Outline

• Soil diversity
• Soil properties and nutrient availability
• Essential plant nutrients and deficiency symptoms
• Soil nutrient management
Plant Growth Factors
Soil Fertility

- Type of soil
  - Physical
  - Chemical
  - Biological

J.L. Deenik
Hawaii`s Diverse Soils

http://soils.usda.gov/gallery/photos/profiles/
47 soil map units
Windward Soils

Two basic soil types:

1. Weathered soils (Ultisols, Oxisols)
   *Alaeloa, Lolekaa, Lahaina*…
   - higher rainfall areas (upland)
   - red, acid, infertile
   - good physical properties
Windward Soils

Two basic soil types:

2. Unweathered soils (Mollisols, Inceptisols)
   *Waialua, Hanalei, Mokuleia…*
   - dark, neutral, fertile
   - drier climate (valley floor)
   - poor physical properties
Soil Properties

Lolekaa, Alaeloa:
- extremely acid
- low in calcium
- high P fixation (low P availability)
- good physical properties

Lahaina:
- acid
- sufficient Ca, Mg
- moderate P fixation
- good physical properties
Soil Properties

**Waialua:**
- neutral
- rich in Ca & Mg
- low P fixation (P available)
- poor physical properties
Know Your Soil!

Soil Determines:

• Water storage and movement
• Nutrient availability
• Workability
## Essential Elements

<table>
<thead>
<tr>
<th>Element</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong> – nitrogen</td>
<td>- Proteins, DNA, RNA, NH$_4^+$, NO$_3^-$</td>
</tr>
<tr>
<td><strong>P</strong> – phosphorus</td>
<td>- Energy (ATP), Sugars, DNA, RNA, H$_2$PO$_4^-$, HPO$_4^{2-}$</td>
</tr>
<tr>
<td><strong>K</strong> – potassium</td>
<td>- Enzyme activation, Photosynthesis, Sugar transport, RNA, K$^+$</td>
</tr>
</tbody>
</table>
Essential Elements

Secondary

Ca – calcium  Mg – magnesium  S – sulfur
- cell wall  - chlorophyll  - proteins
- Ca$^{2+}$  - Mg$^{2+}$  - SO$_4^{2-}$

Micronutrients

B – boron  Fe – iron  Mn – manganese  Cu – copper
Zn – zinc  Mo – molybdenum
Soil-Nutrient-Plant Relations

- pH
- Type and quantity of clay
  - determines behavior
- Water content
- Organic matter
pH and Nutrient Availability

When pH drops below 5.5, Al$^{3+}$ toxicity can be a serious problem.
Liming

Uchida & Hue, 2000
Liming

1. To raise pH
   - Reduces P fixation
   - Reduces Al solubility
   - Increases N, S, B, Cu and Mo availability

2. To supply Ca
Clays

Alaeloa/Lahaina

Kaolinite-Fe/Al oxides
- Low CEC (pH dependent)
  - Low nutrient holding capacity
- High P-fixation
- No shrink/swell
- Strong aggregates

Waialua/Hanalei

Smectite
- High CEC
  - High nutrient holding capacity
- Low P-fixation
- Shrink/swell
- Poor aggregation
Soil: Nutrient Reservoir

Nutrient reservoir: Cation Exchange (CEC)

Brady & Weil, 2004
P-Fixation

The diagram illustrates the amount of phosphorus fixation in soil at different pH levels. It shows that phosphorus fixation by iron and aluminum peaks at different pH values, with a range for highest P availability indicated. The pH levels are marked as pH3 to pH9, with acid soils on the left, neutral in the middle, and alkaline soils on the right.
Water

1. Nutrients move to the roots with water
   - Mass flow: N, Ca, Mg
   - Diffusion: P, K

2. Saturated soils
   - Loss of N (denitrification)
   - Accumulation of toxic compounds (H\textsubscript{2}S, CH\textsubscript{4})

3. Salinity
   - salt build-up under dry conditions
Organic Matter

1. Improves aggregation
   - Increases drainage
2. Increases CEC
3. Increases moisture holding capacity
4. Increases nutrient availability
   - source of N, P, S
   - N fixation
   - Increases micronutrient availability

Brady & Weil, 2004
## Plant Nutrient Requirements

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield T/acre</th>
<th>N lbs/acre</th>
<th>P lbs/acre</th>
<th>K lbs/acre</th>
<th>Ca lbs/acre</th>
<th>Mg lbs/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn (FW)</td>
<td>20</td>
<td>233</td>
<td>30</td>
<td>212</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>Cabbage</td>
<td>29</td>
<td>136</td>
<td>16</td>
<td>99</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Onions</td>
<td>41</td>
<td>114</td>
<td>20</td>
<td>104</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>Lettuce</td>
<td>30</td>
<td>113</td>
<td>15.4</td>
<td>180</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Cucumber</td>
<td>22</td>
<td>44</td>
<td>13</td>
<td>65</td>
<td>28</td>
<td>7</td>
</tr>
<tr>
<td>Tomato</td>
<td>27</td>
<td>200</td>
<td>20</td>
<td>297</td>
<td>103</td>
<td>29</td>
</tr>
<tr>
<td>Banana</td>
<td>47</td>
<td>252</td>
<td>27</td>
<td>933</td>
<td>97</td>
<td>18</td>
</tr>
</tbody>
</table>

1. N & K high
2. P, Ca, and Mg generally low
3. Residues return nutrients to the soil
Deficiency Symptoms
Law of the Minimum

“Plant production can be no greater than that level allowed by the growth factor present in the lowest amount relative to the optimum amount for that factor.”

Justus von Liebig, 1862
General Types of Deficiency Symptoms

- **Chlorosis** - yellowing due to reduction in chlorophyll
  - uniform or interveinal
- **Necrosis** - death of plant tissue
- Lack of new growth or terminal growth resulting in **rosetting**
- **Anthocyanin** accumulation resulting in reddish color
- **Stunting** with either normal or dark green color or yellowing
<table>
<thead>
<tr>
<th>Mobile</th>
<th>Immobile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms appear in older leaves first</td>
<td>Symptoms appear in younger leaves first</td>
</tr>
<tr>
<td>• nitrogen</td>
<td>• sulfur</td>
</tr>
<tr>
<td>• phosphorous</td>
<td>• calcium</td>
</tr>
<tr>
<td>• potassium</td>
<td>• boron, iron, manganese, zinc, copper, molybdenum, chloride</td>
</tr>
<tr>
<td>• magnesium</td>
<td></td>
</tr>
</tbody>
</table>
Nitrogen

- Chlorosis on older leaves
- Stunted plants
- Reduced yields

All deficiency symptom photos taken from Uchida, 2000
Phosphorus

- Purple or reddish color
- Necrotic spots on older leaves
- Overall stunting
Potassium

- Chlorosis along leaf margins
- Stems weak, lodging common
- Small fruits (some deformity)
Calcium

- New leaves necrotic
- Growing point dies
- New leaves twisted or fail to unfold
Magnesium

- Interveinal chlorosis on older leaves
Sulfur

- Younger leaves chlorotic
- Poor growth with delayed maturity
Boron

- Young leaves thicken, curl and become brittle
- Stunted growth

Specific symptoms:
- Peanuts: hollow heart
- Celery: crooked cracked stem
- Papaya: distorted, lumpy fruit
- Cabbage, cauliflower, broccoli: pith in hollow stem
Copper

- Distorted young leaves with possible necrosis of apical meristem
- Stunted growth
Iron

- Interveinal chlorosis in young leaves
Manganese

- Interveinal chlorosis in young leaves
- Monocots: streaking
- Dicots: chlorosis in small yellow spots
Zinc

- Interveinal chlorosis in bands on young leaves
- New leaves small, mottled and chlorotic
- Leaf rosetting
Benefits of Manures

- Soil chemical properties
  - source of plant nutrients
  - Increase in buffering capacity
  - Increase in CEC
Benefits of Manures

• Soil biological properties
  - diversity
  - nutrient cycling
  - pest/pathogen suppression
  - symbioses
# Manure as a Source of Nutrients

## Locally available manures

<table>
<thead>
<tr>
<th>M. Type</th>
<th>DM</th>
<th>pH</th>
<th>EC</th>
<th>C</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Cu*</th>
<th>C/N</th>
<th>N/P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy pen</td>
<td>71</td>
<td>8.7</td>
<td>20</td>
<td>28</td>
<td>1.9</td>
<td>1.0</td>
<td>2.4</td>
<td>120</td>
<td>14.7</td>
<td>1.9</td>
</tr>
<tr>
<td>Chicken</td>
<td>35</td>
<td>7.9</td>
<td>30</td>
<td>27</td>
<td>3.2</td>
<td>2.8</td>
<td>2.0</td>
<td>88</td>
<td>8.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Swine pen</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2.1</td>
<td>2.6</td>
<td>0.5</td>
<td>90</td>
<td>--</td>
<td>0.8</td>
</tr>
</tbody>
</table>

* DTPA extractable (pH 7.3)

(Source: Hue, 2004)
Manure as a Source of Nutrients

Total nutrient contents of some commonly used manures.

<table>
<thead>
<tr>
<th>Material</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry (broiler) manure*</td>
<td>4.4</td>
<td>2.1</td>
<td>2.6</td>
<td>2.3</td>
<td>1.0</td>
<td>0.6</td>
<td>1000</td>
<td>413</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Composted chicken (layer) manure b</td>
<td>2.3</td>
<td>3.5</td>
<td>2.9</td>
<td>15.5</td>
<td>1.3</td>
<td>-</td>
<td>1800</td>
<td>165</td>
<td>165</td>
<td>30</td>
</tr>
<tr>
<td>Dairy cow manure*</td>
<td>2.4</td>
<td>0.7</td>
<td>2.1</td>
<td>1.4</td>
<td>0.8</td>
<td>0.3</td>
<td>1100</td>
<td>182</td>
<td>390</td>
<td>150</td>
</tr>
<tr>
<td>Swine manure*</td>
<td>2.1</td>
<td>0.8</td>
<td>1.2</td>
<td>1.6</td>
<td>0.3</td>
<td>0.3</td>
<td>-</td>
<td>150</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Sheep manure*</td>
<td>3.5</td>
<td>0.6</td>
<td>1.0</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>-</td>
<td>150</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Horse manure*</td>
<td>1.4</td>
<td>0.4</td>
<td>1.0</td>
<td>1.6</td>
<td>0.6</td>
<td>0.3</td>
<td>-</td>
<td>200</td>
<td>125</td>
<td>25</td>
</tr>
<tr>
<td>Feedlot cattle manure*</td>
<td>1.9</td>
<td>0.7</td>
<td>2.0</td>
<td>1.3</td>
<td>0.7</td>
<td>0.5</td>
<td>5000</td>
<td>40</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

(Source: Hue and Silva, 2000)
N Mineralization and Immobilization

- **Manure addition**
  - **R - NH$_2$** Organic N (amine groups)

  - **Mineralization** If C:N < 20
    - N available for plant uptake
  - **Immobilization** If C:N > 30
    - N unavailable for plant uptake
Factors Affecting Mineralization

1. Temperature

- Reaction rates double with every 10°C increase
2. Moisture

- Mineralization low under dry conditions
- Increase to optimum under moist conditions
- Decrease as soil becomes saturated

Source: Cassman & Munns, 1980
Factors Affecting Mineralization

3. Mineralogy
   - Volcanic ash soils
   - Adobe soils
   - Weathered acid soils
N Mineralization and Crop Nutrition

Source: Pang & Letey, 2000
Manure Application

- Manure composed of Ammonia (10-30%) and organic N
- Manure should be incorporated
  - 25% NH₃ lost to volatilization after 1 day
  - 75% NH₃ lost after a week
Manure Application Rate

• Assumptions:
  - Ammonium component immediately available
  - A fraction of organic N available

<table>
<thead>
<tr>
<th>UVM, Cornell, PSU</th>
<th>NRCS</th>
<th>U. Manitoba</th>
</tr>
</thead>
<tbody>
<tr>
<td>60% (poultry)</td>
<td>50%</td>
<td>30%</td>
</tr>
<tr>
<td>50% (swine)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35% (other)*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• Calculation for dairy cow manure:
  - Crop N requirement = 150 lb/acre
  - 150 lb N/(0.35*0.024) = 17,857 lb manure/acre
    or 8.9 t/acre
Manure Application Rate

- **P and K inputs:**
  - Assume 40% of the P available
  - \((0.4 \times 0.007 \times 17,857\text{lb}) = 50 \text{ lb P per acre}\)
  - Assume 90% of the K available
  - \((0.9 \times 0.021 \times 17,857\text{lb}) = 337 \text{ lb K per acre}\)

- **P from poultry**
  - 2.84 t/acre to satisfy 150 lb N/acre
  - \((0.21 \times 5680\text{lb}) = 120 \text{ lb P/acre}\)
  - Research suggests that 40-50% of the P available to the crop
Summary

- Manures essential component of sustainable nutrient management
- Management critical to balance benefits and possible environmental harms
- Research required to develop appropriate management strategies for Hawaii and the Pacific Basin