A Study in Soil

Soil formation, biology, and improvement practices

Matt Prendergast

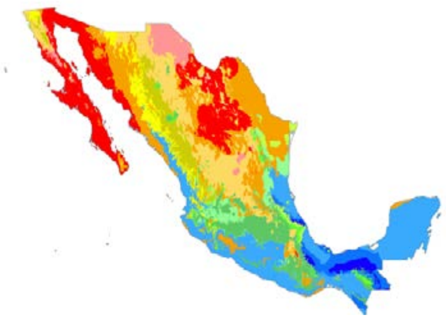
Leaf & Trowel

Table of Contents

Fun Facts!

- **1** tablespoon of soil has more organisms in it than there are people on earth
- **1,400,000** earthworms that can be found in an acre of healthy cropland soil
- **10** percent of the world's carbon dioxide emissions stored in soil
- **500** minimum years is what it takes to form one inch of topsoil
- We know more about the bottom of the ocean than we do about what lives in the soil

SOIL FORMATION



Climate

The long-term weather patterns of a particular area

Organisms

Soil life: macro, micro, plant, and fungi

Relief

Slope or Landform

Parent Material

Origin of mineral soil

Time

How weathered is the soil?

$$S = f(CL, O, R, P, T)$$

Climate

- Regulates soil formation
- Soils are more developed in areas with higher rainfall and higher average temperatures
  - Despite this, rainforest soils are not productive: highly weathered/leached
- High temps = faster OM decomposition

  = greater proliferation of all lifeforms
- Similar climates tend to have similar soils

Organisms

- Includes: plants, animals, bacteria, and fungi

- Organisms can alter the chemical & physical properties of the soil

- Examples:
  - Conifers have acidic needles – leaches into soil and alters pH
  - Deciduous trees build up humus – improves fertility, water holding capacity, reduced evaporation, etc.
  - Grasses (combined with grazing/fire) build up high levels of OM

- *Pedoturbation:* the mixing of soil horizons due to biological activity
  - Burrowing, root growth/tree uprooting, mycelia growth, etc.
  - Improves water infiltration
  - Creates desirable flow paths for soil gas exchanges

Relief

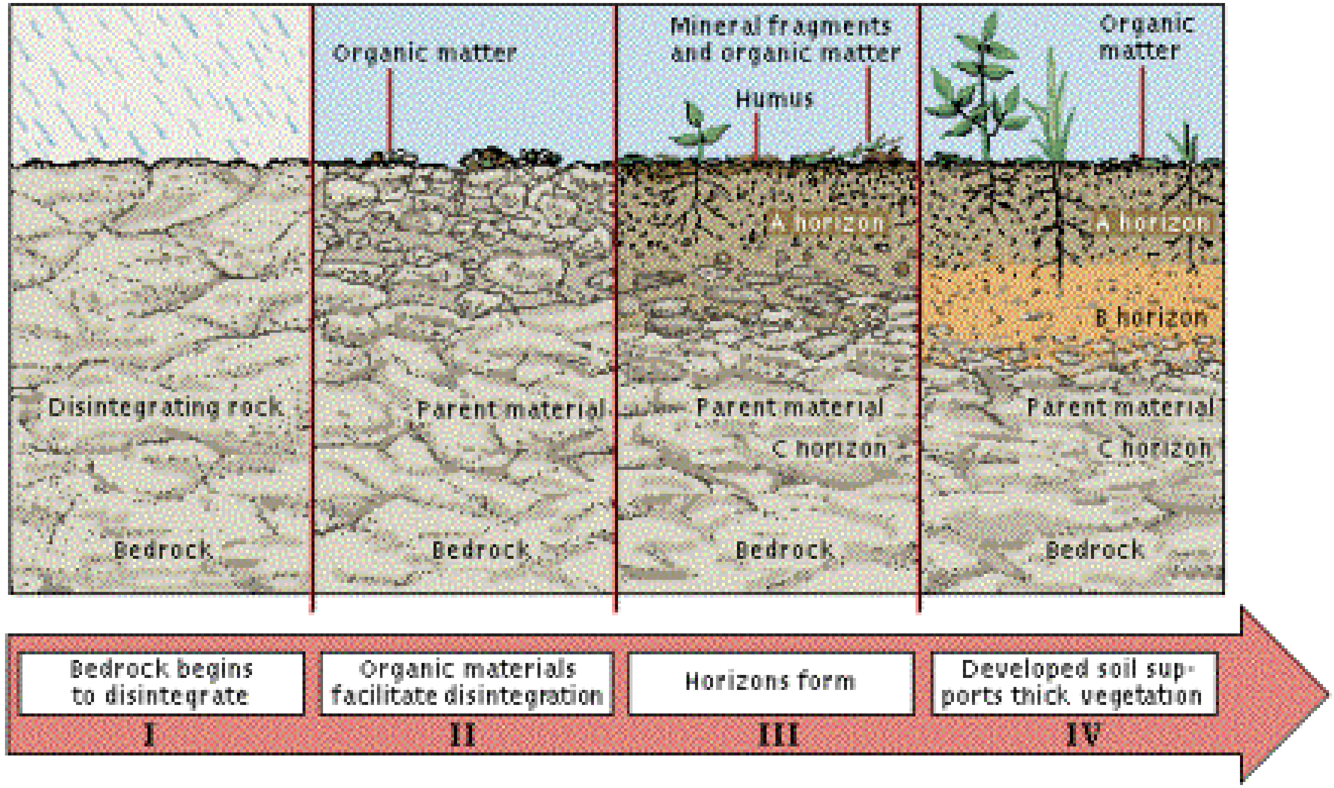
- Formed from tectonic activity
- Flatter land accumulates deeper soil profiles, steeper slopes are susceptible to erosion

Parent Material

- "Rock from which soil is formed"
- Mineral/chemical properties of the PM will be present in weathered material (i.e. soil)
- Consolidated vs. Unconsolidated
  - Consolidated: classified by parent material (igneous, metamorphic, and sedimentary rock)
  - Unconsolidated: classified by last means of transport
    - Ex: **Alluvium** (floodplains), **Lacustrine** (lake beds), **Colluvium** (accumulated rock fragments), **Loess** (wind-blown)

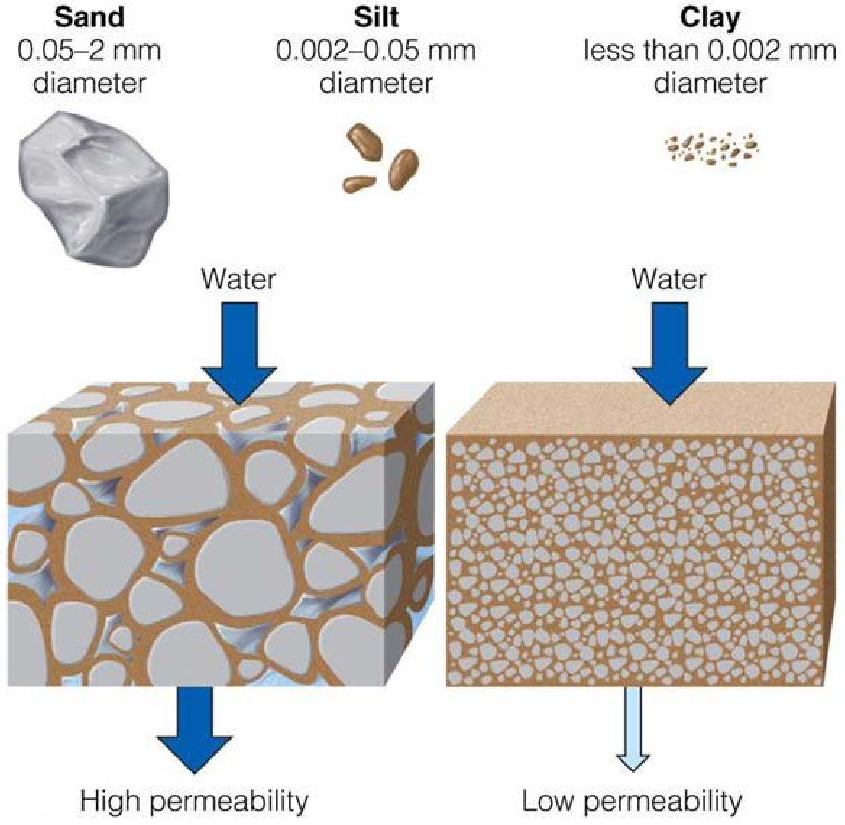
Time

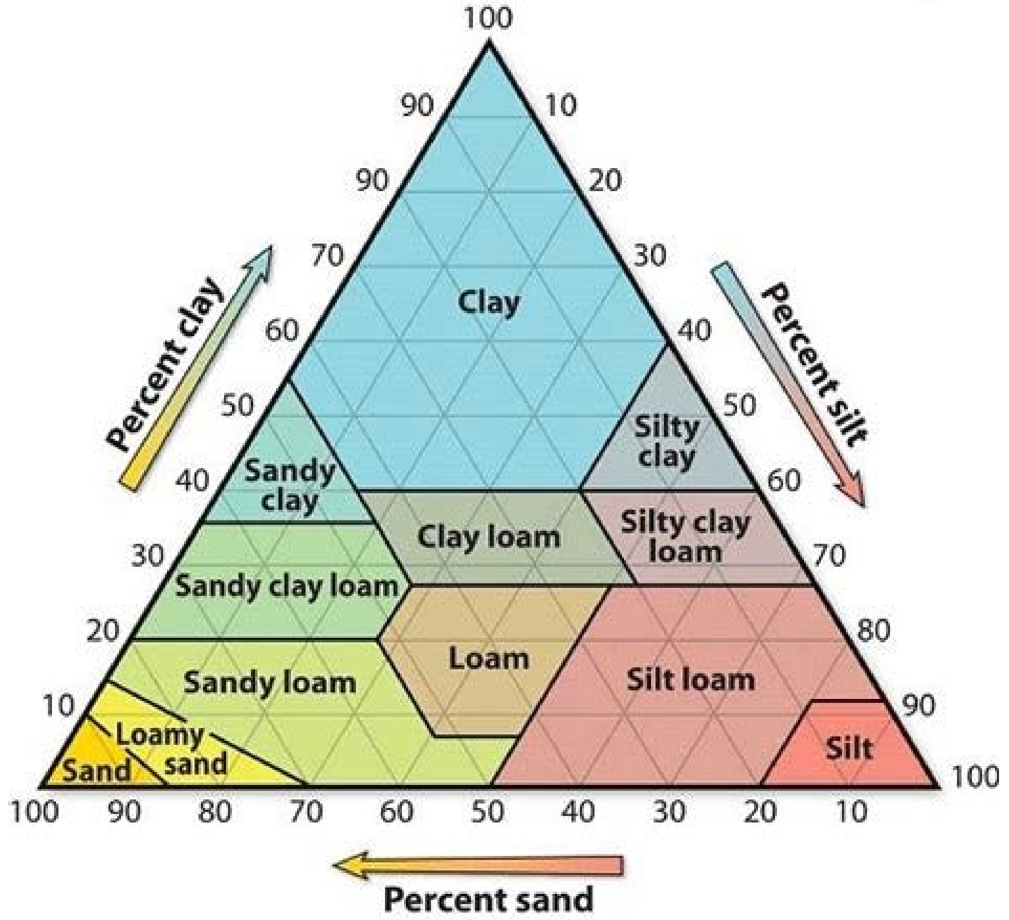
- More time = more weathering or formation



Soil Types

- **Sand**
  - Largest
- **Silt**
  - Medium
- **Clay**
  - Smallest



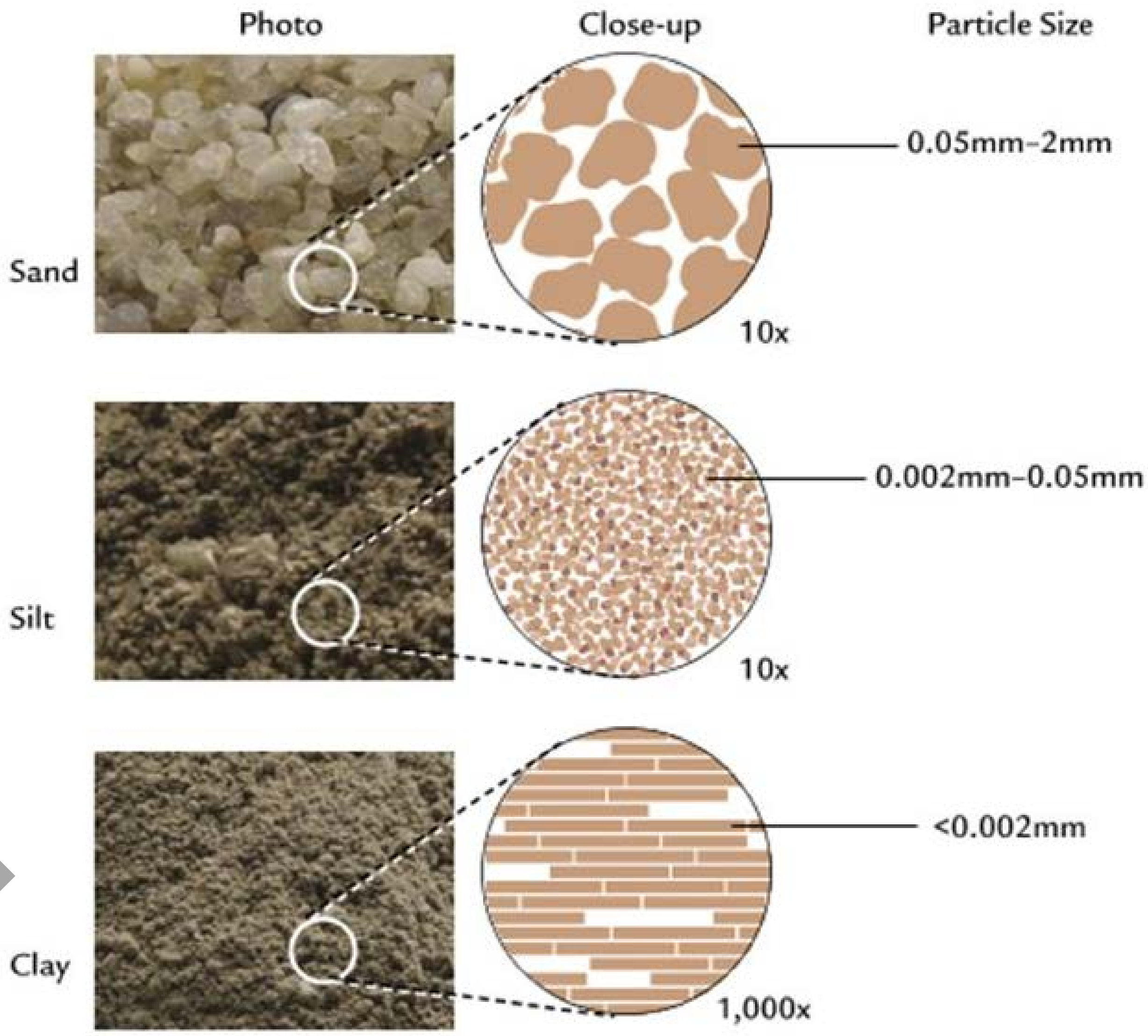


Sand, Silt, & Clay

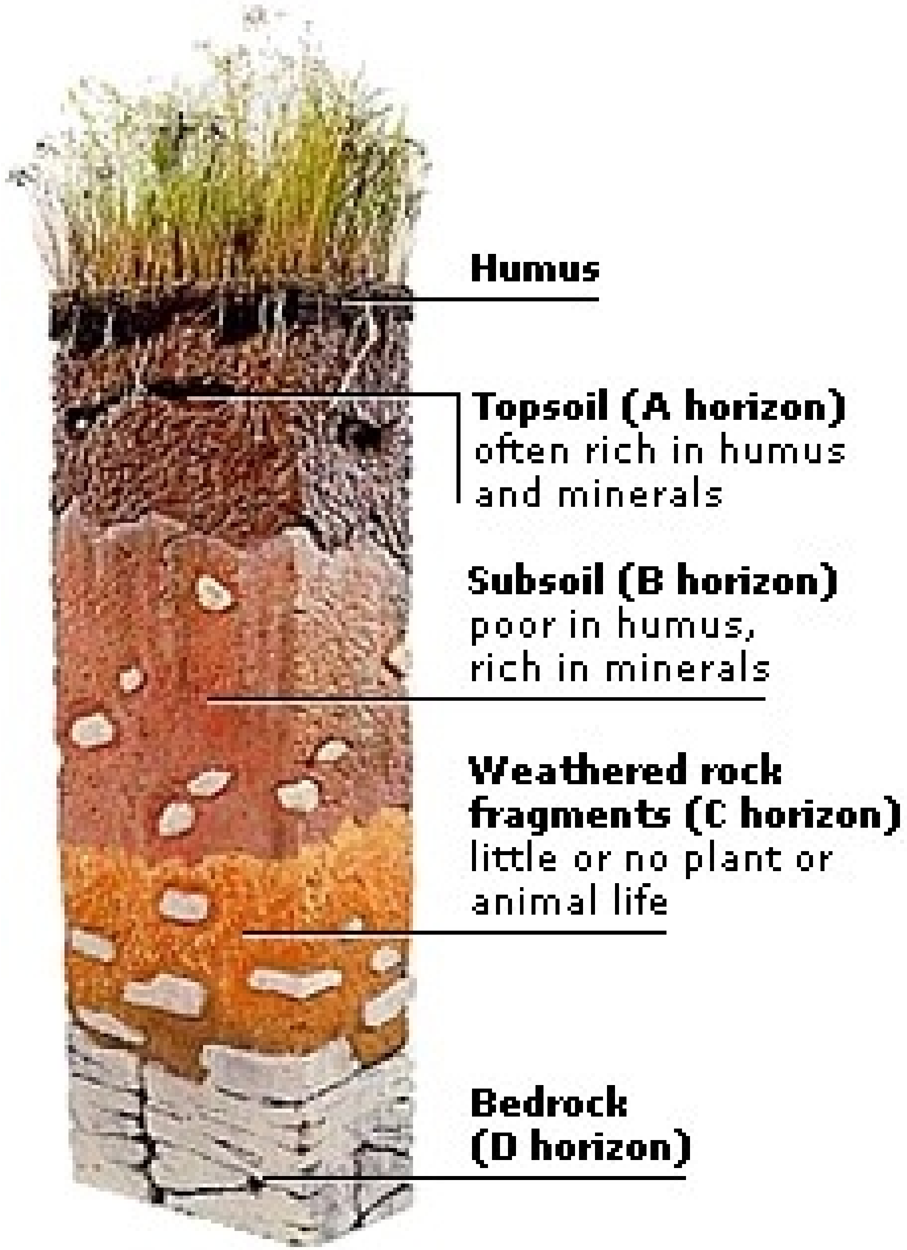
- Holds very little water
- Essentially small rock fragments
- Water passes through very easily
- No cohesion

- Mainly caused by abrasion of rock – "rock flour"
- Easily transported by water & air
- Can hold onto water – easily releases to plants
- Does not stick together well

- Formed from chemical weathering of rocks
- Large surface area – attracts water molecules
- More pore space than sandy soil – lower bulk density than sand
- Poorly drained



Soil Horizons



Bacteria

Decomposers

- Consume root exudates and fresh plant litter
- Can break down pesticides & pollutants
- Immobilize nutrients in their cells – preventing nutrient loss from the rooting zone

Mutualists

- Form beneficial relationships with plants
- Ex: N-fixing bacteria on legumes

Pathogens

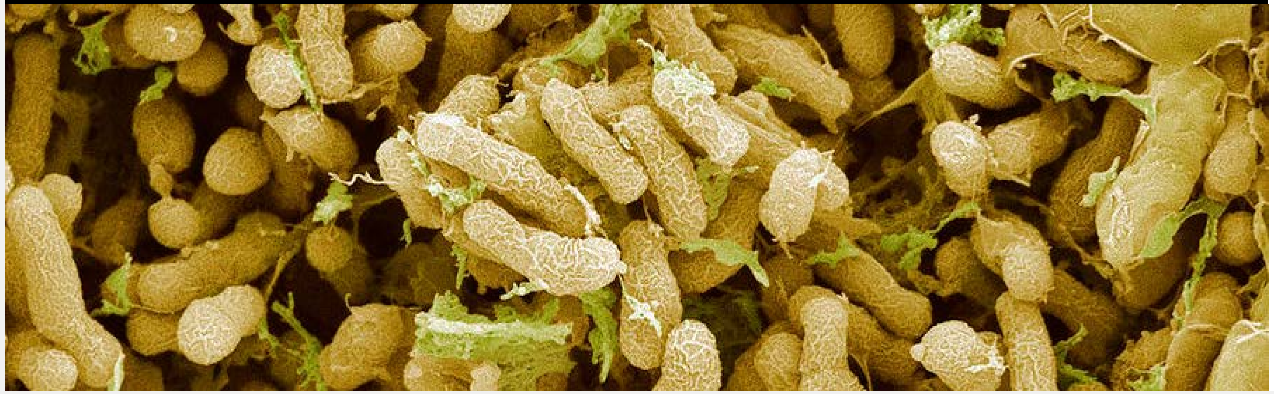
- Detrimental to plants
- Ex: causes gall formation on plants

Lithotrophs

- Consume Nitrogen, Sulfur, Iron, and Hydrogen instead of carbon
- Assist N-cycling and pollutant breakdown

- Some bacteria produce soil-binding substances that bind soil particles into small aggregates
  - This improves water infiltration and the soil's water-holding capacity

Nitrogen-fixing Bacteria

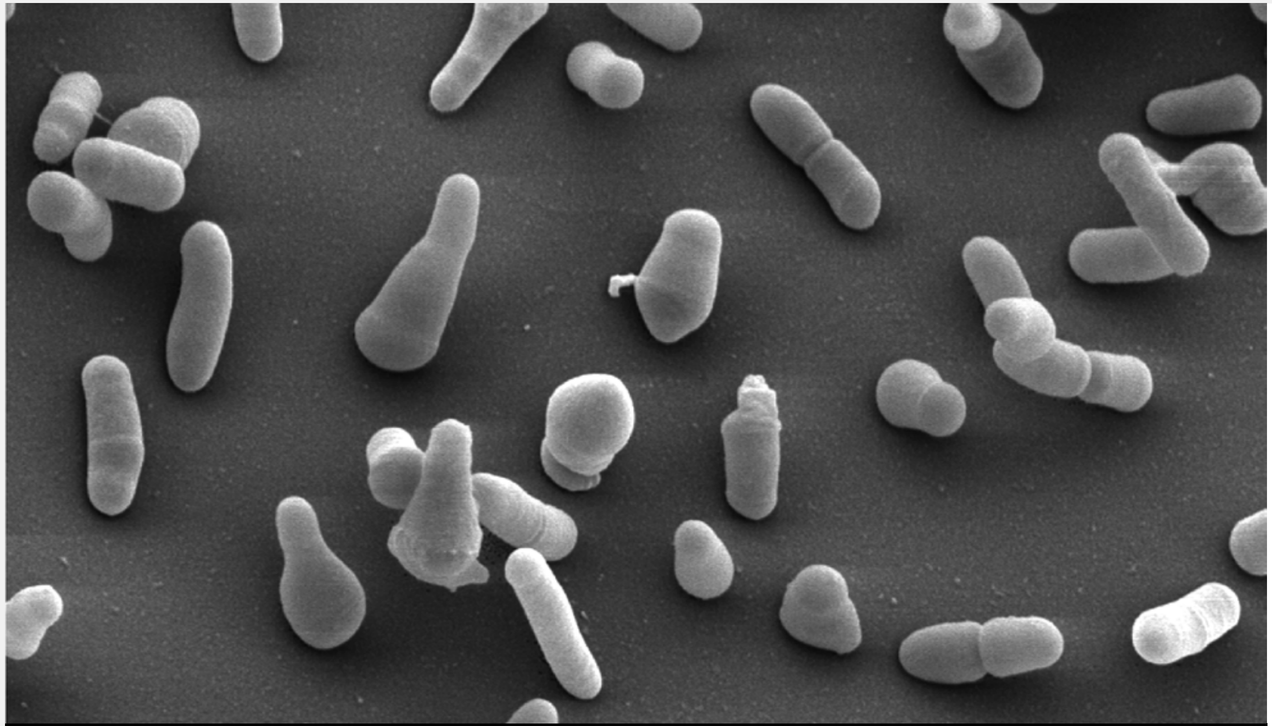


- Form symbiotic association with roots of legumes
  - Ex: clover, lupine, alders, locust
- The host plant supplies simple carbon compounds to the bacteria, and the bacteria converts N_2 from the air into a form the plant can use
- When leaves or roots from the host plant decompose, nitrogen is deposited in the surrounding soil

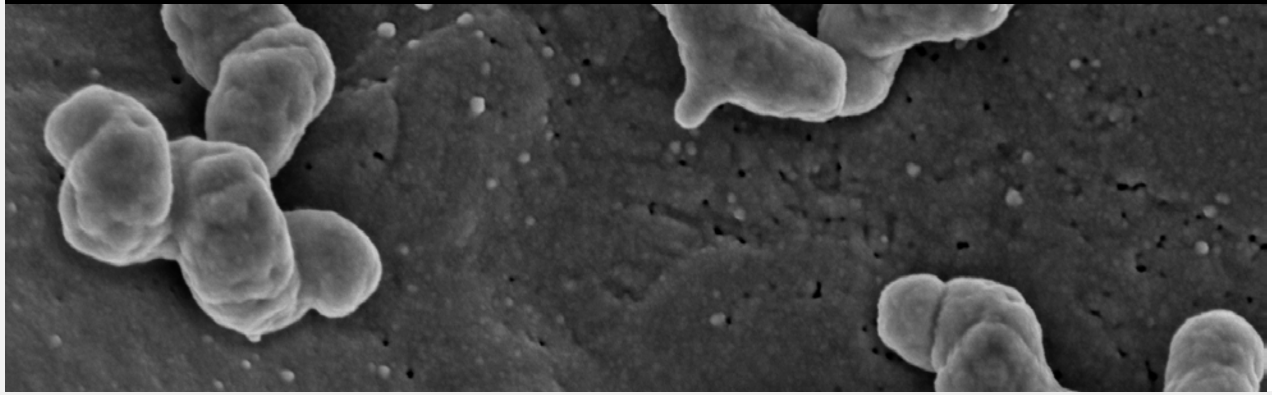
Nitrifying Bacteria

Ammonia NH_3 → Nitrite ions NO_2^- → Nitrate ions NO_3^-

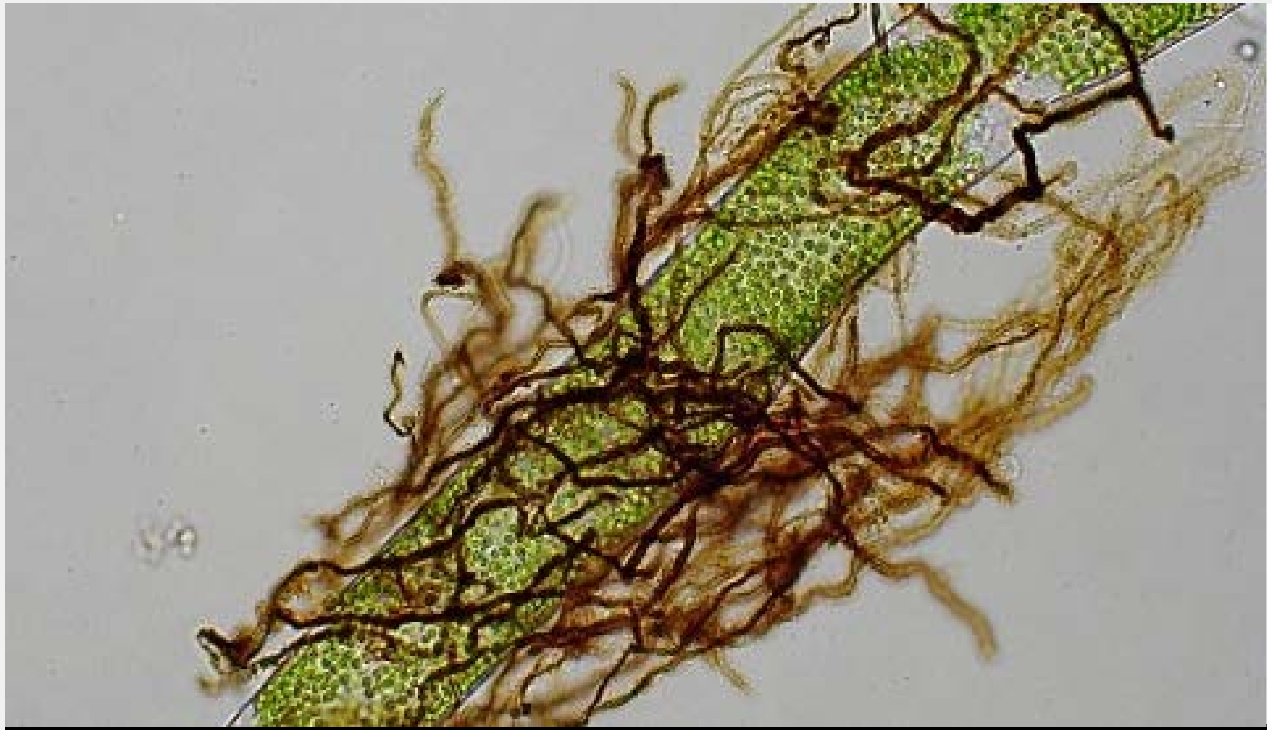
- Changes ammonium (NH_4^+) to Nitrite, then to Nitrate
  - Nitrate is a preferred form of nitrogen for grasses and most row crops
- Nitrate leaches most easily from soil
- Nitrifying bacteria are suppressed in forest soils
  - Most nitrogen remains as ammonium



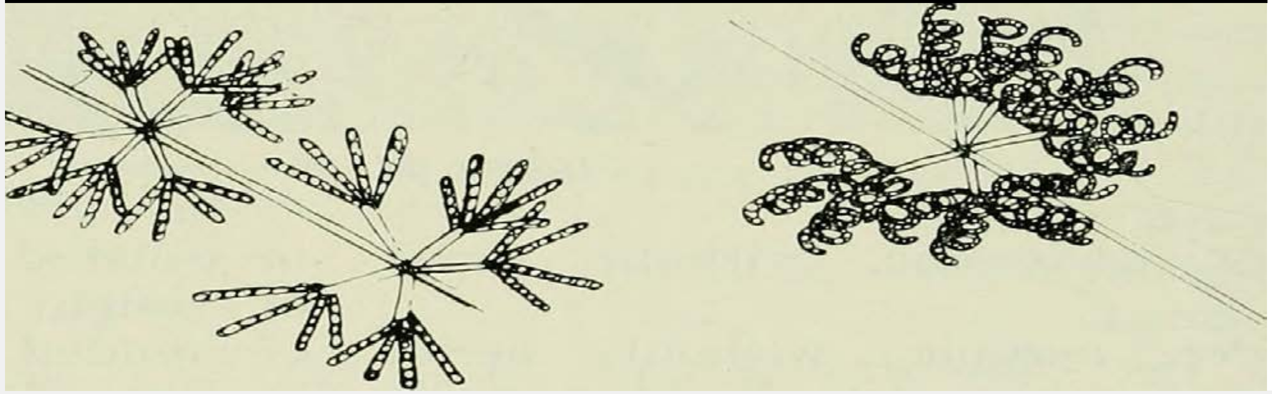
Denitrifying Bacteria



- Convert nitrate to nitrogen or nitrous oxide (N_2O) gas
- Exists in anaerobic environments (void of oxygen)
  - Ex: saturated soils or inside soil aggregates



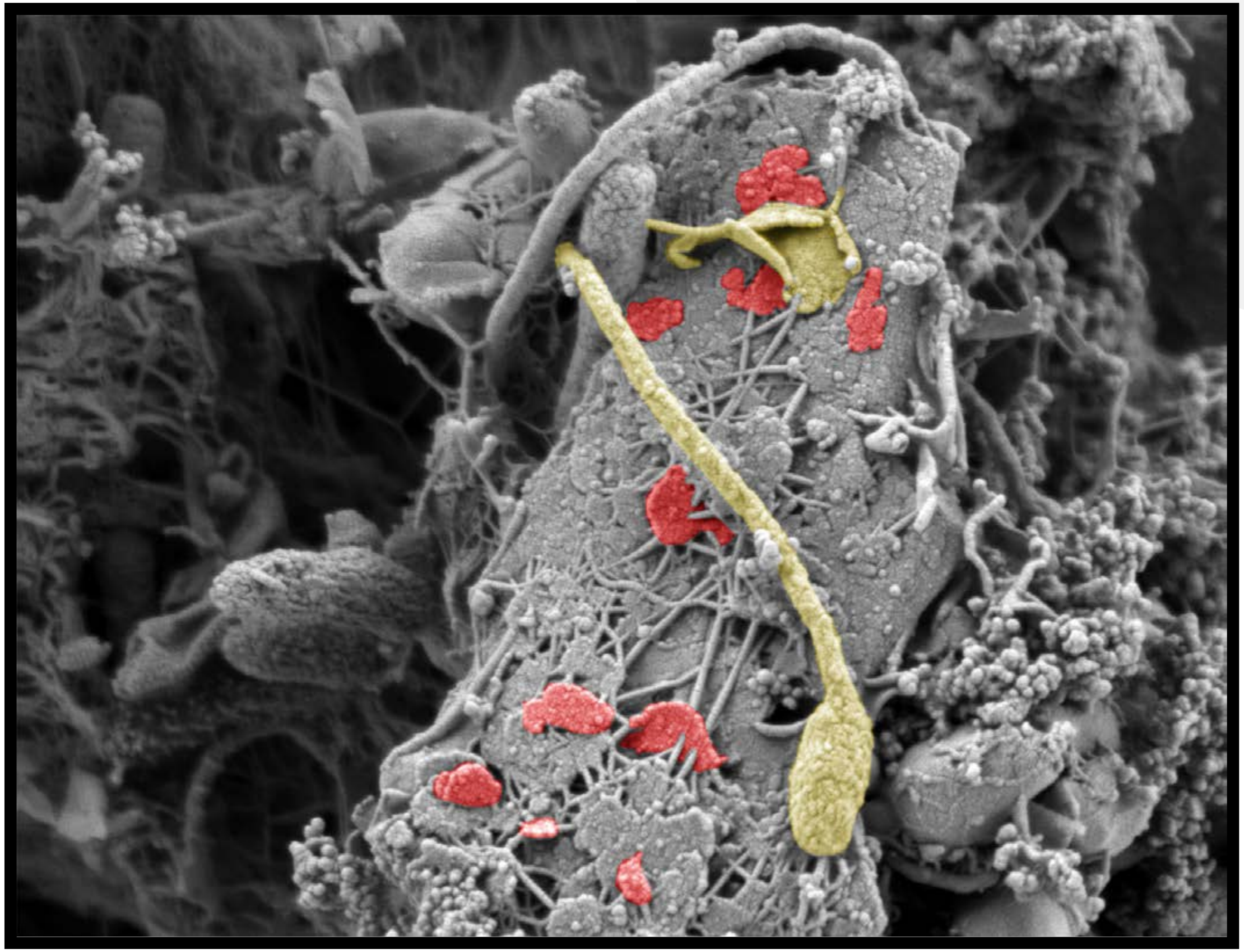
Actinomycetes



- Large group of bacteria that grows like fungal hyphae
- Responsible for “earthy” smell in healthy soil
- Decompose a lot of substrates, but are especially important in degrading recalcitrant (hard-to-decompose) compounds
  - Ex: chitin, cellulose
- Active at high pH levels
  - Fungi are more important at degrading recalcitrant materials at low pH
- Antibiotics created from these bacteria
  - Streptomyces

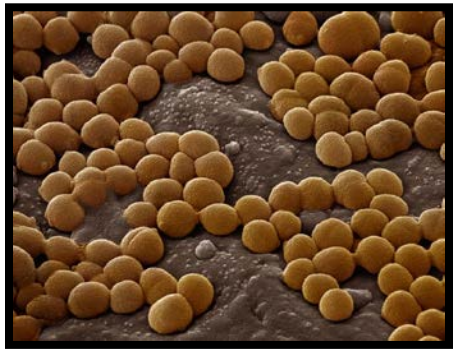
Where is Bacteria Found?

- Generally found where labile (easy-to-metabolize) substrates are present
  - Fresh, young plant residue & compounds near living roots
- Especially present in rhizosphere – the narrow region next to and in the root
  - Evidence shows that plants produce specific root exudates to encourage growth of protective bacteria



Bacteria Cont.

- The bacterial community (starting with photosynthetic bacteria) must establish first on young soil before plant communities can inhabit the soil



Bacteria colonize soil

Fix atmospheric nitrogen and carbon, produce OM, and begin the nitrogen cycling process

Plant community establishes

Plants are able to establish with the available nutrients.

Different types of OM is created, changing the available food for soil bacteria

Bacterial community changes

The altered bacteria community changes soil structure and environment for plants

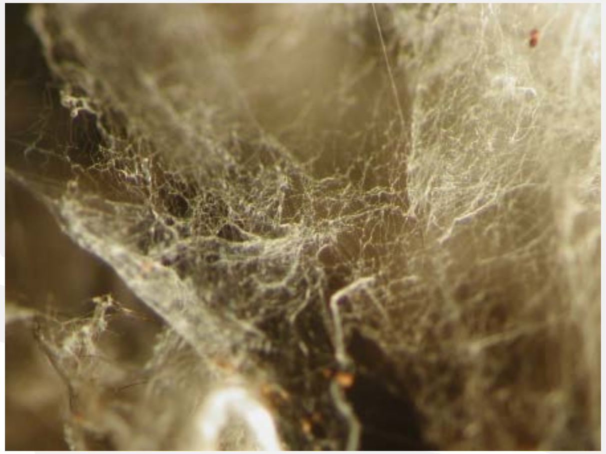
Fungi

- **Hyphae:** a grouping of microscopic cells that usually grow in long strands
    - 0.001 inch thick
    - Range from a few cells to many yards long

- **Mycelium:** a mass of hyphae that forms a root-like structure

- **Mushroom:** fruiting body of the mycelium made of hyphal strands, spores, and gills
    - Many fruiting bodies possible from one fungal body

- Provides services such as water purification/uptake, nutrient cycling, and disease suppression
- Hyphae binds soil into aggregates that increases water infiltration and soil water holding capacity



Fungal Groups

Decomposers

- Saprophytic fungi
- Converts dead OM into fungal biomass, CO_2, and small molecules (organic acids)
- Important for immobilizing nutrients in the soil
- Increase accumulation of humic acid rich OM that is strongly resistant to degradation

Mutualists

- Mycorrhizal fungi
- Colonize plant roots
- Plant exchanges carbon for soil nutrients (P, N, micronutrients) and water

Pathogens

- Result in illness or death when they colonize and organism

Where is Fungi Found

- Saprophytic fungi active around woody plant residue
- Fungi can survive where bacteria might not make it, bridging gaps between pockets of moisture
- Oxygen-rich environments
- Especially extensive in forest lands
  - Forest productivity increases when fungal biomass increases
- Can exist in arid environments
- Found in association with most plants
  - Except: *Cruciferae* family (broccoli, mustard, etc.) and *Chenopodiaceae* family (spinach, beets)
- Fungal populations decrease when:
  - Fields are fallowed
  - Under frequent tillage
  - Fungicides are used
  - High levels of P & N fertilizers used – reduces root inoculation

Soil Organic Matter (SOM)

Benefits of SOM

- Improves soil structure
- Aggregation
- Water retention
- Soil biodiversity
- Absorption & retention of pollutants
- Buffering capacity
- Cycling & storage of plant nutrients
- Increases Cation Exchange Capacity (CEC)
- Huge carbon sink

Humus: well-decomposed OM
mechanically but not chemically degraded
few plant available nutrients but improves soil structure

*Soil organic matter holds 10 to 1,000 times more water and nutrients than the same amount of soil minerals.

Soil Improvement Practices

How to Increase Organic Matter & Fertility

Reduce Irrigation Requirements

What Leads to Healthy Soil and Associated Biological Communities

How to Build Soil Organic Matter

- Don’t disturb the soil and encourage biological tillage (pedoturbation)
- Add compost
- Maintain a layer of mulch
- Plant with diversity in mind
- Mimic grazing systems
- Invite the earthworms in

How to Reduce Irrigation Use

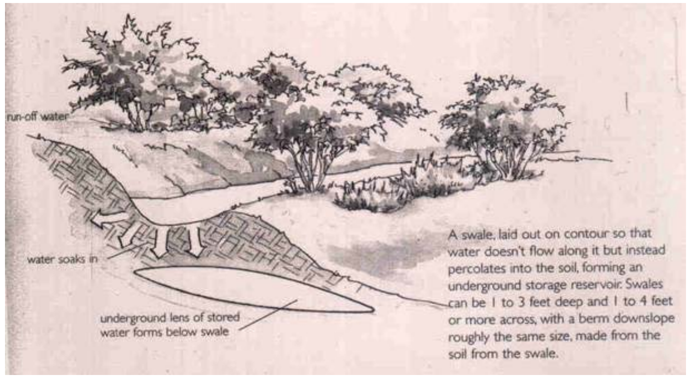
- Design and install earthworks that:
  - **Slow** it
  - **Sink** it
  - **Spread** it

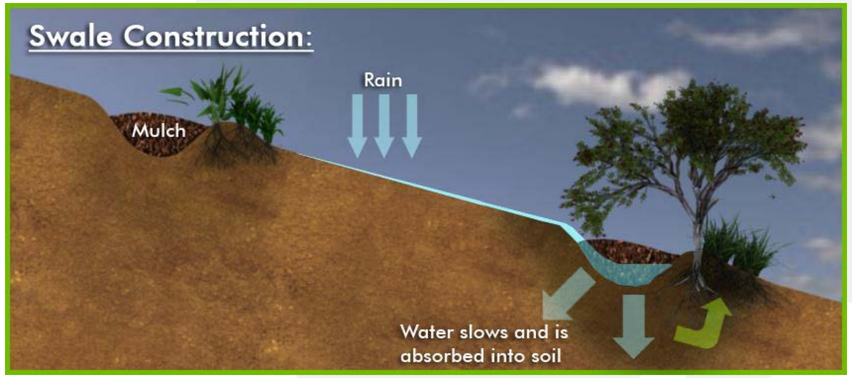
- Swales

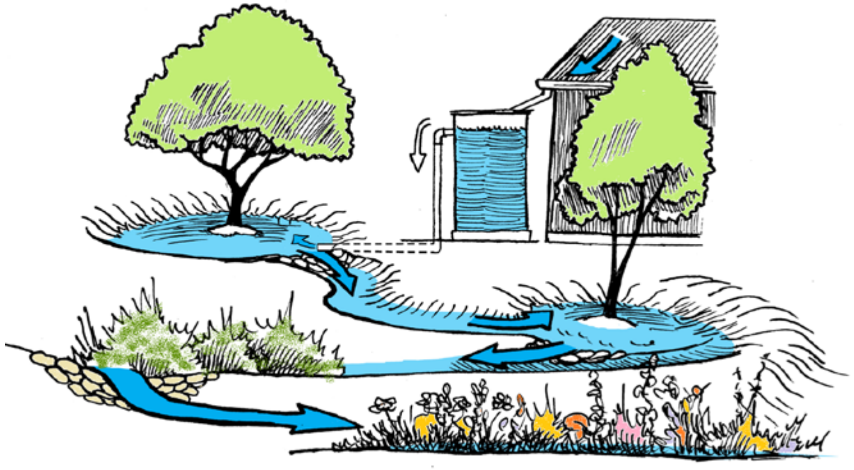
- Catchment depressions

- Rainwater catchment
  - 1000 ft^2 will collect >600 gal. of water with just 1” of rainfall
  - 1/8” rainfall can fill 55 gal. barrel

- Mulch, mulch, mulch!

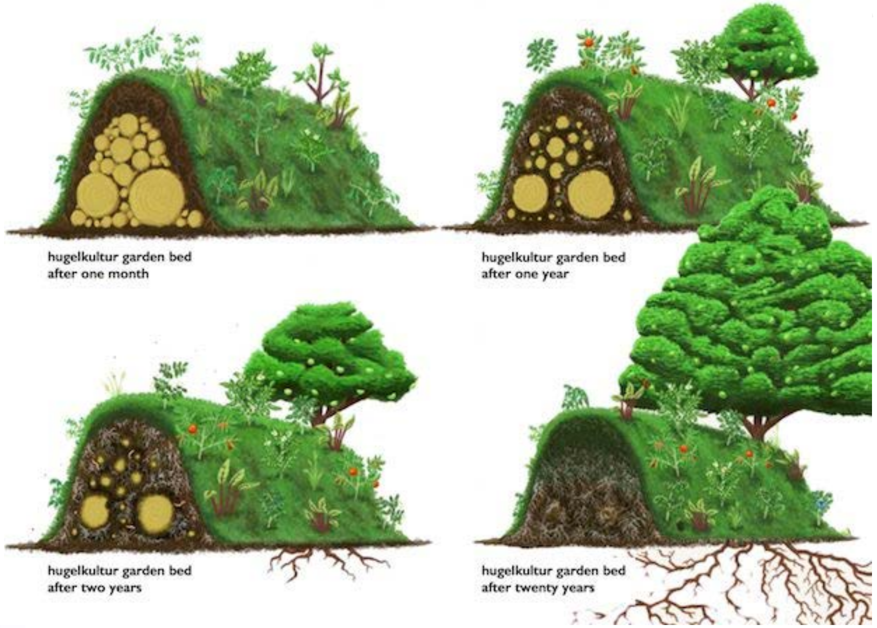


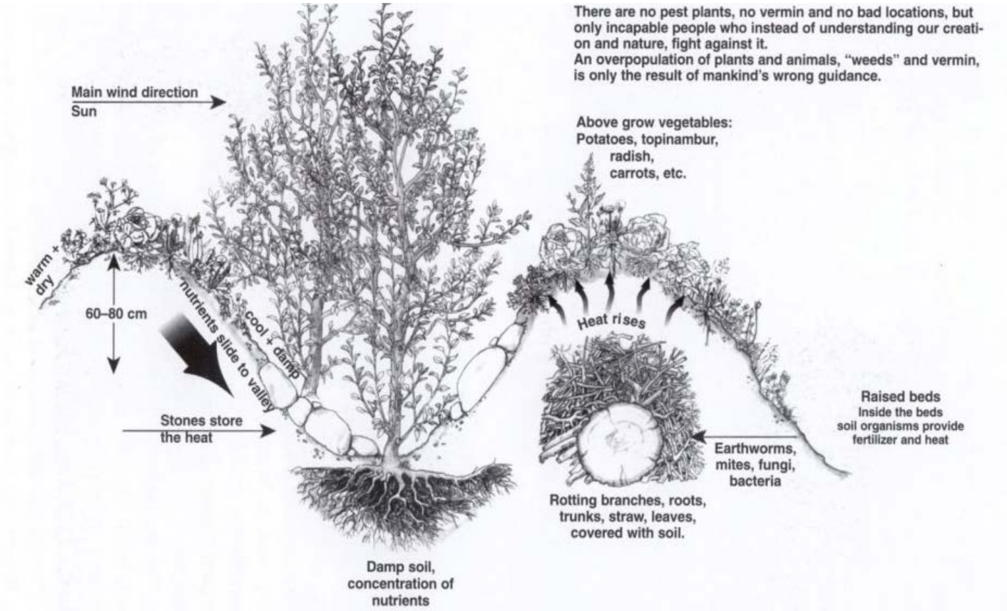




Hugelkulture

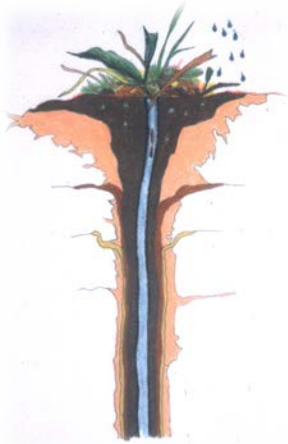
- Raised bed constructed by mounding soil, compost, and/or mulch over logs
- Decaying logs within the soil hold water and nutrients
  - Water is stored in the woody material during the wet season and slowly released as the surrounding soil dries out
  - Nutrients within the wood are slowly released over time
- Fungal activity is increased
- Soil temperatures increase
- Ft^2 of growing space increases

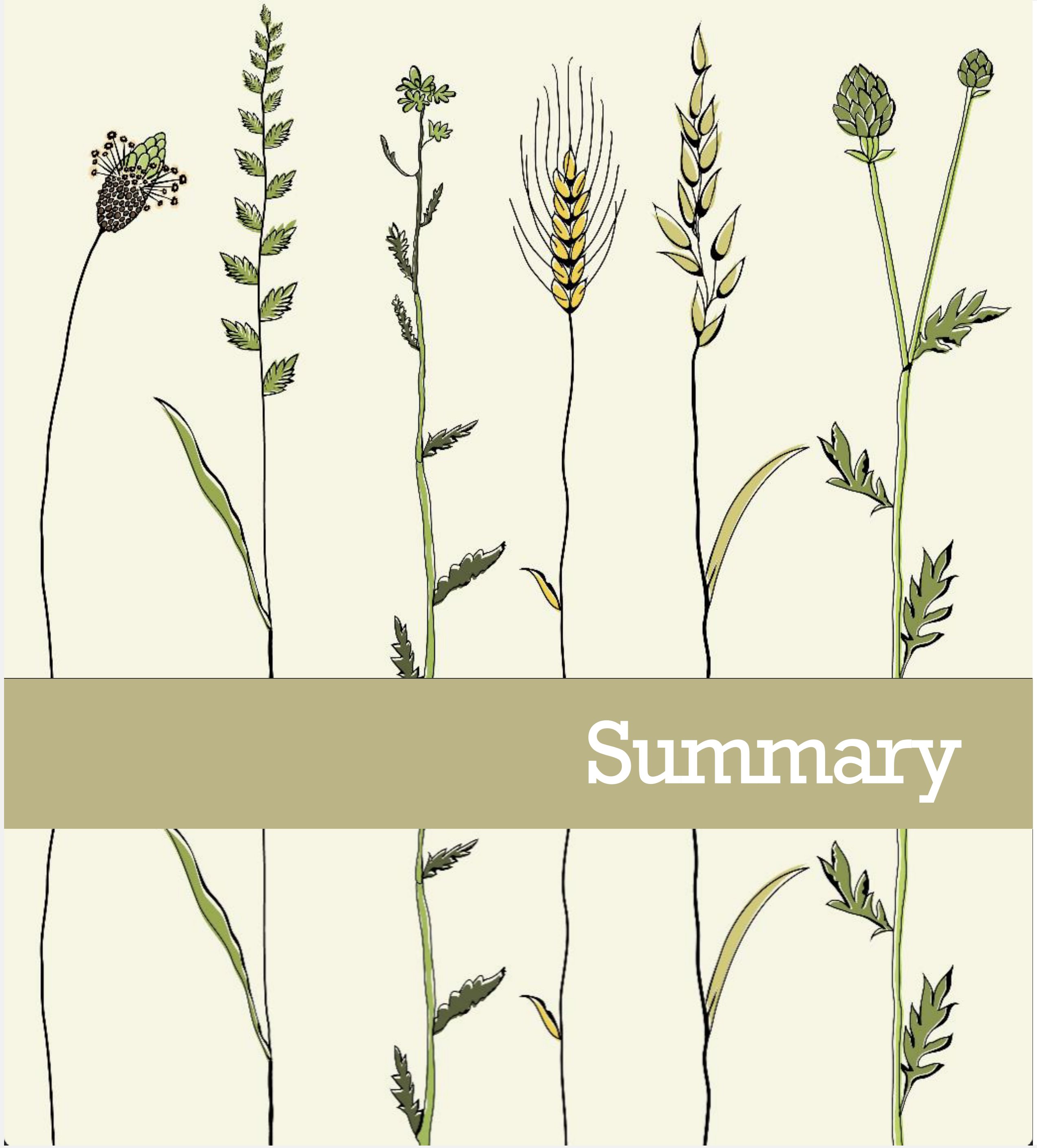




Earthworms

- Predominant soil invertebrate in most soils
- 3 Groups of Earthworms:
  1. Epigeic – surface soil & litter species
  2. Endogenic – upper soil species
  3. Anecic – deep-burrowing species
- Improve water-holding capacity: fragments OM, increases soil porosity & aggregation
- Provides channels for root growth: burrows lined with readily available nutrients – easier for roots to penetrate deeper into soil
- Bury and shred plant residue: pull surface residue into burrows
- Worm populations increase with increased OM, populations decrease with soil disturbance
- Increases microbial and bacterial activity through OM distribution
- Increase in OM = increase in worms = fungi/bacteria/invertebrates = **fertility**





Summary

- CLORPT
- Sand is gritty, silt is smooth, and clay is sticky
- Bacteria and fungi are imperative for plant life
- SOM is the solution
- *Slow* it, *sink* it, *spread* it
- Be an earthworm rancher
- Nature abhors a vacuum
- “You can solve all the world’s problems in a garden”

Thank You

Matt Prendergast
(619) 964-7165
mtp236@gmail.com