Understanding and Managing Soils for a Healthy Landscape

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Introduction

The purpose of this web resource is to provide fundamental concepts for managing nutrients in tropical soils and container crop production. Though basic in principle, the importance of nutrient management cannot be underestimated. If growers are to maximize crop productivity, it is imperative they supply plants with the proper nutrition in both field and greenhouse environments.

The organization of this website consists of four sections:

- Section 1 explores the basic principles that govern crop performance in tropical soils.
- Section 2 discusses the diversity of soils which make up the island of Maui.
- Section 3 focuses on the proper management techniques for maintaining or enhancing the nutrition of tropical soils.
- Section 4 introduces nutrient management strategies for container crop production in soil less media.

Much of the information provided in this website is unique to Maui. We aim to provide the College of Tropical Agriculture and Human Resources’ (CTAHR) clients with resources, knowledge and tools that are easily accessible, comprehensible and useful for properly managing their crops. Despite the localized nature of some information supplied here, much of it can be applied elsewhere in the tropics particularly throughout the Pacific.

http://www.ctahr.hawaii.edu/mauisoil/
Outline

• Importance of Soils
• Soil Diversity on Maui
• Soil Properties
• Soil Quality/Health
• Management for Health
Importance of Soil
Medium for Plant Growth
Habitat for Soil Organisms

The Soil Food Web

- Nematodes (Root-feeders)
- Arthropods (Shredders)
- Arthropods (Predators)
- Birds
- Fungi (Mycorrhizal fungi, Saprophytic fungi)
- Nematodes (Fungal- and bacterial-feeders)
- Nematodes (Predators)
- Protozoa (Amoebae, flagellates, and ciliates)
- Bacteria
- Organic Matter: Waste, residue and metabolites from plants, animals, and microbes.

R.A. Norton
Recycling System

http://compost.tamu.edu/demos/palopinto/compost.jpg

Courtesy E. Brennan
Water Supply and Purification
Engineering Medium
Soil Diversity

Kula: fertile ash soil

Omaopio: fertile heavy clay soil

Napili: infertile, acid soils
Origin of Soil Diversity

Factors
- Time
- Parent Material
- Climate
- Biota
- Topography

Processes
- Physical weathering
- Chemical weathering
Origin of Soil Diversity

Climate - Precipitation

Wet = high weathering, acid & infertile *Haiku* series

Dry = less weathering, fertile *Keahua* series
Twelve Soil Orders

Alfisols
Andisols
Aridisols
Entisols
Gelisols
Histosols
Inceptisols
Mollisols
Oxisols
Spodosols
Ultisols
Vertisols

www.soils.uidaho.edu/soilorders
Soil Orders of Maui

<table>
<thead>
<tr>
<th>Soil Order</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andisol</td>
<td>99,244.7 acres</td>
</tr>
<tr>
<td>Aridisol</td>
<td>14,203.7 acres</td>
</tr>
<tr>
<td>Entisol</td>
<td>8,352.2 acres</td>
</tr>
<tr>
<td>Histisol</td>
<td>5,761.7 acres</td>
</tr>
<tr>
<td>Inceptisol</td>
<td>21,805 acres</td>
</tr>
<tr>
<td>Mollisol</td>
<td>66,917 acres</td>
</tr>
<tr>
<td>Oxisol</td>
<td>12,155.9 acres</td>
</tr>
<tr>
<td>Ultisol</td>
<td>21,853.8 acres</td>
</tr>
<tr>
<td>Andisol/Histosol</td>
<td>45,836 acres</td>
</tr>
<tr>
<td>Andisol/Spodosol</td>
<td>12,350.7 acres</td>
</tr>
</tbody>
</table>

Legend:
- Major Roads
- Andisol
- Aridisol
- Entisol
- Histisol
- Inceptisol
- Mollisol
- Oxisol
- Ultisol
- Andisol/Histosol
- Andisol/Spodosol
- Other*
Andisols of Maui

General Characteristics
- light and fluffy (low bulk density)
- high in organic matter
- tendency to “fix” P

Kula Series (dry areas)
- Very fertile
- well-suited to vegetable, fruit, flower production

Hana Series (wet areas)
- Infertile (low in Ca & K)
- P deficient
Mollisols of Maui

General Characteristics
- fertile, productive soils
- rich in Ca, K, Mg
- shrink/swell clay

Common Examples:
- Ewa
- Iao
- Kaupo
- Paia
- Pulehu, Wailuku

Legend
- Purple: Paia Series
- Yellow: Mollisol
Oxisols of Maui

General Characteristics
• moderately fertile soils
• can be low in Ca, K, Mg
• good physical properties

Common Examples:

Lahaina
Molokai

Legend

<table>
<thead>
<tr>
<th>Color</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple</td>
<td>Lahaina Series</td>
</tr>
<tr>
<td>Brown</td>
<td>Oxisol</td>
</tr>
</tbody>
</table>
Ultisols of Maui

General Characteristics
- strongly acidic soils
- depleted in Ca, K, Mg
- good physical properties

Common Examples:
- Alaeloa
- Haiku
- Honolua
- Makawao
- Olelo

A. McClellan
Soil Physical Properties

1. Soil texture/structure
2. Soil Water
3. Soil Organic Matter
Soil Texture

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>Percentage of Maui soils that fall within the major textural classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silty clay</td>
<td>44%</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>23%</td>
</tr>
<tr>
<td>Silty loam</td>
<td>11%</td>
</tr>
<tr>
<td>Loam</td>
<td>10%</td>
</tr>
<tr>
<td>Clay</td>
<td>5%</td>
</tr>
</tbody>
</table>

Soil Texture

Important Clay Minerals

1. Kaolinite
   - non-expanding
   - Low CEC

2. Al/Fe oxides
   - non-expanding
   - no CEC

3. Smectite
   - expanding
   - high CEC

4. Allophane
   - high surface area

http://www.cst.cmich.edu/users/Franc1M/esc334/lectures/physical.htm
Soil aggregation is an important indicator of the workability of the soil. Soils that are well aggregated are said to have “good soil tilth.”

Clay minerals and aggregate strength

- Al/Fe oxides = very strong
- Kaolinite = strong
- Smectite = week
- Allophane = strong
Soil Water

Soil water holding capacity depends on texture

*clay = high*
*sand = low*
Soil Water

Saturation

Field capacity

Wilting point
Soil Air

$$CH_2O + O_2 = CO_2 + H_2O$$

Respiration
soil microorganisms > plant roots > soil animals

http://faculty.plattsburgh.edu/robert.fuller/370%20Files/Weeks13/Soil%20Air%20&%20Temp/Respiration.htm
Negative Effects of Anaerobic Soils

1. Root growth decreases
2. Nutrient uptake decreases
3. Plant available N decreases
4. Toxic levels of some compounds formed by some anaerobic organisms:
   - Mn⁴⁺ - Mn²⁺
   - Fe³⁺ - Fe²⁺
   - SO₄²⁻ - H₂S
   - Ethylene
   - Ethanol
   - Organic acids
Soil Chemical Properties

Cation Exchange Capacity

CEC is defined as the degree to which a soil can adsorb and exchange cations

\[(\text{NH}_4^+, \text{K}^+, \text{Ca}^{++}, \text{Mg}^{++}, \text{Fe}^{++} \ldots)\]

Negative surface charge

http://www.extension.umn.edu/distribution/cropsystems/images/6437f01.gif

http://www.vabf.org/InfolImages/soil1.jpg
Cation Exchange Capacity

1. Clay surfaces
   - Smectite: 80 – 100 cmol$_c$kg$^{-1}$
   - Kaolinite: 3 – 15 cmol$_c$kg$^{-1}$
   - Al/Fe oxides: 0 cmol$_c$kg$^{-1}$

2. Organic matter
   - Humus: 200 cmol$_c$kg$^{-1}$
Soil Acidity

Source of soil acidity
- carbonic acid
- organic acids
- oxidation reactions
- leaching
- synthetic fertilizers
- acid rain

Negative Impacts
- Ca and K deficiency
- P deficiency
- Al toxicity (pH < 5.5)
- Mn toxicity (pH < 5.5)
Soil Acidity

The diagram illustrates the relationship between soil pH and the availability of nutrients. As the pH decreases from strongly alkaline (pH 10) to strongly acid (pH 4), the availability of nutrients such as Nitrogen, Phosphorus, Potassium, Calcium, Magnesium, Iron, Manganese, Copper and Zinc, and Molybdenum increases. This information is crucial for understanding soil fertility and for selecting appropriate crops and nutrient management practices.
Soil Biological Properties

Soil Organic Matter

Soils ≈ 5% OC
Andisols 8 – 15% OC

http://www.soilandhealth.org/01aglibrary/ingam/Soil%20Food%20Web%20NRCS%20SQ_files/soil_f1.gif
Soil Organic Matter

- **Physical**
  - Improves aggregation
  - Improves water holding capacity (surface area)

- **Chemical**
  - Increases nutrient availability (N & P cycling, solubility)
  - Increases CEC
  - Buffers against pH changes

- **Biological**
  - Increases microbial diversity
  - N fixation (rhizobia), P availability (myccorhiza)
  - Increases pathogen suppression
Soil Organisms

The Soil Food Web

- **Plants**: Shoots and roots
- **Organic Matter**: Waste, residue and metabolites from plants, animals and microbes
- **Bacteria**
- **Protozoa**: Amoebae, flagellates, and ciliates
- **Fungi**: Mycorrhizal fungi, Saprophytic fungi
- **Nematodes**: Root-feeders
- **Nematodes**: Fungal- and bacterial-feeders
- **Arthropods**: Shredders, Predators

Insert images of soil organisms and soil structure.
Definition

The capacity of a soil to:

1. Sustain biological productivity and diversity
2. Maintain environmental quality
3. Promote plant and animal health
Soil Quality is Soil Specific
Impacts on Soil Quality

How do soils respond to management?
Tillage Effects on SOM

Brady & Weil, 2004
Effects Due to Loss of SOM

- Increased bulk density
- Decreased soil tilth
  - Poor soil structure
- Decreased water infiltration
  - Increased erosion
- Decreased water holding capacity
  - Increased susceptibility to drought
- Decreased N mineralization potential
- Decreased microbial biomass/activity
- Decreased macrofauna
Management Effects

Soil Organic C (%)

Total N (%)

Uncultivated
Cultivated
Management Effects

- MBC (ppm)
- Aggregate Stability (5)

- Uncultivated
- Cultivated
Management Effects

Effects of organic management on a Vertisol, Waianae

MBC (mg C kg⁻¹)

Aggregate Stability (%)
Management for Soil Quality

“Feed the Soil”
Organic Matter
Compost

Supplemental Nutrients

Courtesy E. Brennan
Compost

- Improves physical, chemical, and biological properties
- Need to add in large quantities (> 20 T/acre)
- Relatively low N content (< 2.0%)
- Slow-release nutrients
N Management

Losses

- NH₃ Volatilization
- Denitrification (NO₃⁻)
- Immobilization
- Leaching (NO₃⁻)

N Management

N Deficiency
• Yellowing of older leaves
N Fertilizers

Organic
- Fish meal (≈10% N)
- Feather meal (12 - 13% N)
- Chicken manure (≈3% N)

Conventional
- Urea (46-0-0)
- Ammonium sulfate (21-0-0)
- 16-16-16
- Calcium nitrate
- Potassium nitrate
P Management

Losses
- P fixation
- Run-off
- Immobilization

The Phosphorus Cycle

- Phosphate Inputs
- Soluble Phosphate
- Fixed Phosphate
- Soil Organic Phosphate
- Biomass Phosphate

Andisols
Oxisols
Ultisols

http://filebox.vt.edu/users/chagedor/biol_4684/Cycles/phosph.JPG
P Management

P Deficiency
• Puyrpling of older leaves

http://www.ctahr.hawaii.edu/nelsons/Misc/
P Fertilizers

Organic
- Bone meal (≈12-15% P)
- Rock phosphate (2-5% P)
- Chicken manure (2-3% P)

Conventional
- TSP (0-45-0)
- DAP (18-46-0)
- 10-30-10
Nutrient Management

[Graphs showing the relationship between dry matter and N uptake over time from June 1 to September 1.]
Adverse Effects of Nutrients

Water
• Algal blooms (N & P)
• Groundwater contamination
  NO$_3^-$

Greenhouse Gases
• NH$_3$ volatilization
• Denitrification

http://serc.carleton.edu/images/microbelife/topics/red_tide_genera.v3.jpg
Mahalo!