Understanding and Managing the Soils of Puna for Sustainable Food Production

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Outline

• Soil Diversity
• Soils of Puna
• Soil Properties
• Soil Quality/Health
• Management Strategies for Healthy Productive Soils
Soil Diversity

- **Hamakua**: infertile ash soil
- **Kohala**: fertile clay soils
- **Waimea**: fertile, ash soils
- **Puna**: a’a/pahoehoe soils
Factors

- Time
- Parent Material
- Climate
- Biota
- Topography

Processes

- Physical weathering
- Chemical weathering

Origin of Soil Diversity
Origin of Soil Diversity

Climate - Precipitation

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

Dry = less weathering, fertile
*Waimea* series
Soil Orders of Hawaii

Legend
- Major Roads
- Andisol
- Andisol
- Entisol
- Histosol
- Inceptisol
- Mollisol
- Inceptisol/Histosol
- Cinder
- 'A'a/ Pahoehoe Lava Flow
- Other

UTM Zone 5N NAD 83

Kona
Kawaihae
Waipio
Hilo
South Point
23 Soil Series in Puna District
Five Main Soil Types
- **Seasonal** = 40 – 90”
- **Wet** = 90–>150”
A`a a Soils

Soil Series:
- Kaimu
- Kiloa
- Laloau
- Malama
- Papai

Roads
Physical Properties of A`a Soils

- Dominated by coarse materials (80%)
- Minimal clay content
- Very low water retention capacity (droughty)
- Excessively well-drained
- Extremely difficult to cultivate
Organic matter is the primary source of nutrient supply and retention.

pH is relatively high due to high Ca.

K tends to be low under natural conditions.

### Chemical Properties of A`a Soils

<table>
<thead>
<tr>
<th>Management</th>
<th>OC</th>
<th>TN</th>
<th>pH</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
<th>CEC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>cmol_c kg^{-1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>24.0</td>
<td>1.48</td>
<td>6.9</td>
<td>46.4</td>
<td>3.62</td>
<td>0.42</td>
<td>2.08</td>
<td>80.3</td>
</tr>
<tr>
<td>Cultivated</td>
<td>22.8</td>
<td>1.41</td>
<td>6.9</td>
<td>48.7</td>
<td>7.10</td>
<td>1.29</td>
<td>3.83</td>
<td>69.5</td>
</tr>
</tbody>
</table>

Source: Periswamy, 1973
Physical Properties of Pahoehoe Soils

- Even coarser than A`a soils
- Organic matter accumulation above solid pahoehoe lava
Organic matter accumulates to high levels in shallow organic layer above pahoehoe bedrock. pH is typically very acid due to organic matter and no mixing with fine inorganic minerals.

### Chemical Properties of Pahoehoe Soils

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<td>A`a</td>
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</tr>
<tr>
<td>Pahoehoe</td>
<td>55.3</td>
<td>1.99</td>
<td>4.6</td>
<td>57.1</td>
<td>10.0</td>
<td>1.6</td>
<td>1.50</td>
<td>152</td>
</tr>
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</table>

Source: Periswamy, 1973
Conventional rules of soil science not always applicable to Puna soils.
Soil Organic Matter is Queen

Soils < 5% OC
Ash soils: 8 – 15% OC
Puna soils: 4 – 60% OC

- Living organisms <5%
- Fresh residue <10%
- Stabilized organic matter (humus) 33% - 50%
- Decomposing organic matter (active fraction) 33% - 50%
Humus

1. End product of decomposition
2. Relatively stable
   - half-life: decades to centuries
   - Humic substances (stable)
   - Non-humic substances (<stable)
3. Properties of Humic substances
   - high surface area
   - high charge density
4. Role
   - Increase water retention
   - Increase CEC

www.californiagreensolutions.com
Soil Water

Saturation

Field capacity

Wilting point

Source: Brady & Weil, 2004
Water Retention

Soil water holding capacity depends on texture

- clay = high
- sand = low
- OM = high

Source: Brady & Weil, 2004
Water Release Curve

Source: Periswamy, 1973
Water Storage

- 1.5 cm available water in 15 cm of soil
- Evapotranspiration = 0.39 cm/day
- $\frac{1.5}{0.39} = \text{almost 4 days before water consumed}$
- If roots could access 1 m of soil, then there would be 26 days of available water.
- **So, regular rainfall is necessary for good plant growth!**
Cation Exchange Capacity

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

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

CEC of humus = 200 cmol\(_c\) kg\(^{-1}\)

CEC of clays = 10 – 80 cmol\(_c\) kg\(^{-1}\)
Cation Exchange Capacity

CEC of a`a surface soil = 80.3 cmol$_c$ kg$^{-1}$, but this is for < 2 mm Fraction, which makes up only 9.8% of the soil volume.

Converted to a volume, CEC = 7.9 cmol$_c$ L$^{-1}$, which is considered low.

A Waimea soil will have a CEC of around 25 cmol$_c$ L$^{-1}$ in top 15 cm.
Soil Acidity

![Soil Acidity Graph](http://ecology.botany.ufl.edu/ecologyf03/graphics/soilpH.jpg)
## Effects of Soil Acidity

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<th>Typical Acid Soils</th>
<th>A`a/Pahoehoe Soils</th>
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<td>- Al toxicity</td>
<td>- Can be very acid</td>
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<td>- Mn toxicity</td>
<td>- No Al toxicity because OM forms complexes w/ Al</td>
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<td>- Low base saturation</td>
<td>- High base saturation because primary minerals release bases</td>
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<td>- P deficiency</td>
<td>- Low P fixation capacity</td>
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- Mn toxicity
- Low base saturation
- P deficiency

- Can be very acid
- No Al toxicity because OM forms complexes w/ Al
- High base saturation because primary minerals release bases
- Low P fixation capacity
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 (mycorrhiza)
  - Increases pathogen suppression
Soil Organisms

The Soil Food Web

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

R.A. Norton
Agricultural Potential of Puna Soils

- A`a soils better suited than Pahoehoe
- Rainfall should exceed 90”/yr
- Pahoehoe soils require higher rainfall to maintain good crop growth than a`a soils.
- Nutrient and water retention is low for these soils
  - low CEC leads to rapid leaching losses
  - high proportion of coarse fragments leads to low surface area and low water retention.
Management for Soil Health and Food Security

“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

- Immobilization
- Leaching (NO$_3^-$)

N Deficiency

- Yellowing of older leaves
**Amendments**
- Fish meal (≈10% N)
- Feather meal (12 - 13% N)
- Chicken manure (≈3% N)

**Cover Crops**
- Sunn hemp
- Perenniel peanut
- legumes
P Amendments

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

Cover Crops
- Sunn hemp
- Sudex
- Oats
Biochar Soil Amendments

www.eprida.com/eprida_flash
Terra Preta (Amazonian Dark Earths): Highly Fertile Anthropogenic Soils

Terra Preta Soil

Typical Upland Amazonian Soil
Effect of Charcoal on Plant Growth

Photo source: http://tinselwing.wordpress.com/tag/terra-preta/

Charcoal Additions

No Charcoal Additions
Charcoal as a Soil Amendment

Potential Advantages

- Stable organic matter
- Good way to recycle invasive species/waste
- Increases water retention and CEC
- Promotes microbial diversity

Source: Cornell University
Charcoal as a Soil Amendment

Potential Disadvantages

• Some charcoals have negative effect on plant growth

• Some charcoal inhibits plant N uptake
Summary

Management Strategies

• Maximize organic matter inputs
  – compost
  – green manures

• Keep soil covered
  – cover crops
  – mulches

• Maximize biodiversity
  – multi-story planting
Mahalo!