Introduction

- Soils
  - Definition
  - Function
  - Physical characteristics
  - Chemical properties
  - Soil biology and organic matter management

- Soil Fertility
  - Plant nutrients
  - Fertilizers
  - Soil testing
Soils Defined

An ecological system consisting of inorganic minerals, organic matter, living organisms, water & air and plant roots

Ideal ratio by volume:

- \( \frac{1}{2} \) Soil particles (5% OM by weight)
- \( \frac{1}{2} \) Pore spaces (\( \frac{1}{2} \) water, \( \frac{1}{2} \) air)
Soil Composition

Soils are composed of:

- **Mineral** 45% by volume
- **Organic** 5% by volume
- **Water** 25% by volume
- **Soil gases** 25% by volume

% by volume *(but % weight for OM)*

Ideally, a volume of soil should be ½ solid material and ½ pore space.

Ron Smith, 2005
Soil Horizons

\begin{itemize}
  \item \textbf{O} - Accumulated plant matter & debris
  \item \textbf{A} - Mineral horizon enriched with \textbf{OM}
  \item \textbf{E} - Horizon w. clays, & \textbf{OM} ‘washed’ out
  \item \textbf{B} - Horizon where clays, \textbf{OM} accumulate
  \item \textbf{C} - Substratum - parent material
  \item Bedrock
\end{itemize}
Soil peds (one = pedon) are individual small crumbs
Functions of Soil

- **Basic Functions**
  - Anchors plants
  - Reservoir for nutrients
  - Allows for water and air exchange

- **Benefits**
  - Regulates water in the environment
  - Cycles nutrients between plants and animals
  - Filters and detoxifies pollutants
Micropores

- Micropores = water holding capacity, minerals

Macropores
- Macropores = earthworms & root channels (drainage)
- Micropores = water holding capacity, minerals
The Mineral Part of Soil

- **Clay**
  - Less than 0.002 mm in diameter
  - Feels smooth when dry, slick & sticky when wet

- **Silt**
  - Between 0.002 and 0.05 mm in diameter
  - Feels ‘floury’ when dry, smooth when wet

- **Sand**
  - Between 0.05 and 2.0 mm in diameter
  - Feels rough
Soil Separates

- **Sand** (see with naked eye)
- **Silt** (size of flour)
- **Clay** (Electron Microscope)
### Surface Area in One Acre* Plow Layer

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>500</td>
</tr>
<tr>
<td>Fine sand</td>
<td>5,000</td>
</tr>
<tr>
<td>Silts</td>
<td>50,000</td>
</tr>
<tr>
<td>Clays</td>
<td>25,000,000</td>
</tr>
</tbody>
</table>

*(Oregon is 60,000,000 acres)*

*One acre = 43,560 ft\(^2\)*
Soil Texture

**Texture** is the proportional amount of each of these groups (using size of particles only)

- Use textural triangle
- Loam soil has about 40% sand and silt and 20% clay
- Good soils are loam, sandy loam, silt loam & clay loam
• There are 12 texture classes

• A texture class is determined by the relative proportions of sand, silt, and clay in a soil body
Water Infiltration

Any soil texture is good for gardening if you know what its limitations.

Redrawn from Cooney & Peterson

Diagram showing water infiltration in sandy loam and clay loam, with time periods in hours and depth in centimeters.
Sandy soils drain faster and warm up fast

Clay soils remain cold and wet late into the spring

Due to their large surface area, clay soils take more lime to raise pH

Clays soils may require drainage

Clay-loam soils hold enough water for good plant growth
**Determine Soil Texture at Home**

- Fill a quart jar filled about half way with a sample of your soil and then topped off with water.
- If you have it, add a teaspoon of Calgon or activated carbon.
- Cover & shake it (min 2 min) energetically until everything is swirling around.
- Set it aside and let it settle until the water clears.
- The sand particles are the heaviest and they will settle to the bottom within a few minutes.
- Within an hour or two, the silt will have formed the next layer.
- The fine clay particles will finally settle in a day or two.
- OM may remain floating around on the top.
- Measure layer heights and convert to percentage ratios.
- If the clay layer makes up half or more of your sample, you have a heavy clay soil.
Soil Texture

52% sand, 17% silt, & 32% clay
Soil Structure

- Arrangement of soil particles into secondary units (peds)
- Allows for movement of air and water; lets roots penetrate
- Compaction squeezes macropores to micropores
  - Less water movement
  - Less root penetration
- If you can make a soil ribbon = too wet to till

Excessive tillage by roto tiller destroys soil structure
What soil structure is this?
Gray mottles indicate soil stays too wet e.g. soil around septic systems.
Soil pH

- Measure of hydrogen ion activity
- pH range of 0-14
  - Less than 7: acidic
  - 7: neutral
  - Greater than 7: alkaline
- One unit change in pH represents 10 fold change in $H^+$ ion concentration
  - pH of 5 is 10 times acidic than pH of 6
- Optimal plant growth between 5.5-7.5
Soil pH & Plants

- Affects availability of nutrients
- Affects microorganism populations
- Affects availability of toxic metals in soil solution

  e.g. aluminum is toxic in low pH and Fe is unavailable in higher pH
Causes of Soil Acidity

- Acidic parent material
- Leaching or plant removal of basic cations
- Decomposing organic matter
  - Acids formed in decomposition process
- Certain nitrogen fertilizers
  - Conversion of ammonium to nitrate generates H⁺
- Acid rain
  - pH of rainwater is 5.6, becomes more acidic with dissolved nitrous oxide or sulfur dioxide
Adjusting Soil pH

Adjust low soil pH
- Lime - calcium carbonate ($\text{CaCO}_3$)
  - Use 50lb per 1000 square feet of garden
- Dolomitic lime - lime w. magnesium ($\text{CaMg(CO}_3\text{)}_2$)
- Quicklime ($\text{Ca(OH)}_2$)
- Wood ash ($\text{CaO}$)
  - Use 20-25 lb/ 1000 sq ft of garden
  - High rates may cause salt injury

Lower pH
- Use 50 lb/1000 sq ft of elemental sulfur
### Calcium Carbonate Equivalents

<table>
<thead>
<tr>
<th>Material</th>
<th>Calcium Carbonate Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limestone ((\text{CaCO}_3))</td>
<td>100%</td>
</tr>
<tr>
<td>Dolomitic lime ((\text{CaO} \cdot \text{MgO}))</td>
<td>109%</td>
</tr>
<tr>
<td>Quicklime ((\text{CaO}))</td>
<td>179%</td>
</tr>
<tr>
<td>Hydrated lime (\text{Ca(OH)}_2)</td>
<td>135%</td>
</tr>
<tr>
<td>Wood ash</td>
<td>50%</td>
</tr>
</tbody>
</table>

The average agricultural limestone is about 5% Mg and 35–40% Ca by weight.
Additional Tips

Lime before you fertilize

<table>
<thead>
<tr>
<th>pH</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>53%</td>
<td>34%</td>
<td>52%</td>
</tr>
<tr>
<td>6.0</td>
<td>89%</td>
<td>52%</td>
<td>100%</td>
</tr>
<tr>
<td>7.0</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Plant Nutrients

- Soil supplies 13 essential plant nutrients
- Primary: N, P, K
- Secondary: S, Mg, Ca
- Micronutrients: B, Mo, Cu, Zn, Fe, Mn, Cl
- We're deficient in N, S, Ca, Mg, B, Zn
- OM supplies 1-4% of its nutrients annually
<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical symbol</th>
<th>Relative % in plant to N</th>
<th>Function in plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary macronutrients</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>100</td>
<td>Proteins, amino acids</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>6</td>
<td>Nucleic acids, ATP</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>25</td>
<td>Catalyst, ion transport</td>
</tr>
<tr>
<td><strong>Secondary macronutrients</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
<td>12.5</td>
<td>Cell wall component</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
<td>8</td>
<td>Part of chlorophyll</td>
</tr>
<tr>
<td>Sulfur</td>
<td>S</td>
<td>3</td>
<td>Amino acids</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>0.2</td>
<td>Chlorophyll synthesis</td>
</tr>
<tr>
<td><strong>Micronutrients</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>0.01</td>
<td>Component of enzymes</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn</td>
<td>0.1</td>
<td>Activates enzymes</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
<td>0.03</td>
<td>Activates enzymes</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>0.2</td>
<td>Cell wall component</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>Mo</td>
<td>0.0001</td>
<td>Involved in N fixation</td>
</tr>
<tr>
<td>Chlorine</td>
<td>Cl</td>
<td>0.3</td>
<td>Photosynthesis reactions</td>
</tr>
</tbody>
</table>
Plant Nutrients

Soil nutrients are in form of **cations** and **anions**
- Cations e.g. NH\(^+\), Mg\(^{2+}\), Ca\(^{2+}\)
- Anions e.g. Cl\(^-\)

Clay & OM particles are negatively charged

So cations are adsorbed to these particles

A soil's capacity to hold cations is CEC
Cation Exchange Capacity

Soil particles are negatively charged, attract positively charged ions (cations)

CEC measure of the number of adsorption sites in a soil to adsorb and release cations

CEC measured as meq/100 g.

A soil with a CEC of one (1) has 600,000,000,000,000,000,000 adsorption sites in 100 grams (about ¼ tsp) of soil.

Low CEC soils leach & store less nutrients
Cation Exchange Capacity

- Measured in milliequivalents per 100 grams
- Varies with soil texture & OM content

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>CEC (meq/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sands</td>
<td>1 - 5</td>
</tr>
<tr>
<td>Fine sandy loams</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Silt loams</td>
<td>5 - 15</td>
</tr>
<tr>
<td>Clay loams</td>
<td>15 - 30</td>
</tr>
<tr>
<td>Clays</td>
<td>30+</td>
</tr>
</tbody>
</table>
Uptake of Minerals by Plants
CATION EXCHANGE

reprinted by courtesy of Paul Sachs from:
"Edaphos: Dynamics of a Natural Soil System"
The Living

- Soil microorganisms (bacteria, fungi, algae, etc.)
- Plant roots
- Animals - Earthworms, insects, mammals
- Aerate the soil
- Produce compounds for soil aggregates
- Microorganisms important in nutrient cycling
Soil Microbes

• Break down Organic Matter to:
  • Humus
  • Energy
  • Plant nutrients
  • Good temp for microbes 70-100°F
Bacteria & Fungi in \( \frac{1}{4} \) tsp of soil

- **Bacteria**
  - 100m-1 billion

- **Fungi**
  - 100,000-1 million

- Abundant on rhizosphere (area around the roots)
Yeast & Protozoa

- **Yeasts**
  - 10,000-100,000

- **Protozoa**
  - 10,000-100,000
Actinomycetes & Nematodes

- **Actinomycetes**
  - 10m-100million

- **Nematodes**
  - 10-100
The Dead

- Fresh residues
- Recently added manures
- Recently deceased microorganisms, plants, or animals
- Source of food & energy for microbes
The Very Dead

- Well-decomposed organic matter - humus
- Provides chemical properties of organic matter
  - Contributes to CEC
  - Buffers the soil against changes in pH
  - Helps form soil beds
Functions of Soil
Organic Matter

- Source of plant nutrients
- Helps to keep nutrients available
- Improves soil structure and porosity
- Improves water holding capacity
- Improves CEC
OM Importance

First, the organic matter coats soil particles, physically separating clay particles and aggregates from each other.

Second, and more important, microorganisms that degrade organic matter produce byproducts called **glomalin** that bind individual clay particles together into aggregates.
SOM enhances water-holding capacity

25 yrs of conventional corn

20 yrs of bluegrass, then 5 yrs conventional corn

photo by Ray Weil

Gruver, 2005
After adding water...
Bio-solids

- By-products of waste water treatment plants
- Supply 3-6% Nitrogen, 2-3% phosphorus

Two classes
- Class A heat & lime treated - no pathogens
- Class B, not heat treated

Bio-solids are not certified organic fertilizers
Fertilizers

• Materials containing plant nutrients that are added to the environment around the plant

• Usually sold as N, P, K shown as a ratio e.g. 10:10:10
  • i.e. 10% of nitrogen, phosphorus and potassium
  • Phosphorus as $P_2O_5$ and
  • Potassium as $K_2O$
Types of Fertilizer

- **Complete** - contains Nitrogen, Phosphorus, and Potassium
- **Acid Plant Fertilizers** - acidify soil for certain species
- **Slow Release** - materials are treated so that nutrients diffuse slowly
  - Pelletized MagAmp 7-40-0 2yrs, Ureaform 38-0-0 70% WIN. Coated eg osmcote, and sulfur coated urea
- **Fertilizer-Pesticide combination** - convenient, but expensive, not always necessary eg weed & feed
# Common Fertilizer Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>46</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium sulfate</td>
<td>21</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>18</td>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>Monoammonium phosphate</td>
<td>11</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>Triple superphosphate</td>
<td>0</td>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>Muriate of potash</td>
<td>0</td>
<td>0</td>
<td>60</td>
</tr>
</tbody>
</table>
## Organic Fertilizer Materials

Analysis shows total nutrients not available 

<table>
<thead>
<tr>
<th>Material</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottonseed meal</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Dried blood</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bone meal</td>
<td>3</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Seaweed</td>
<td>2</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Greensand</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Rock phosphate</td>
<td>0</td>
<td>33</td>
<td>0</td>
</tr>
</tbody>
</table>
Commercial vs. Organic

Commercial
- Usually less expensive per unit actual plant nutrient
- Less bulk to handle
- Available quickly
- Greater potential for plant burning

Organic
- Can be expensive per unit actual plant nutrient
- Can be bulky
- Slowly available
- Less potential for burning
- Still potential to pollute

Plant’s cannot distinguish between commercial and organic nutrient sources; it’s all just N, P, K, etc…
How Much Fertilizer Do You Need?

Soil Testing

- Index of soil nutrient availability
- Predicts probability of plant response to added nutrients
- Evaluation of soil fertility status
- Provides basis for recommendations
RATINGS

SOIL TEST INFORMATION

<table>
<thead>
<tr>
<th>V. Low</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>V. High</th>
<th>Excess</th>
</tr>
</thead>
</table>

| pHs    | 6.9  | ***************** |

| Phosphorus (P) | 241 lbs/a | *************************** |

| Potassium (K) | 640 lbs/a | ***************************************** |

| Calcium (Ca) | 9090 lbs/a | ************************************* |

| Magnesium (Mg) | 907 lbs/a | ************************* |

| Organic Matter: 4.2% | Neutr. acidity: 0.0 meq | CEC: 27.3 meq |

FERTILIZER & LIMESTONE SUGGESTIONS

Nitrogen (N): 0.5 Phosphate (P2O5): 0.0 Potash (K2O): 0.0 Lime: 0.0
Soil Nutrients & Crop Performance

Crop Yield vs Nutrient Level

- Low
- Optimal
- High
- Excessive

Crop response
Fertilizer Math

Fertilizer guides dealing with lawns and gardens provide recommendations in lb/1,000 sq ft.

If no test, use 2 lbs N/1000 sq ft using a fertilizer with 1:1:1 ratio

To calculate rate to use:
1. Get recommendations (2 lb N/1000 sq ft)
2. Determine available rate (as percentage) of nutrient from fertilizer bag
3. Divide recommended rate by available rate
4. Adjust this rate rate to your garden/lawn area
Math Example

Recommended rate is 4 lb/1000 square feet of phosphorus, your fertilizer analysis is 10:16:10, your garden is 500 sq ft

1. Recommended rate is 4 lb P/1000 sq ft
2. Available rate from bag as % is $16 \div 100 = 0.16$
3. Divide recommended rate by available rate => $4 \div 0.16 = 25$ lbs P/1000 sq ft
4. But your garden is 500 sq ft => $(500 \div 1000 \times 25) = 12.5$ lb P/1000 sq ft
LIEBIG’S “LAW OF THE MINIMUM”

Yield increases until the minimum factor becomes the factor limiting growth.

FIGURE 1.8 An illustration of the law of the minimum. The level of water in each barrel above represents the level of crop production. (a) Nitrogen is represented as being the factor that is most limiting. Even though the other elements are present in more adequate amounts, crop production can be no higher than that allowed by the nitrogen. (b) When nitrogen is added, the level of crop production is raised until it is controlled by the next most limiting factor, in this case potassium.
Organic Manures

For Organic fertilizers, use recommendations on package

For farm yard manures use
- 5 gallons per 50-150 sq ft of garden
- Use 1-2 inch layer deep for horse manure with beddings

Use manures and fertilizers at the time the plant needs most nutrition
- Tomatoes - when they start flowering
- Blueberries - at bud break
- Brassicas - during leaf growth

Use green manures (cover crops) in the fall to trap plant nutrients and add OM to soil
Taking Soil Samples

- Sample area at least every 3 years
- 10-15 random areas for gardens
- Sample at a depth of 4-6 inches
- Mix in a plastic container
- Get one cup of soil for analysis
- Separate samples for different conditions
- Go online and get labs that test soils
  - (EM 8677 Laboratories Serving Oregon: Soil, Water, Plant Tissue, and Feed Analysis)
Soil Test Results

- pH - actual and buffer pH for lime recs.
- Available Ca, Mg, K, P (VL, L, M, H, VH, Excess)
- CEC, OM, Neutralizing acidity
- Nutrient recommendations (N, P$_2$O$_5$, & K$_2$O)
- Specific application information
Composting

- Will be covered in another class
- Generally do not compost materials that have high C:N ratio greater than 30:1
- Usually straw, sawdust and bark have ratios greater than 30:1
- If a compost pile is not heating, check:
  - C:N Ratio & turn pile more frequently
  - Add greens (Low C:N ration materials)
  - Check moisture content