Soils, Plant Nutrition & Fertilizers

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Soil, What Is It?

• The unconsolidated inorganic and organic materials on the surface of the earth which support the growth of plants.

Soil, What Is It?

• Soil is a living entity: the crucible of life, a seething foundry in which matter and energy are in constant flux and life is continually created and destroyed.

• Daniel Hillel, “Out of the Earth”

Soil Functions-Big Picture

• General Concepts
  – Sustain plant and animal productivity
  – Regulate water flow through the environment
  – Buffer environmental changes in air quality, water quality and global climate
  – Support human health and habitation
  – Filter and detoxify pollutants

• “The thin layer of soil covering the earth’s surface represents the difference between survival and extinction for most terrestrial life”

• J.W. Doran and T. B. Parkin
• Defining and Assessing Soil Quality
Soil Functions-Garden Perspective

- Specific Functions
  - Anchor plants
  - Provide mineral nutrients
  - Supply water
  - Allow air exchange
  - Provide a “home” for many living organisms

Factors of Soil Formation

- Or, why are soils different from each other?
  - Parent Material
  - Climate
  - Vegetation
  - Topography
  - Time

Factors of Soil Formation

- Parent Material
  - Bedrock weathered in place
  - Deposits left by glaciers
  - Materials deposited by wind or water
  - Decaying plant material

Wanna know your soil type

- Web Soil Survey (USDA-NRCS)

Factors of Soil Formation

- Climate
  - Temperature
  - Rainfall
### Factors of Soil Formation

- **Vegetation**
  - Forest
  - Prairie

- **Topography**
  - Lay of the land
    - Flat or Rolling
  - Position in the landscape
    - Hilltop
    - Slope
    - Valley
    - Depression

### Factors of Soil Formation

- **Time**
  - Development of horizons

### Soil Horizons

- Or, how a soil differs from the surface to greater depths
Global Distribution of Mollisols

Physical Properties of Soil

- Texture
- Structure
- Soil water—infiltration rate and capacity to hold water
- Tilth, porosity and bulk density
- Color
- Temperature

Understanding soil composition

1. Soils are a mixture of different sized mineral particles

Understanding soil composition

2. Clay particles are layered and have a negative surface charge

Understanding soil composition

3. The soil matrix has three phases
   - Solid (mineral and organic)
   - Pore space occupied by air and water
   In some ways the soil is much like a hyper-active sponge

Understanding soil composition

4. Water is the medium for interaction between plants and soil
Texture—The Individual Particles That Make Up Soil

- **Sand**
  - Between 0.05 and 2.0 mm in diameter
  - Feels rough, gritty
- **Silt**
  - Between 0.002 and 0.05 mm in diameter
  - Feels smooth, like flour
- **Clay**
  - Less than 0.002 mm in diameter
  - Feels sticky when wet

Soil Texture Affects

- Porosity
- Organic matter retention
- Bulk density
- Water retention
- Mineral and nutrient retention

Volume Composition of Soil

- Air: 25% of volume
- Water: 25% of volume
- Mineral matter: 45-49% of volume
- Organic matter: 1-5% of volume

Surface Area In One Acre Of Soil Six Inches Deep

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Area ratio</th>
<th>Equivalent acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>Silt</td>
<td>100</td>
<td>50,000</td>
</tr>
<tr>
<td>Clay</td>
<td>50,000</td>
<td>25,000,000</td>
</tr>
</tbody>
</table>

Relationship between soil texture, bulk density, and pore space

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>Bulk density (g/cc)</th>
<th>Pore space (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>1.6</td>
<td>39</td>
</tr>
<tr>
<td>Loam</td>
<td>1.3</td>
<td>50</td>
</tr>
<tr>
<td>Silt loam</td>
<td>1.2</td>
<td>54</td>
</tr>
<tr>
<td>Clay</td>
<td>1.1</td>
<td>58</td>
</tr>
<tr>
<td>Muck</td>
<td>0.9-1.1</td>
<td>variable</td>
</tr>
<tr>
<td>Peat</td>
<td>0.7-1.0</td>
<td>variable</td>
</tr>
</tbody>
</table>
Soil Structure

- Combination of individual soil particles, with soil organic matter, into larger units
- Necessary so that air, water and plant roots can move through the soil

Types of Structure

- Single grain (sands)
- Granular
- Platy
- Blocky
- Prismatic
- Massive

Soil Structure Affects

- Water movement
- Root penetration
- Porosity and aeration
- Bulk density
- Susceptibility to erosion

Composition of Soil

- Organic Matter - 2.5%
- Minerals - 44.48%
- Air - 25%
- Water - 25%

Figure 9-5: Composition of a natural soil, by weight.

Figure 9-6: Composition of a composted soil, by weight.
Simple concepts of soil water

- Field capacity = Water content of a soil after gravitational water has drained
- Permanent wilting point = Water content of a soil where plant cannot absorb water
- Plant available water = Difference between field capacity and permanent wilting point
Plant available water

- **Sand**
- **Silt loam**
- **Clay**

Preferential flow examples

Dye movement through soil
Tile line smoking demonstration

Preferential flow on a large scale

Water flow and texture

- Textural changes always restrict flow

The “Teacup” Effect

Amended soil
Rootball
Unamended Slow-draining soil
Perched water

Water Infiltration
Textural Class Available Water Capacity (Inches/Foot of Depth)

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>Available Water Capacity (Inches/Foot of Depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>0.25 – 0.75</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.75 – 1.00</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>1.10 – 1.20</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>1.25 – 1.40</td>
</tr>
<tr>
<td>Silt loam</td>
<td>2.00 – 2.50</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>1.80 – 2.00</td>
</tr>
<tr>
<td>Clay</td>
<td>1.20 – 1.50</td>
</tr>
</tbody>
</table>

Soil water holding capacity

- Coarse soils 0.5 - 1.0 inches per foot
- Medium soils 1.8 - 2.8 inches per foot
- Fine soils 1.5 - 2.2 inches per foot
- Evapotranspiration rate = 0.25 inches per day

Chemical Properties of Soil

- Nutrient content
- Cation exchange capacity
- pH

Plant Nutrients

- Structural nutrients provided by air and water
  - Carbon (C), Hydrogen (H), and Oxygen (O)
- Primary nutrients
  - Nitrogen (N), Phosphorus (P), and Potassium (K)
- Secondary nutrients
  - Calcium (Ca), Magnesium (Mg), and Sulfur (S)
- Micronutrients
  - Cobalt (Co), Copper (Cu), Zinc (Zn), Iron (Fe), Molybdenum (Mo), Boron (B), Manganese (Mn), Nickel (Ni), and Chlorine (Cl)

Nutrient Content and Available Forms

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>% of plant dry matter</th>
<th>Available forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>41.2</td>
<td>CO₂</td>
</tr>
<tr>
<td>Oxygen</td>
<td>48.3</td>
<td>CO₂, H₂O, O₂</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5.4</td>
<td>H₂O, H⁺</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>3.3</td>
<td>NH₄⁺ (ammonium), NO₃⁻ (nitrate)</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.1</td>
<td>Ca²⁺</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.80</td>
<td>K⁺</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.42</td>
<td>Mg²⁺</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.30</td>
<td>H₂PO₄⁻, HPO₄⁻ (orthophosphate)</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.085</td>
<td>SO₄²⁻ (sulfate)</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.011</td>
<td>Cl⁻</td>
</tr>
<tr>
<td>Iron</td>
<td>0.0086</td>
<td>Fe⁺, Fe²⁺</td>
</tr>
<tr>
<td>Boron</td>
<td>0.0045</td>
<td>H₂BO₂⁻ (boric acid)</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.0036</td>
<td>Mn²⁺</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.0009</td>
<td>Zn²⁺</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0007</td>
<td>Cu²⁺</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>0.000005</td>
<td>MoO₄²⁻ (molybdate)</td>
</tr>
<tr>
<td>Cobalt</td>
<td>-</td>
<td>Co²⁺</td>
</tr>
</tbody>
</table>
Nutrient Deficiency

- Mobile nutrients-deficiency appears on older leaves first
  - N, P, K, Mg, S
- Immobile nutrients-deficiency appears on new leaves first
  - Ca, Fe, Zn, Mo, B, Cu, Mn

How Plant Roots Get Nutrients

- Mass flow
- Diffusion
- Root interception

Mass flow – dissolved nutrients move to the root in soil water that is flowing towards the roots

Diffusion – nutrients move from higher concentration in the bulk soil solution to lower concentration at the root;
- In the time it takes NO₃⁻ to diffuse 1 cm, K⁺ diffuses 0.2 cm, and H₂PO₄⁻ diffuses 0.02 cm

Root interception – roots obtain nutrients by physically contacting nutrients in soil solution or on soil surfaces;
- roots contact ~1% of soil volume;
- mycorrhizal infection of root increase root-soil contact

Cation Exchange Capacity

- Cation Exchange Capacity is the ability of a soil to hold and release positively charged ions (Ca++, K+, H+, Mg++)
- The soil particles (clay, silt and sand) and soil organic matter are negatively charged and will attract positively charged ions
Clay minerals and CEC

Soil pH

- How acidic or basic
- Measurement is of hydrogen ion concentration
- Range goes from 0 to 14
- 7 is neutral, less than 7 is acidic, greater than 7 is basic
- One unit change in pH is a 10 fold change in hydrogen ion concentration
Adjusting Soil pH

- Raising low soil pH
  - Dolomitic limestone—mixture of calcium carbonate and magnesium carbonate
  - Calcitic, hydrated, burned lime
  - Wood ash—40% as effective as limestone
- Lowering soil pH
  - Elemental sulfur
  - Iron sulfate
  - Acidic fertilizers, acidic mulches

### Amounts of sulfur to apply to soils to reduce the pH

<table>
<thead>
<tr>
<th>Desired pH Change</th>
<th>Sandy Soils</th>
<th>Loam Soils</th>
<th>Clay Loams</th>
<th>Organic Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0 to 6.0</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td>6.0 to 5.0</td>
<td>1.5</td>
<td>2.0</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>5.0 to 4.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

The sulfur is to be mixed with the top 7 inches of soil.

Aluminum sulfate has also been used to reduce soil pH. It reacts faster than sulfur, but you need to use 7 times as much. The aluminum in the aluminum sulfate has been shown to harm plant roots, so the use of aluminum sulfate to acidify is not currently recommended.

### Pounds of Lime Needed per 100 Square Feet to Raise Soil pH to 6.5

<table>
<thead>
<tr>
<th>Soil pH</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>2</td>
<td>3.5</td>
<td>5</td>
</tr>
<tr>
<td>5.5</td>
<td>4.5</td>
<td>7.5</td>
<td>10</td>
</tr>
<tr>
<td>5.0</td>
<td>6.5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>4.5</td>
<td>8</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>4.0</td>
<td>10</td>
<td>17.5</td>
<td>23</td>
</tr>
</tbody>
</table>

### Soil Biology & Soil Organic Matter

- **the Living**
- **the Recently Dead**
- **and the Long Time Dead**

**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
The Recent Dead

- Fresh residues
- Recently added manures
- Recently deceased microorganisms, plants, or animals
- Source of nutrients for plants
- Source of food for animals
- Source of energy for microbes

The Long Time Dead

- Well-decomposed organic matter – humus
  - 70-80% of added carbon is lost as CO₂
  - Approximately 15% is incorporated in humus
- Provides chemical properties of organic matter
  - Contributes to CEC
  - Buffers the soil against changes in pH
  - Effect on plant growth-like hormones

Relationship to soil quality?

Soil organisms are involved in nearly every aspect of soil quality

- Structure/Aggregation
- Organic matter
- Humification
- Nitrification
- Nutrient cycling
- Decomposition
Soil Animals
- Termite
- Earthworm
- Centipede
- Snail
- Vole

Soil mesofauna
- Nematodes
- Mites
- Protozoa

Soil microorganisms
- Fungi
- Bacteria
- Yeasts
- Protozoa
- Nematodes

Soil Microbes

<table>
<thead>
<tr>
<th>Species</th>
<th>Population per gram of soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>&gt;100,000,000</td>
</tr>
<tr>
<td>Fungi</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Yeasts</td>
<td>100,000</td>
</tr>
<tr>
<td>Protozoa</td>
<td>500,000</td>
</tr>
<tr>
<td>Nematodes</td>
<td>5,000</td>
</tr>
</tbody>
</table>

Source: Harrison et al 1999

Roots without mycorrhizae
Roots with mycorrhizae
Diversity may be important in response to management

**Change in soil organisms with change in cropping systems**

<table>
<thead>
<tr>
<th></th>
<th>Corn Field</th>
<th>Organic Apples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>186ug/g</td>
<td>338ug/g</td>
</tr>
<tr>
<td>Fungi</td>
<td>37ug/g</td>
<td>618ug/g</td>
</tr>
<tr>
<td>Flagellates</td>
<td>1,200ug/g</td>
<td>115,000ug/g</td>
</tr>
<tr>
<td>Amoebae</td>
<td>7,400ug/g</td>
<td>156,000ug/g</td>
</tr>
<tr>
<td>Ciliates</td>
<td>58ug/g</td>
<td>7,700ug/g</td>
</tr>
<tr>
<td>Bacterial feeding nematodes</td>
<td>365/100cm³</td>
<td>882/100cm³</td>
</tr>
<tr>
<td>Fungal feeding nematodes</td>
<td>55/100cm³</td>
<td>870/100cm³</td>
</tr>
<tr>
<td>Plant parasitic nematodes</td>
<td>42/100cm³</td>
<td>28/100cm³</td>
</tr>
</tbody>
</table>

**Earthworm Casts vs Soil**

- Structural stability: 849 vs 65
- CEC: 13.8 vs 3.5
- Exchangeable K: 0.6 vs 0.2
- Soluble P: 17.8 vs 6.1
- Total N: 0.33 vs 0.12

**Soil Organic Matter Is**

- Carbon containing compounds
- Formed by living organisms
- In many physical and chemical configurations
C : N ratio of organic materials

- Soil organic matter: 10:1
- Clover – green manure: 12:1
- Manure: 20:1
- Rye – green manure: 36:1
- Cornstalks: 60:1
- Straw: 80:1
- Leaves: 150:1
- Sawdust: 300:1

Avoid N Deficiency

- You need to add 3 to 4 lbs of actual N per cubic yard of leaves, sawdust, or straw to avoid nitrogen deficiency.

Beneficial Practices for Improving Soil Quality

- Add organic matter
- Avoid excess tillage
- Prevent soil compaction
- Keep the ground covered
- Diversify cropping systems
- Carefully manage fertilizer and pesticide use

Effects of Soil Quality Changes

- Crops ability to withstand drought, pests and other stress
- Soil’s ability to minimize erosion losses
- Soil’s ability to minimize nitrogen losses
- Soil’s ability to store carbon

Soil Amendments

- Fertilizer
- Manure
- Compost
- Lime, sulfur, gypsum
- Humus, peat moss
- Cover crops, “green manure”
- Mulch, raw organic matter
Fertilizer Analysis

Amount of nutrient fertilizer contains, expressed as percent by weight

\[
\begin{array}{c}
10 - 20 - 20 \\
\end{array}
\]

Turf Fertilizer Materials

- Regular or general use
  - High nitrogen 27-4-6
- Starter
  - High phosphorus 9-13-7 or 18-24-6
- Winterizer
  - High potassium 5-5-25

Organic vs Conventional

- Organic
  - Natural material
  - Manure, fish by-products, rock phosphate
  - Slow release
  - Low nutrient content
- Conventional
  - Manufactured or extracted
  - Potassium chloride, urea, ammonium sulfate
  - Immediately available
  - High nutrient content

Organic Fertilizer Materials

<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>

Manipulate Growth

- For vegetative growth
  - Use a high N, low P and K fertilizer
- For flower, root, nutrient storage
  - Use a low N, high P and K fertilizer

Testing Soil

- How, when and where to sample
- Interpretation of results
Good Fertilizer Recommendations Depend On:

- A representative soil sample
- Accurate soil and crop history
- Good laboratory testing techniques
- Valid interpretation of results
- Knowing nutrients removed by the crop

Sampling Methods Are Critical!

- The soil sample has to represent the field.

Sampling Soils for Testing - Techniques -

- Take at least ten cores per composite sample
- Use a sampling probe or auger
- Sample to plow depth (at least 6 inches)
- Be consistent in depth of sampling
- Avoid small areas that are not typical of the whole field:
  - Dead furrows; lime, sludge or manure piles; animal droppings; fences or roads; previous fertilizer bands; eroded knolls; low spots

Soil Test Interpretation Categories

<table>
<thead>
<tr>
<th>Soil Test Level</th>
<th>Relative Supply of Nutrients From Soil and Fertilizer</th>
<th>Probability of Yield Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>Soil Fertilizer</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>High</td>
<td>Soil Fert.*</td>
<td>5-30%</td>
</tr>
<tr>
<td>Optimum</td>
<td>Soil Fertilizer</td>
<td>30-60%</td>
</tr>
<tr>
<td>Low</td>
<td>Soil Fertilizer</td>
<td>60-90%</td>
</tr>
<tr>
<td>Very Low</td>
<td>Soil Fertilizer</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Low</td>
<td>Soil Fertilizer</td>
<td></td>
</tr>
</tbody>
</table>

Nutrients available from soil
Nutrients used at high soil test levels are for starter or maintenance purposes

Soil Test Results

- pH-6.2 to 7.0 most desirable
- % O.M.—Goal is to increase it
- ppm P-35-50 ppm satisfactory
- ppm K-120-150 ppm satisfactory

Soil Math

43,560 square feet = 1 acre.

Divide per acre recommendations by 43.56 to get amount to apply to 1000 square feet.

Divide per acre recommendations by 435.6 to get amount to apply to 100 square feet.

Fertilizer analysis of 9-23-30
9% N 23% P2O5 30% K2O
Fertilizer analysis of 0-0-60
0% N 0% P2O5 60% K2O

Example: Recommendation calls for 275 lbs/acre of K2O. If we apply 0-0-60 fertilizer, divide 275 lbs/acre by .6 to get 458 lbs/acre of 0-0-60.

To treat 100 square feet, we would divide 458 by 435.6 to get 1.05 lbs of 0-0-60 per 100 square feet.