Soils of Maui

Concepts in Soil Fertility

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Outline

• Importance of Soils
• Concepts in Soil Fertility
  - Clays
  - CEC
  - Organic matter
  - pH
  - N and P
• Soils of Kona
Essential Plant Nutrients

Air and water: C, H, O

Macronutrients: N, P, K, Ca, Mg, S

Micronutrients: B, Cu, Fe, Mn, Zn, Mo, Ni, Co, Cl
Soil Factors Affecting Plant Nutrients

- Type and amount of clay
- pH
- Organic matter
- Water
Hawaii`s Diverse Soils

1. Parent rock
2. Age
3. Climate (rainfall, temperature)
4. Biota (vegetation, micro-organisms)
5. Topography (drainage)
Idealized Soil Composition

50% Solids

45% Mineral

25% H₂O

25% Air

5% Organic Matter

50% Pores
Clay is Where the Action is!

Clay Properties:
Microscopic size (<0.002 mm)

Extremely high surface area
- water retention
- chemical reactions
- biological activity

Clay surfaces carry charge (-/+)

In Hawaii, the type of clay is critical.
Kaolinite

Properties:

- Non-expanding
- Low CEC, low fertility
- Non-sticky
- Good physical properties
Smectite

Montmorillonite

Properties:

- Expanding
- High CEC, fertile
- High surface area
- Sticky
- Poor physical properties
**Oxides**

**Al & Fe Oxides**

**Properties:**
- Non-expanding
- Very little CEC, infertile
- Non-sticky, form strong aggregates
- Good physical properties
Volcanic Ash Soils Contain Allophane

Allophane

Properties:

- Exceptionally high surface area
- Variable charge (-/+)
- High CEC (Kula)
- Low CEC (Hana)
Cation Exchange Capacity CEC

Negatively charged sites that adsorb cations:
Ca$^{2+}$, Mg$^{2+}$, K$^+$, NH$_4^+$
Organic Matter and CEC

- Organic matter has a high CEC
  - OM high in surface horizon
  - CEC always higher in surface soil
Soil Acidity

Natural Sources of Acidity:
- Precipitation and cation leaching
- Carbonic acid and organic acids
- Organic matter

Human Induced Acidity:
- Acid rain
- Urea
- Ammonium fertilizers
- Mono and diammonium phosphate
- Elemental S
Soil pH and Nutrient Availability

- Soil pH controls nutrient solubility
- Ideal range 6.0-6.5
- CEC decreases at low pH
- P fixation increases at low pH
P-Fixation

- Adsorption of P on Oxides

\[
\text{Oxide Mineral} \quad \text{Al} \quad \text{Al} \quad \text{Al} \quad \text{Al} \\
| \quad \text{OH} \quad \text{OH} \quad \text{OH} \quad \text{OH} \\
| \quad \text{O} \\
| \quad \text{Al} \quad \text{Al} \quad \text{Al} \quad \text{Al} \\
| \quad \text{OH} \\
| \quad \text{OH}_2 \\
+ \quad \text{H}_2\text{PO}_4^- \\
\rightarrow \quad \text{O} \quad \text{O} \quad \text{O} \quad \text{O} \\
\quad \text{Al} \quad \text{Al} \\
\quad \text{OH} \\
\quad \text{OH} \\
\quad \text{OH} \\
\quad \text{OH} \\
+ \quad \text{H}_2\text{O}
\]
P-Fixation

- Chemical bonding of phosphate with Aluminum/iron on clay surfaces
- High in weathered soils rich in oxides (Ash soils, red soils of West Maui)
- P-fixation increases as soils become more acid
- High P-fixing soils require high P inputs
- Organic matter inputs reduce fixation capacity
Aluminum Toxicity

- At pH below 5.0 Al solubility increases
- Ultisols most likely to have Al toxicity under acid conditions
- Soils acidified by pineapple production may be prone to Al toxicity
- Ca deficiency may be the more serious limitation
- Liming (CaCO$_3$/CaSO$_4$) and/or organic matter inputs alleviate Al toxicity
Soils with Potential Al Toxicity

- Ultisols/Inceptisols existing at low to moderate elevation (200-750 ft) with high rainfall (60-100 in/yr)
Manganese

- A mineral in basalt
- $\text{Mn}^{2+}$ is an essential plant nutrient, but at high concentrations it becomes toxic
- $\text{Mn}^{2+}$ concentration depends on pH, $\text{O}_2$ availability and organic matter
  - As Soil pH decreases Mn toxicity increases
  - As Oxygen is depleted (saturated soil) Mn toxicity increases
  - Adding organic matter increases Mn toxicity increases
Soils with Potential Mn Toxicity

- Oxisols/Inceptisols existing at low to moderate elevation (200-750 ft) with moderate rainfall (20-60 in/yr)
Weathering Intensity and Clay Type

TROPICAL SOIL FORMATION AND DEGRADATION

Leaching and Desilication

- Smectite: High activity clays
- Kaolinite: Low activity clays
- Oxides: Variable charge colloids

Nutrient Accumulation

Fertility

Nutrient Depletion

Exhaustion

Time (pedological) X Weathering Intensity
Organic Matter

Living Organism (<5%)

Fresh Organic Residue (<10%)

Stabilized Organic Matter (33% to 50%)

Active Fraction (decomposing organic matter) (33% to 50%)

Humus
Importance of Organic Matter in Soils

- Physical Properties
  - Improves aggregation (glue)
  - Improves water holding capacity (surface area)
Importance of Organic Matter in Soils

Chemical
- Increases nutrient availability (N cycling, P and micronutrient solubility)
- Increases CEC (200 cmol_c kg^{-1})
- Buffers the soil against pH changes

N mineralization
Conversion of organic N to inorganic N

\[ R-NH_2 \rightarrow NH_4 \rightarrow NO_3 \]
Importance of Organic Matter in Soils

- Biological
  - N fixation
  - Increases microbial diversity
  - Assists in pathogen suppression
Microbial Functional Groups

● Bacteria
  - decomposers, primary players in N, P and S cycling
  - Actinomycetes act on more complex compounds to form humus - fundamental to composting

● Fungi
  - Decomposers, attack lignin
  - Nutrient acquisition (mycorrhiza)

● Protozoa and Nematodes
  - Consume bacteria and fungi releasing plant nutrients (N)
  - Activity increases decomposition rates
Nitrogen Dynamics

**Mineralization**: microbial conversion of organic N into plant available inorganic forms (NH$_4^+$, NO$_3^-$)
Nitrogen Dynamics

**Immobilization**: Conversion of inorganic N to organic N by microbes

![Graph showing nitrogen dynamics over weeks with soil and soil + coconut leaves compared.](chart.png)
**Denitrification**: Conversion of NO$_3^-$ into N$_x$O gases

Denitrification occurs when:

- Soils are saturated and lack oxygen
- Denitrification rate increases with temperature and organic matter content
Soil Fertility Depends on:

Fertile Soils:
- Slightly acid to neutral pH
- High CEC
- High organic matter

Infertile Soils:
- Acid to strongly acid pH
- Low CEC
- High P fixation
Summary

- Clays interact with soil nutrients
- Soil pH affects nutrient availability
- Organic matter makes a difference
- Soils vary on the landscape
- If we know our soils we can manage them well