody>
</table>

What is Soil Organic Matter?

- C = 45 to 58 % of all organic matter
- Biomass: carbon in living organisms
- Organic residues: carbon in undecayed and partially decayed plant and animal tissues
- Humus: soil organic matter
  - Black-brown, high molecular mass
  - Biochemical compounds and humic substances
  - Colloidal, amorphous, high CEC
  - 60 to 70% of total organic C

Decomposition in Soil

- Biological Synthesis
  - Storage of energy in plant and animal structures
  - Plants are primary producers
- Decomposition
  - Release and reuse of energy from plants and animals
  - Microbes (fungi and bacteria) are primary decomposers
Decomposition Processes

- Chemical
  - Hydrolysis, oxidation-reduction, etc.
- Biological
  - Require enzymes
- Enzymes
  - Protein molecules
  - Catalysts
  - Greatly increase reaction rates

Enzymes in Action

1. Specific binding site for compound

2. Compound is bound, making the -O- bond more susceptible to hydrolysis.

3. After hydrolysis, products dissociate from the enzyme

4. After dissociation, the enzyme can catalyze another reaction.

Extracellular Enzymes

- Microorganisms excrete enzymes into soil
- These catalyze decomposition reactions and polymerization reactions
- Provides for release of nutrients
- Reduces size of biomolecules
  - Microbes can not absorb huge molecules!
- Increases size of humic substances
Decomposition Processes

- What are the end-products?
  - CO₂, NH₄⁺, NO₃⁻, H₂PO₄⁻, SO₄²⁻, H₂O
- Anaerobic conditions:
  - CH₄, H₂S, NH₃
- Microbial biomass
- Humic substances

Nutritional Requirements

- Nutrients are required to decompose organic materials
- If N, P, S, K, etc. are low or missing, decomposition will be very slow
- Why?
  - Synthesis (microbes) requires these!

Example - C:N Ratios

- If residue has low N, degrades slowly
- Residue with high N, degrades quickly
- Microorganisms require N to make proteins
- Can’t use the C without the N
- If C:N > 30, residue is N-deficient
- If C:N < 20, residue is N-rich

Examples

- Legumes
  - alfalfa ~ 13:1
  - clover ~ 18:1
- Cornstalks > 40:1
- Wheat straw > 80:1
- Sawdust > 200:1
- Bacteria ~ 5:1

Example - Added Substrate

- Added substrate = green manure (C/N = 15/1), assume 45% C
- For every 100 kg of substrate added to the soil:
  - 0.45 × 100 kg = 45 kg of carbon added to soil
  - 0.45 × 15 = 6.75 kg of N added to the soil
  - 0.65 × 45 = 29.25 kg is given off as CO₂ and doesn’t enter into the rest of the calculation
  - 0.35 × 45 = 15.75 kg of carbon will be incorporated into microbial biomass
  - 15.75 + 7.5 = 2.1 kg of N will be needed
  - 3 kg N – 2.1 kg N = 0.9 kg of excess N is contained in 100 kg of substrate. Therefore there will be a net mineralization of N.
Mineralization vs. Immobilization

Factors Affecting Decomposition and Humus Formation

- Temperature
  - Cold: low production, low humus
  - Temperate: good production, high humus
    - As you go north, humus increases
  - Tropical: high production, low humus
- Moisture
  - High rainfall: high production
  - Water-logging: high humus (Histosols)

Temperature Effect in Aerobic Soil

Temperature Effect in Anaerobic Soil

Factors Affecting Decomposition and Humus Formation

- Nutrients
- pH
  - 6 - 8 best
  - Poor below 4.5 and above 8.5
- Texture
  - Clayey soils accumulate more humus. WHY?
- Tillage

Humus

- *Humic* and *non-humic* substances
- Non-humic substances are known biochemical compounds
  - Carbohydrates (polysaccharides)
  - N, P, and S compounds (proteins, inositol phosphates)
  - Lipids (fats, waxes, resins)
  - Lignin and other recalcitrant compounds (lignin, tannins, sporopollenins)
- Humic substances are *unique to soil*
  - High molecular weight
  - Highly aromatic ring structure
  - Formed by decomposition and synthesis processes, microbial and chemical
Humus is a Colloid

- Very high specific surface area
- Very high CEC
  - pH dependent
  - 200 to 300 cmol_c kg^{-1}
- High water holding capacity
  - 4 to 5 times its mass

Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Humic acid</th>
<th>Fulvic acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular mass, g mol^{-1}</td>
<td>2,000 – 1,300,000</td>
<td>300 – 2000</td>
</tr>
<tr>
<td>Total acidity, mol kg^{-1}</td>
<td>67</td>
<td>103</td>
</tr>
<tr>
<td>Carboxyl groups, mol kg^{-1}</td>
<td>36</td>
<td>82</td>
</tr>
<tr>
<td>Phenolic groups, mol kg^{-1}</td>
<td>39</td>
<td>30</td>
</tr>
</tbody>
</table>

Characteristics Summarized

- Humic acids are larger than fulvic acids
- Fulvic acids have more total acidity and more carboxylic acid functional groups than humic acids
- Fulvic acids are more oxygenated than humic acids
- Humic acids are more aromatic than fulvic acids
- Fulvic acids are more water soluble than humic acids

Benefits of Soil Organic Matter

- Source of plant nutrients: N, P, and S
- Soil aggregation
- CEC and buffering capacity
- Water holding capacity, air movement, etc.
- Chelation of metals (Fe, Zn, Cu)
- C supply for microorganisms
- Surface mulches regulate temperature, moisture

Maintaining Soil Humus

- Minimize soil disturbance
- Maximize surface residues
- Grow “Green Manures”
- Utilize animal manure, sewage sludge
Characteristics of Histosols

Organic Soils

- 8 to 16% organic carbon
  - If > 60 % clay: > 16 % organic C
  - If no clay: > 8 % organic C
  - If < 60 % clay: > 8 % organic C + % clay + 7.5
    (example: if 30 % clay, organic C must be greater
    then 8 % + 30 ÷ 7.5 > 12 %)
- *Fibric* and *hemic* (peats): brownish, fibrous, partially decomposed
- *Sapric* (mucks): highly humified, black, powdery
- Wetland soils

Characteristics of Histosols

- Dark brown to black color
- Low bulk density: < 0.1 to 0.4 g cm⁻³
- Water holding capacity 2 to 3 times weight
- Higher CEC than mineral soils
- Only 1% of ice-free land surface
- ~23 % of global soil carbon

**HISTOSOL**

This soil has 1+ meter of muck overlying marl, a soft deposit of calcium carbonate materials

Subsidence Post at the Belle Glade, Florida Research Center

The top of this post was even with the soil surface in 1924. This Histosol has subsided due to accelerated oxidation associated with artificial drainage, an average subsidence rate of nearly one inch per year. Sustainable?
Why is Organic Matter Important?
- Structure (aggregation)
  - Drainage and aeration
- Water holding capacity
- Nutrient holding capacity (CEC)
- Nutrient reservoir
- Immobilization of toxic metals & toxic organics
- Food Source for soil organisms
- Absorbs heat

Composting
- Mixing, piling of organic materials to cause aerobic decomposition and nutrient conservation
  - Much C lost as CO$_2$
  - Most nutrients remain
- Decrease volume by 30-50%
- Increases CEC of material
- When stable, C:N ~ 15:1 to 20:1

Composting Process
- Heat energy generated from decomposition heats the pile
- At peak microbial activity level, temperature may be 65 to 72 °C.
- Thermophilic bacteria
- Heat kills most weed seeds & pathogenic organisms.
- May take a several days to several months

Managing Soil Organic Matter
- Add organic materials
  - Crop residues
  - Manure, compost, biosolids
  - Cover crops
- Get maximum plant growth
Managing Soil Organic Matter

- Minimize tillage
  - Decreases oxidation of OM
  - Keep residues on the soil surface to slow the decay process
  - Conservation tillage can increase soil OM levels (0.1% per year)
- Perennial vegetation should be encouraged

Soil and Greenhouse Effect

- A loss of soil organic matter results in an increase in atmospheric CO₂ levels
- Biologically produced gases account for half of the problem (Fig. 12.26)
- Under poor aeration, CH₄ is produced instead of CO₂ (as in rice paddies)
  - Methanotrophs can oxidize methane to methanol
- Soil can be a source or sink for most gases