Introduction to Soils

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Learning Objectives

• Soil components and their relative proportion in soils
• Texture of a soil & influence of texture on plant growth
• Soil compaction, how to alleviate it, & how compaction affects plant growth.
• Soil organisms & effect on the chemical and physical properties of soil

• Importance of soil organic matter

• How different soil amendments affect the structure, texture, and pH of soils
• Colloids, CEC, cations, and anions and how they affect plant nutrition
• Why pH is such an important factor in nutrient uptake and plant nutrition and how changing pH affects different soil properties
• Essential elements required for plant growth and the different inorganic and organic fertilizer sources of each.
What Is Soil?
Webster Defines Soil As…..

• The upper layer of the earth that may be dug or plowed and in which plants grow
• However, to soil scientists the definition is more complex
• It may have different meanings to different people
Farmer
Forester
Horticulturist
Golf Course Superintendent
Engineer
Know Your Soil!
Soil Composition - Volume Basis

- Air: 25%
- Water: 25%
- Organic Matter: 5%
- Mineral Matter: 45%
Soil Profile
Permanent Soil Properties

- Texture
- Thickness of topsoil
- Thickness of subsoil
- Certain Chemical Properties
Changeable Soil Properties

- Soil Structure
- Soil Organic Matter
- Soil Color
- Soil pH (Acidity)
- Soil Nutrient Levels
SOIL TEXTURE
Soil Texture

- Soil texture refers to the relative proportions of sand, silt, and clay in a soil.
- 12 textural classes.
- Loam is considered to be ideal texture for growth of plants.
- Difficult to alter soil texture on large scale.
Importance of Soil Texture

- Influences pore size and pore space
  - large pores - air
  - small pores - water
  - sandy soils have larger pores, less surface area, and water drains more freely compared to clay soils

- Influences a soil's water holding capacity
  - fine textured soils have more and smaller pores
  - hold more water than sandy soils
  - also hold water more tightly
Soil Structure

- Manner in which soil particles are arranged together
- Particles in sandy soils may remain independent of each other
  - single grain texture
- Particles in fine textured soils are arranged in a definite manner to form stable aggregates
Soil Structure - 4 Types of Aggregates

- Granular
- Prismatic
- Blocky
- Platy
Importance of Soil Structure

- Improves air & water relationships
- Improves root penetration
- Improves water infiltration
- Reduces erosion
- Ease of tillage
- Reduces crusting
Maintaining Soil Structure

- Add Organic Matter
- Till Soil When Moist
  - Not Too Wet or Too Dry
- Grow Grasses
- Grow Cover Crops
  - Keeps Soil Protected from Rain, etc.
- Restrict Traffic
Relative Compacting Effects of Soils by Different Agencies

<table>
<thead>
<tr>
<th>Item</th>
<th>Pressure, Lb. Per Sq. Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man (150 pounds)</td>
<td>6</td>
</tr>
<tr>
<td>Crawler Tractor</td>
<td>12</td>
</tr>
<tr>
<td>Farm Tractor</td>
<td>20</td>
</tr>
<tr>
<td>Cattle</td>
<td>24</td>
</tr>
<tr>
<td>Trucks</td>
<td>50 – 100</td>
</tr>
<tr>
<td>Rototiller (garden)</td>
<td>107 – 750</td>
</tr>
</tbody>
</table>
Soil Color

• Many different soil colors
• Give important clues about soils chemical and physical environment
Soils Vary in Clay and Humus Content
Organic Matter

- Improves soil physical condition
- Reduces erosion
- Improves water infiltration
- Improves water holding capacity
- Increases soil cation exchange capacity
- Source of nutrients
Organic Matter

• Contains varying amounts of all the essential nutrient elements
  - e.g. ~ 5% Nitrogen
• Serves as important storehouse of elements such as nitrogen and sulfur
• Nutrient elements contained in freshly added organic matter are not immediately available to plants
• Residues must be decomposed into humus, and nutrients released in ionic form
Humus Formation

Residues → Carbohydrates, Cellulose, Proteins, Lignin → CO₂ → Protein, Lignin → Humus
Nitrogen Uptake

The diagram illustrates the uptake of nitrogen by plants. The plant roots are shown absorbing nitrate ($\text{NO}_3^-$) and ammonium ($\text{NH}_4^+$) from the soil.
Soil Microorganisms

- Bacteria
- Fungi
- Actinomycetes
- Algae
Major Roles of Bacteria in Plant Nutrition

**Fixation**
- Symbiotic (with legumes)
- Nonsymbiotic (without legume)

**Transformation**
- Mineralization (organic N to $\text{NH}_4^+$)
- Nitrification ($\text{NH}_4^+ \rightarrow \text{NO}_2^- \rightarrow \text{NO}_3^-$)
- Denitrification ($\text{NO}_3^- \rightarrow \text{N}_2\text{O}^- \rightarrow \text{or N}$)

**Oxidation**
- Elemental and organic S
  
  $$S \rightarrow \text{SO}_4^{2-}$$
Regular Additions of Organic Residues Must Be Made to Maintain Soil Organic Matter Levels
ORGANIC MATTER

TEMPERATURE

RAINFALL

= % SOIL ORGANIC MATTER

AMOUNT OF RESIDUE
Soil Colloids
Soil Colloids

- Chemically active fraction
- Made up of colloidal & colloidal-like particles
  - organic matter
  - clay
- Colloids and clays develop electrical charges (+,-) as they are formed
- Predominant electrical charge most clays and organic matter is negative (-)
Soil colloids may be envisioned as a huge anion.
Cation Exchange

\[ \text{Ca} + 2\text{H}^+ \rightarrow \text{H}^+ + \text{Ca}^{2+} \]
# Cation Exchange Capacity of Clays & Organic Matter

<table>
<thead>
<tr>
<th>Clay Mineral</th>
<th>Exchange Capacity cmol(+)/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolinite</td>
<td>3-5</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>100-120</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>100-180</td>
</tr>
<tr>
<td>Illite</td>
<td>40</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>200-400</td>
</tr>
</tbody>
</table>
pH is a term used to describe the H ion (H\(^+\)) activity and/or concentration in solution

\[
pH = -\log (H^+)\]
Sorensen pH Scale

Scale ranges from 0 to 14.

A pH of 7.0 is neutral meaning the hydrogen ion and hydroxyl ion activity are equal.

pH values greater than 7.0 are alkaline.

pH values less than 7.0 are acidic.
## pH Expressions

<table>
<thead>
<tr>
<th>pH of Solution</th>
<th>Hydrogen ion activity, g/liter</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0 (strongly alkaline)</td>
<td>$10^{-9}$ (0.0000000001)</td>
</tr>
<tr>
<td>8.0 (moderately alkaline)</td>
<td>$10^{-8}$ (0.0000000001)</td>
</tr>
<tr>
<td>7.0 (neutral)</td>
<td>$10^{-7}$ (0.0000001)</td>
</tr>
<tr>
<td>6.0 (moderately acidic)</td>
<td>$10^{-6}$ (0.000001)</td>
</tr>
<tr>
<td>5.0 (strongly acidic)</td>
<td>$10^{-5}$ (0.00001)</td>
</tr>
<tr>
<td>4.0 (very strongly acidic)</td>
<td>$10^{-4}$ (0.0001)</td>
</tr>
</tbody>
</table>
Soil pH Reflects Hydrogen Ion Activity

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Acidity/Alkalinity Compared to pH 7.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Neutral</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>1000</td>
</tr>
</tbody>
</table>
pH of Common Products & Soils

Range found in common products

- Milk of magnesia: pH 10
- Bicarbonate of soda: pH 9
- Pure water/Milk: pH 8
- Natural rain: pH 7
- Beer/Coffee: pH 6

pH scale

Range found in various soils

- Sodic soils
- Calcareous soils
- Humid region arable soils
- Forest soils
Soil pH is one of the most important chemical reactions that occurs in soils.

Why?
It affects so many reactions and activities that occur in soils.
Chemical Reactions
• Nutrient Availability
• Toxic Elements in Soils
• Al and Mn
• Toxic Elements in Soils
• Al and Mn
Relation of Soil pH to Nitrification

Relative Nitrification in Soil by Bacteria

pH

4.0  5.0  6.0  7.0  8.0  9.0

GOOD

POOR
Relative Nitrogen Efficiency

![Bar chart showing relative nitrogen efficiency at different soil pH levels.](chart.png)
Relative Potassium Efficiency

Soil pHw

Relative Efficiency, %

5 6 6.5

Soil pHw
Soils Become Acid Because-

- Developed in areas with high rainfall, resulting in:
  
  a. leaching and plant uptake of base forming cations (Ca$^{2+}$, Mg$^{2+}$, and K$^+$)
  
  b. rapid reaction of water with Al & Fe, which produces H ions

- Application of acid forming fertilizers
  - mostly those containing ammonical (NH$_4^+$) nitrogen

- Decomposition of organic matter

- Microbial activity
Nitrogen Conversion in the Soil Produces Acidity

Organic Matter
Manure, etc.

\[ 2 \text{NH}_4^+ + 4\text{O}_2 \xrightarrow{\text{Bacteria}} 2\text{NO}_3^- + 2\text{H}_2\text{O} + 4\text{H}^+ \]

NH\(_4\) - N Fertilizer Sources

Note: The H\(^+\) is the acidity component
Determining Soil Acidity

- pH Kits
- pH Meters
Determining Soil pH & Limestone Requirement at UGA Laboratory

- Automated soil pH analyzer (130 samples can be analyzed per hour)
- Two analyzers operational gives the Lab capacity to analyze 260 samples/hour for pH and lime requirement
- Soil pH is recorded on soil test report as pH$_{\text{CaCl}_2}$ and Equivalent Water pH along with the lime buffer capacity.
Desired pH

6.0 - 6.5

Note these pH values are equivalent to 5.4 and 5.9 for pH determined in calcium chloride
## Desired pH for Some Crops

<table>
<thead>
<tr>
<th>pH Range</th>
<th>Blueberries</th>
<th>Irish Potatoes</th>
<th>Azaleas</th>
<th>Rhododendrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 – 5.5*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.5 – 6.0*</td>
<td>Sweet Potatoes</td>
<td>Lawn Grasses</td>
<td>Annual Flowers</td>
<td>Perennial Flowers</td>
</tr>
<tr>
<td>6.0 – 6.5*</td>
<td>Sweet Corn</td>
<td>Tomatoes</td>
<td>Onions</td>
<td>Cabbage</td>
</tr>
<tr>
<td></td>
<td>Watermelon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*pH<sub>w</sub> Values
How Can We Reduce Soil Acidity?

Apply Liming Materials
Lime Sources and Their Relative Neutralizing Values

<table>
<thead>
<tr>
<th>Liming Material</th>
<th>Relative Neutralizing Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcitic Limestone</td>
<td>85 – 100</td>
</tr>
<tr>
<td>Dolomitic Limestone</td>
<td>95 - 108</td>
</tr>
<tr>
<td>Burned Lime</td>
<td>179</td>
</tr>
<tr>
<td>Hydrated Lime</td>
<td>120 - 135</td>
</tr>
<tr>
<td>Gypsum</td>
<td>None</td>
</tr>
</tbody>
</table>

*Calcium Carbonate is used as a standard with a neutralizing value of 100
Incorporate Lime for Best Results
FREQUENCY AND RATE OF LIMING DEPENDS ON:

- SOIL pH
- SOIL TEXTURE
- NITROGEN FERTILIZATION RATES
- REMOVAL OF Ca AND Mg BY PLANTS
- AMOUNT OF LIME PREVIOUSLY APPLIED
- SOIL pH RANGE DESIRED
Acidifying Soils

• Acidifying soils is frequently required in nursery and horticultural situations.
Materials Used for Acidifying Soils

- Elemental sulfur
- Aluminum sulfate (Alum)
- Iron sulfate
Reducing Soil pH with Sulfur or Aluminum Sulfate

<table>
<thead>
<tr>
<th>Initial Soil pH&lt;sub&gt;w&lt;/sub&gt;</th>
<th>5.5</th>
<th>6.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6.0</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>6.5</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>7.0</td>
<td>12</td>
<td>29</td>
</tr>
<tr>
<td>7.5</td>
<td>15</td>
<td>38</td>
</tr>
</tbody>
</table>

Textural Classification

<table>
<thead>
<tr>
<th>Sandy</th>
<th>Loamy</th>
<th>Clayey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy</td>
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<td>Clayey</td>
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Sulfur Required, lbs per 1000 ft<sup>2</sup>**

**Aluminum sulfate rate = lbs. Sulfur x 6**
# Reducing Soil pH with Sulfur or Aluminum Sulfate

<table>
<thead>
<tr>
<th>Initial Soil pH&lt;sub&gt;W&lt;/sub&gt;</th>
<th>Textural Classification</th>
<th>Sulfur Required, lbs per 1000 ft&lt;sup&gt;2**&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sandy</td>
<td>4.5</td>
</tr>
<tr>
<td>Sandy</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Loamy</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Clayey</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Sandy</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Loamy</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>Clayey</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
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**Aluminum sulfate rate = lbs. Sulfur x 6**
• Elemental sulfur and sulfur compounds are the most popular acidifying materials.

• Bacteria are required for this process to occur.

\[
2S + 3O_2 + 2H_2O \rightarrow 2H_2SO_4
\]

(Thiobacillus)
• Aluminum and iron sulfates can also be used

• These materials are very effective but are sometimes difficult to find

• They react quicker and do not require microbial oxidation

• Acidity is result of hydrolysis reaction:
  \[ \text{Al}_2(\text{SO}_4)_3 + 6\text{H}_2\text{O} \leftrightarrow 2\text{Al(OH)}_3 + 6\text{H}^+ + 3\text{SO}_4^= \]
  \[ \text{Fe}_2(\text{SO}_4)_3 + 6\text{H}_2\text{O} \leftrightarrow 2\text{Fe(OH)}_3 + 6\text{H}^+ + 3\text{SO}_4^= \]
Questions?
Thank You