UCDAVIS
UNIVERSITY OF CALIFORNIA

Department of LAND, AIR AND WATER RESOURCES
University of California, Davis
Climate Change • Sustainable Agriculture
Environmental Quality • Landscape Processes

Introduction to Soils

Daniel Geisseler
Nutrient Management Specialist, UC Davis

UCCE Master Composter Training
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Overview

- Introduction
- Soil components
- Soil formation
- Important soil physical, chemical and biological properties
- Soil fertility, nutrient availability
- Nitrogen in soil and organic amendments

What is soil?

- Soil is the unconsolidated cover on the surface of the earth.
- Solid earth material that has been altered by physical, chemical and biological processes.

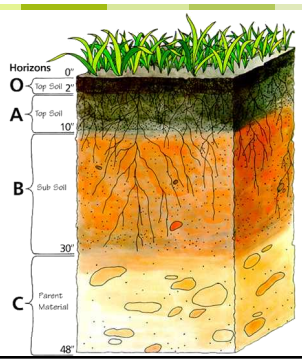
Introduction

Functions of agricultural soils

- Anchor plant roots
- Supply water and oxygen to plant roots
- Furnish nutrients for plant growth
- Provide water, oxygen and food to soil microorganisms
- Bind toxic compounds

Introduction

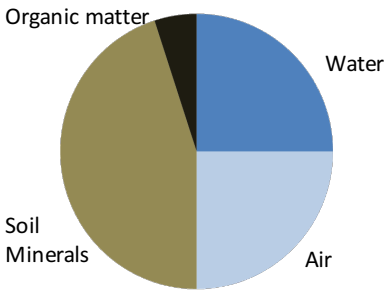
The soil profile



Components

Soil components

Solid material | **Pores**

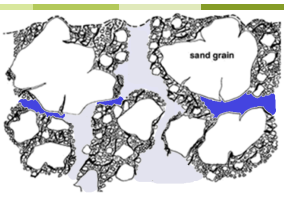


Components

Soil pores

Functions:

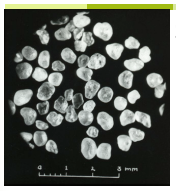
- Water infiltration
- Aeration
- Water retention



- Large pores are readily drained of water and filled by air after a heavy rain
- Small pores hold water against gravity and pull water up from a water table by capillary action.

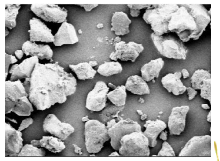
Components

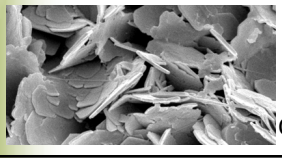
Soil mineral particles



Sand: feels gritty

Silt: feels smooth





Clay: feels sticky

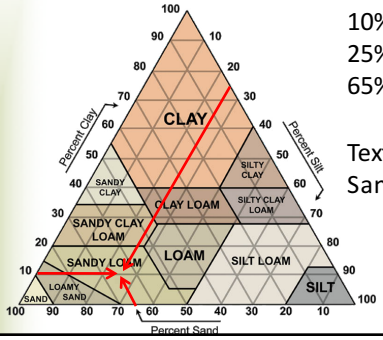
Components

Soil mineral particles

Particle	Diameter	# of particles in 1 gram	Surface area of 1 gram
Sand	0.05 - 2 mm	90	11 cm^2
Silt	0.002 - 0.05 mm	90,000,000 ($9x10^7$)	1,130 cm^2
Clay	< 0.002 mm	$9x10^{13}$	113,000 cm^2

Components

Particle size distribution: Texture



10% clay
25% silt
65% sand

Texture class: Sandy loam

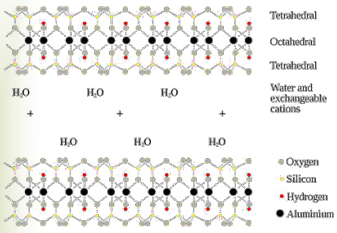
Components

Effect of soil mineral particles on soil properties

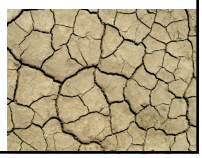
Property/Behavior	Sand	Silt	Clay
Water holding capacity	Low	Med-high	high
Aeration	Good	Med	Poor
Leaching potential	High	Med	Low
OM decomposition	Fast	Med	Slow
Water erosion susceptibility	Med	High	Low
Wind erosion susceptibility	Med	High	Low
Susceptibility to compaction	Low	Med	High
Nutrient supply	Poor	Med-high	High

Components

Clay minerals



Many clay minerals are negatively charged (⇨CEC)



Clay shrinks and swells

Components

Functions of organic matter

- Supplies nutrients to soil organisms and plants
- Prevents cations from leaching (CEC)
- Energy and carbon source for soil organisms
- pH buffer
- Improves soil structure and aggregate formation
- Increases pore volume, water holding capacity and infiltration
- Binds toxic compounds

Components

Effect of soil organic matter on soil properties

Effect of soil organic matter

Property/Behavior	Sand	Silt	Clay
Water holding capacity ↗	Low	Med-high	high
Aeration ↗	Good	Med	Poor
Leaching potential ↘	High	Med	Low
OM decomposition	Fast	Med	Slow
Water erosion susceptibility ↘	Low	High	Low
Wind erosion susceptibility ↘	Med	High	Low
Susceptibility to compaction ↘	Low	Med	High
Nutrient supply ↗	Poor	Med-high	High

Components

Sources of organic material

- Plants
  - Shoots (if not harvested)
  - Roots
  - Root exudates
- Microbial residues
- Soil animals
- Organic amendments (e.g. manure, compost)

Components

Increase soil organic matter

- Apply manure or compost
- Reduce tillage intensity
- Grow cover crops

Formation

Why are there so many different soils?

www.nrcs.usda.gov

Formation

Soil-forming factors

- **Climate:** Temperature, precipitation
- **Organisms:** Vegetation, soil organisms
- **Relief:** Landscape position, topography
- **Parent material:** Material from which the soil developed
- **Time:** The time a soil had to develop

Formation

Climate

Temperature:

- Chemical reactions proceed faster at higher temperatures

Precipitation:

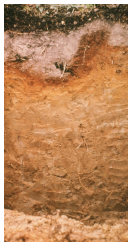
- Chemical reactions take place in solution
- Excess water leaches ions from soil profile
- Plants and soil organisms require water

Formation

Organisms / Vegetation

Grassland: Mollisols

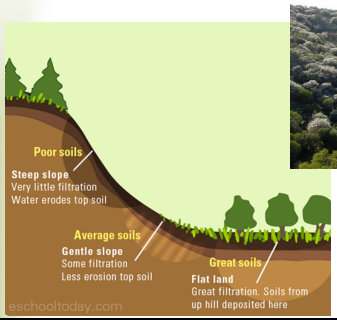
Forest: Spodosols



http://www.nrcs.usda.gov

Formation

Relief / Aspect



Formation

Parent material

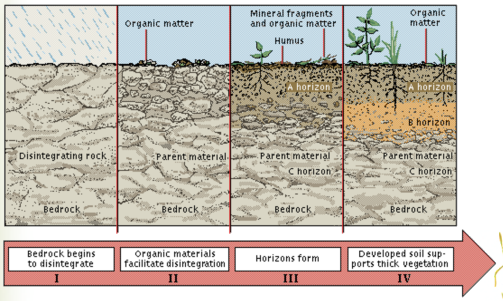
The material from which the soil has developed (e.g. solid rock, deposits by wind or water, volcanic material, organic material)

The parent material can influence:

- Color
- Texture
- Structure
- Mineral composition
- Permeability/Drainage

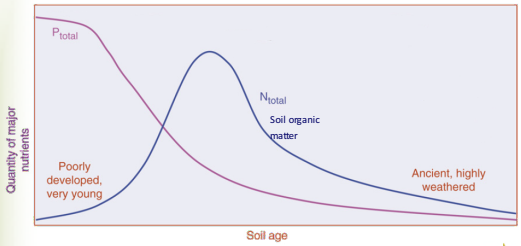
Formation

Time



Formation

Time

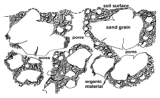


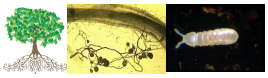
Lambers et al., 2008

Properties

Important soil properties

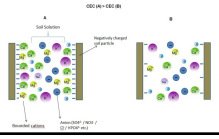
Physical
- Soil structure
- Texture
- Soil color
- Bulk density





Biological
- Soil organisms

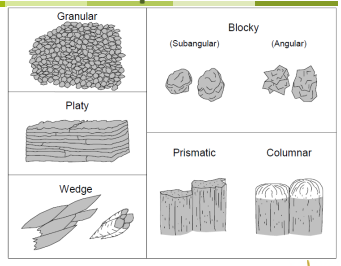
Chemical
- pH
- CEC
- Nutrient availability



Properties

Soil structure: 3-dimensional arrangement of particles

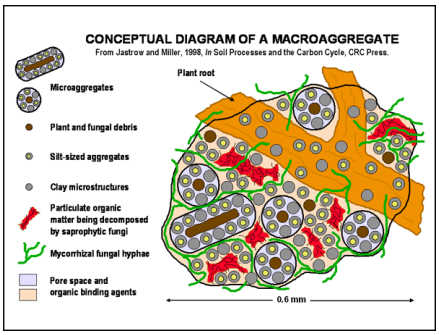
Strong effect on
- water infiltration
- Aeration
- Pore volume



http://cru.cahe.wsu.edu

Properties

Soil structure: Aggregates



Properties

Soil color

Properties

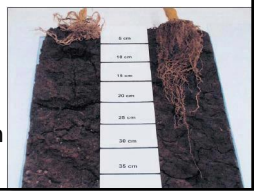
Bulk density

A high bulk density is often the result of compaction

- Compaction reduces the pore volume

Consequences:

- Slow infiltration
- Poor aeration
- Impedes root growth



Properties

Soil pH

What is pH?

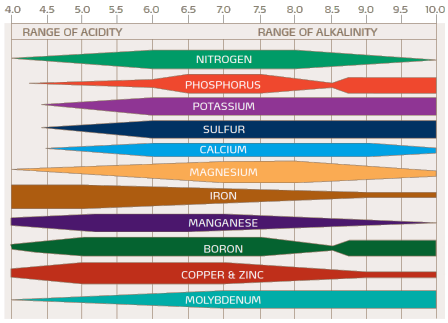
- Concentration of H^+ ions in solution
  - Scale 1-14.
  - Low pH (acidic): High H^+ ion concentration
  - High pH (alkaline): Low H^+ ion concentration

Why is pH important?

- Nutrient availability
- Nutrient toxicity (i.e. aluminum at low pH)
- Extreme pH an physically injure plants
- Affects microbial activity

Properties

Soil pH and nutrient availability



Properties

Cation exchange capacity (CEC)

Capacity of a soil to adsorb positively charged ions (e.g. ammonium, magnesium, calcium, potassium, ….)

Sources:

- Clay minerals
- Soil organic matter
- Iron and aluminum oxides

Properties

CEC and soil type

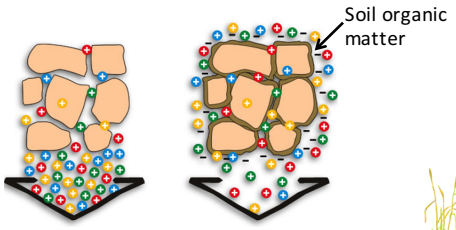
Soil type	Classification	CEC ($mmol_c\ kg^{-1}$)
Strongly weathered, often acidic soil	Ultisol	35
Intermediately weathered soil	Alfisol	90
Soil with organic top soil	Mollisol	187
Clay soil	Vertisol	356
Organic soil	Histosol	1280

Brady and Weil, 2008

Properties

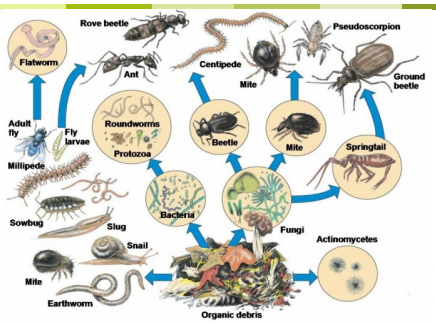
Significance of CEC

- Pool of readily available nutirents
- Reduces leaching of cations



Properties

Soil organisms



One cup of soil contains billions of organisms

Properties

The importance of soil organisms

- Animals mix soils, chop up plant residues
- Soil organisms decompose organic material, recycle nutrients
- Roots create channels for water infiltration
- Roots provide nutrients to soil organisms

Properties

Soil survey data:
http://ucanr.edu/soilweb

Properties

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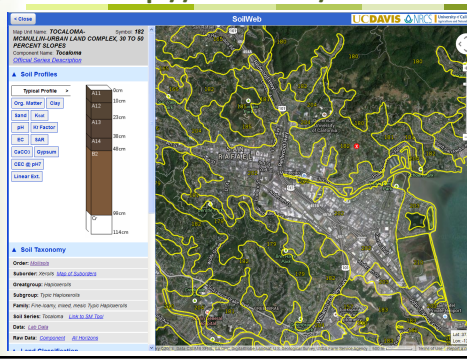

Fertility

Soil fertility

What is soil fertility?

- The capacity of a soil to support plant growth
- Provide plants with mineral nutirents, water and air (O_2)

Fertility

Essential nutrients

Structural elements:
- Carbon (CO_2)
- Oxygen (CO_2, H_2O)
- Hydrogen (H_2O)

Macronutrients:
- Nitrogen (NH_4^+, NO_3^-)
- Phosphorus (HPO_4^{2-}; $H_2PO_4^-$)
- Potassium (K^+)
- Calcium (Ca^{2+})
- Magnesium (Mg^{2+})
- Sulfur (SO_4^{2-})

Micronutrients:
- Boron (H_3BO_3)
- Chlorine (Cl^-)
- Copper (Cu^{2+})
- Iron (Fe^{2+}; Fe^{3+})
- Manganese (Mn^{2+})
- Molybdenum (MoO_4^{2-})
- Nickel (Ni^{2+})
- Silicon (H_4SiO_4)
- Sodium (Na^+)
- Zinc (Zn^{2+})

Fertility

Essential nutrients - cations

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Fertility

Where do plant nutrients come from?

- Decaying plant litter
- Weathering of soil minerals
- Addition by humans
  - Mineral fertilizer
  - Organic amendments (e.g. manure, compost)
  - Lime
  - Biological N fixation (e.g. by rhizobia in root nodules of legumes)

Fertility

Law of the minimum

Justus von Liebig (1803-1873)

The least available nutirent, relative to the plants' demand, limits plant growth

Justus von Liebig

Fertility

Law of the minimum

Some additions

- Not only nutrients limit plant groth, but also growth factors
  - Temperature, water, light, O_2, CO_2
  - Toxic compounds
  - ....
- Different factors may interact (e.g. K^+ and cold resistance; K^+ and Mg^{2+})
- Effect of deficiencies ar less pronounced when availability of other nutirents are balanced

Nitrogen

Nitrogen in the environment

Atmosphere with 78% N_2:
(2000 times more than CO_2)

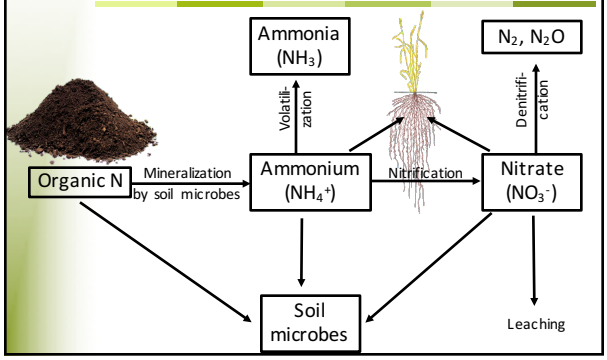
⇨ **1.3 tons N/acre in one foot**

Soil with organic matter content of 2%:

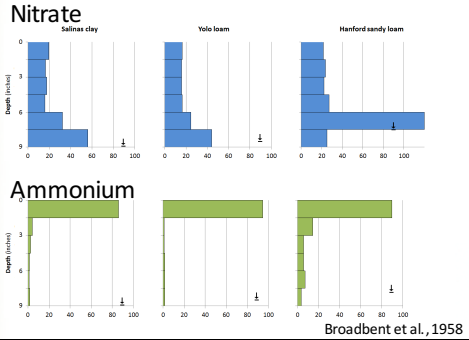
⇨ **2 tons N/acre in top foot**

Nitrogen deficiency

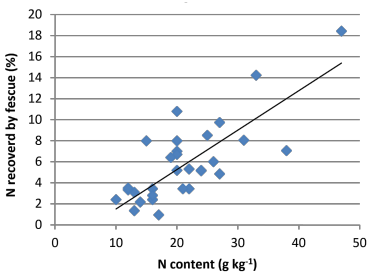
Nitrogen in compost



Nitrate and ammonium leaching potential



N mineralization rate of organic amendments



Hartz, 2000

Why is N content important?

- Soil microorganisms decompose residue
- Need N and C as building blocks for their own biomass
- C is also used as energy source
- **N immobilization:** Uptake of NO_3^- or NH_4^+ from soil solution and incorporation into microbial tissue
- **N mineralization:** Release excess N in the form of NH_4^+ into soil solution

Net mineralization or immobilization?

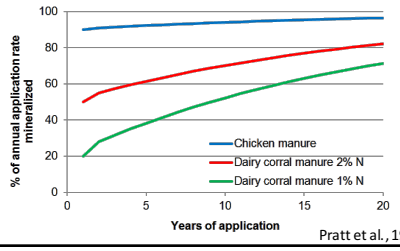
- Depends mainly on the C/N ratio of the organic substrate
  - C/N < 20: Net mineralization
  - C/N > 30: Net immobilization
- Availability of C and N in substrate

  Highly decomposed soil organic matter has a favorable C/N ratio, but both C and N are not readily available

Nitrogen

Long-term effect of organic amendments

Decay series				
Chicken manure		0.9	0.1	0.05
Dairy corral manure	2% N	0.5	0.1	0.05
Dairy corral manure	1% N	0.2	0.1	0.05



Pratt et al., 1973, 1976

Thank you!