Soils for Master Naturalists

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What is Soil?

- the living skin of the Earth (Ian Pepper, soil microbiologist)
- crucible of terrestrial life (Daniel Hillel, soil physicist)
- the pedosphere
  - the interface between the lithosphere, hydrosphere and atmosphere (ecologists)
- a medium for plant growth
- phenomena of nature (natural bodies)
- foundations of ecosystems
Agenda

• review of components
• soils across landscapes
• soils as foundations of ecosystems
What are Soils?

• reactive, dynamic, three-phase ecosystems composed of solids, liquids and gases

- Minerals: 48%
- Air: 25%
- Water: 25%
- Organic Matter: 2%

Topsoil of a cultivated field several days after rainfall or irrigation
First Things First:
Soil Solids

• mineral or inorganic solids
  – often classified based on particle size

• organic solids a.k.a. “organic matter”
## Major Mineral Classes in a Soil

<table>
<thead>
<tr>
<th>Mineral Class</th>
<th>Size of Mineral Particles (mm)</th>
<th>Feel of Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>sands</td>
<td>0.05 – 2 mm</td>
<td>gritty</td>
</tr>
<tr>
<td>silts</td>
<td>0.002 – 0.05 mm</td>
<td>smooth (like flour, cornstarch or talcum powder)</td>
</tr>
<tr>
<td>clays</td>
<td>less than 0.002 mm</td>
<td>sticky when wet</td>
</tr>
</tbody>
</table>
60% silt
20% clay
20% sand
FIGURE 3-8 The soil triangle is redrawn to show fine-, medium-, and coarse-textured soils. An exception is very fine sandy loam, which is considered medium textured.
## Effect of Soil Texture on Soil Properties

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Textural Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>coarse-textured</td>
</tr>
<tr>
<td>drainage</td>
<td>rapid</td>
</tr>
<tr>
<td>water- and nutrient-holding capacity</td>
<td>low</td>
</tr>
<tr>
<td>susceptibility to erosion</td>
<td>low</td>
</tr>
<tr>
<td>leaching potential</td>
<td>high</td>
</tr>
<tr>
<td>aeration</td>
<td>good</td>
</tr>
</tbody>
</table>
The Other Soil Solid Material: Organic Matter

- Humus: 75%
- Biomass: 10%
- Residues & By-Products: 15%
Biomass: What It Is

- the living component of the soil
- consists of a range of creatures
  - as small as microscopic viruses & bacteria
  - as large as roots, worms and other creatures that are visible to the unaided eye
  - and everything between
Microorganisms, Meso-organisms and Macro-organisms

nematode
CA Dept of Ag

springtail (detritivore)

centipede (carnivore)

Department of Environmental Science and Technology
Classification Based on Trophic Level

- herbivores
- carnivores
- detritivores
- parasites
- predators
- fungivores
- bacterivores
Life in the Soil, Nardi, 2007
Question

How many bacteria are there in a handful of soil?

A) 10,000 – 50,000

B) 1,000,000 – 10,000,000

C) 300,000,000 – 50 billion
Question

How many bacteria are there in a handful of soil?

C) 300,000,000 – 50 billion
Organisms based on Respiratory Pathways

• aerobes –
  – need molecular oxygen \((O_2)\) as an electron acceptor to respire
    • obligate aerobes

• anaerobes
  – can use molecules other than oxygen as electron acceptors
    • obligate anaerobes
    • facultative anaerobes
Biomass: What It Does

• participates in nutrient cycling
  – comminute (shred or fragment) plant and animal residues, using what they can utilize and leaving behind what they cannot

• mineralization
  – conversion of organic form of an element to an inorganic form
  – amino acid to ammonium
Biomass: What It Does (cont.)

- creation of biopores
  - larger organisms move through soil creating channels or pores
  - channels promote water infiltration and create a healthy balance between large and medium pores
  - disseminate spores and microbes
Helping One Another
Symbiosis in Soil

mycorrhiza – a symbiotic relationship between certain fungi and higher plants
Soils as a Source of Disease-causing Organisms

- anthrax
  - scourge since ancient times
  - *Bacillus anthracis*
  - aerobe & pathogen

- botulism
  - *Clostridium botulinum*
  - obligate anaerobe & detritivore

- tetanus
  - *Clostridium tetanii*
  - obligate anaerobe & detritivore
Residues and By-products: What They Are

- dead stuff - crop residues, dead roots and bodies of soil creatures
- by-products - materials that plant roots and soil creatures release or exude into the soil
Residues and By-products: What They Do

- fuel and nutrients for soil organisms
  - energy and nutrient source for most of the soil creatures

- formation and maintenance of soil aggregates (structure or architecture)
  - sticky and gummy by-products of residue decomposition hold soil particles together in clumps or aggregates
Amazing By-product!

• Streptomycin
  – bacterial exudate
  – soil organism, *Streptomyces*

• Dr. Selman Waksman
  – soil microbiologist at Rutgers University
  – recognized the antibacterial function and isolated the compound
  – Nobel Prize in Medicine in 1952
Last But Certainly Not Least: Humus

- relatively stable end product of residue decomposition
- composes the majority of organic matter
- resists further decomposition (1% per year)
- it is not a good nutrient or energy source for soil creatures
Humus: What It Does

• very small in particle size & high surface area
• charged sites at many locations on the surface
• effective at holding water and nutrients
The Other Half of Soil: Soil Pores (Void Space)

- soil water
  - adequate (but not too much) quantity
  - adequate supply of nutrients
  - minimize runoff and leaching

- soil air
  - source of oxygen for roots and most soil organisms
  - constantly enriched with carbon dioxide from roots and soil organisms
The Interplay of Air and Water: Soil Aeration

- The exchange of $O_2$ and $CO_2$ between the soil pores and the ambient atmosphere
Comparison of Gasses in the Atmosphere and in Soil Air of Upland Forest Soil (several days after rainfall)

<table>
<thead>
<tr>
<th>Gas</th>
<th>In the Atmosphere</th>
<th>In Soil Air</th>
</tr>
</thead>
<tbody>
<tr>
<td>nitrogen</td>
<td>79%</td>
<td>79%</td>
</tr>
<tr>
<td>oxygen</td>
<td>20.9%</td>
<td>20.6%</td>
</tr>
<tr>
<td>carbon dioxide</td>
<td>0.035%</td>
<td>0.300%</td>
</tr>
</tbody>
</table>
# Order of Use as Electron Acceptors in Soils (Sediments)

Table 6.1. Glucose respiration with different electron-acceptors.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>ΔG°¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.  ( \text{C}<em>6\text{H}</em>{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} )</td>
<td>ΔG°¹ = -686.4</td>
</tr>
<tr>
<td>2.  ( 5 \text{C}<em>6\text{H}</em>{12}\text{O}_6 + 24 \text{NO}_3^- + 24 \text{H}^+ \rightarrow 30 \text{CO}_2 + 12 \text{N}_2 + 42 \text{H}_2\text{O} )</td>
<td>ΔG°¹ = -649.0</td>
</tr>
<tr>
<td>3.  ( \text{C}<em>6\text{H}</em>{12}\text{O}_6 + 12 \text{MnO}_2 + 24 \text{H}^+ \rightarrow 6 \text{CO}_2 + 12 \text{Mn}^{2+} + 18 \text{H}_2\text{O} )</td>
<td>ΔG°¹ = -457.8</td>
</tr>
<tr>
<td>4.  ( \text{C}<em>6\text{H}</em>{12}\text{O}_6 + 24 \text{Fe(OH)}_3 + 48 \text{H}^+ \rightarrow 6 \text{CO}_2 + 24 \text{Fe}^{2+} + 66 \text{H}_2\text{O} )</td>
<td>ΔG°¹ = -100.4</td>
</tr>
<tr>
<td>5.  ( \text{C}<em>6\text{H}</em>{12}\text{O}_6 + 3 \text{SO}_4^{2-} \rightarrow 6 \text{CO}_2 + 3 \text{S}^{2-} + 6 \text{H}_2\text{O} )</td>
<td>ΔG°¹ = -91.0</td>
</tr>
</tbody>
</table>

ΔG°¹ = change is standard Gibbs free energy units: kcal/mol. Based on ΔGf published by U.S. National Bureau of Standards.
Soils, Sediments, Lentic Water Bodies

Fig. 6.1. Schematic presentation of a flooded soil showing the zones with different microbial metabolism.
Now, a Video Interlude -

- Dr. Ian Pepper, soil microbiologist, Arizona State University
Soil Solution

• source of nutrients for plants
  – higher trophic levels depend upon plants
  – deficiencies of nutrients for plants or dependent animals
    • impact health of humans and other animals

• may provide an adverse condition for plant growth
  – acidity
  – salinity
  – toxicity of certain elements
    • impact on animal health
Too Much or Too Little

- serpentine soils
  - occur in a band from Alabama to Canada
  - “barrens”;
    - droughty (shallow, low in clay and organic matter
  - soil-driven stresses
    - may contain toxic levels of cobalt, chromium and nickel
    - deficient in calcium
    - magnesium is over-abundant
Soldiers Delight & Serpentine Barrens (Baltimore & Montgomery counties)

- grassland prior to European settlement
- lower species diversity than other Piedmont habitats
- lower net primary productivity
- 39 rare, threatened or endangered species
Selenium – Too Much or Too Little

• semi-arid zone issue in grazing animals
  – Se-deficient soils
    • white muscle disease
  – Se-excessive soils
    • alkali disease or blind staggers
soil acidity: the adverse condition on humid regions
Soils are Biochemical Reactors

• the various components (soil air, soil water, minerals and organic matter) interact

• a wide array of chemical and biochemical processes occur
Clays and Humus

- center of chemical reactivity in soil
- engine driving chemical transformations in soil
Solid-Liquid Interface

• adsorption of water and nutrients occurs at surfaces
• small particles have more surface area than the same weight of large particles
• surfaces are often charged; most charge is negative
• negatively charged surfaces attract positively charged ions (cations)
Importance of CEC

- nutrient cations exist on exchange phase
  - are protected from leaching
  - can replenish the soil solution when plant uptake or leaching removes nutrients
  - the “storehouse” of cationic nutrients
## Relationship of Textural Class to Clay Content and CEC

<table>
<thead>
<tr>
<th>Textural Group</th>
<th>Range of Clay Content (%)</th>
<th>Cation Exchange Capacity (CEC)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand and loamy sands</td>
<td>0 - 15</td>
<td>1 - 5</td>
</tr>
<tr>
<td>sandy loams</td>
<td>15 - 20</td>
<td>5 - 10</td>
</tr>
<tr>
<td>loams and silt loams</td>
<td>0 - 25</td>
<td>5 - 15</td>
</tr>
<tr>
<td>clay loams, sandy clay loams, silty clay loams</td>
<td>20 - 40</td>
<td>15 - 30</td>
</tr>
<tr>
<td>clays, sandy clays, silty clays</td>
<td>&gt;49</td>
<td>&gt;30</td>
</tr>
</tbody>
</table>

*cmol/kg or centimoles per kilogram, or an older mode of expression, milliequivalent per 100 grams.
Soils across a Landscape
S = f (cloprt)

- S = soil
- f = function of
- cl = climate
- o = organisms
- r = relief, landscape position
- p = parent material
- t = time
Physiographic Provinces of Maryland and Delaware

- Appalachian Plateau
- Valley and Ridge
- Blue Ridge
- Piedmont
- Coastal Plain

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Soil-forming processes

- additions
- losses
- translocations
- transformations
Soil Horizons

O horizon
A horizon
E horizon
B horizon
C horizon
R horizon

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From this … to this.
Soil: The Most Complex Biomaterial on Earth
Questions? Comments?