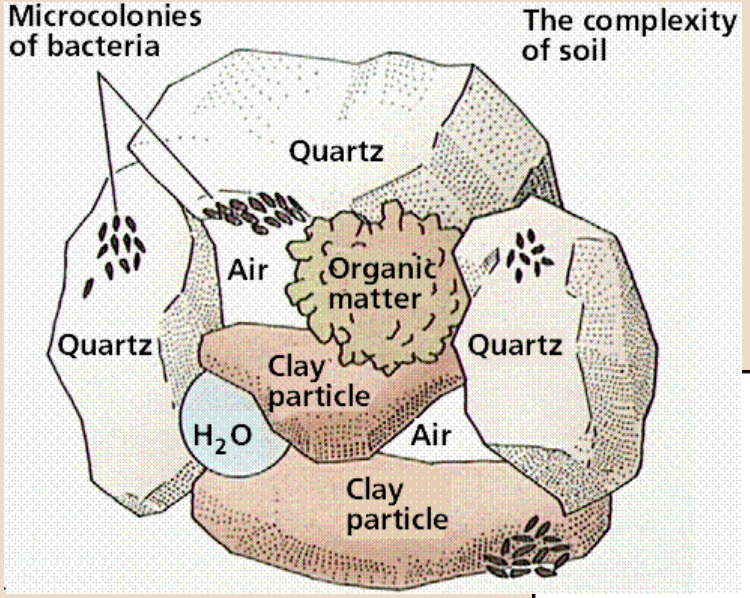
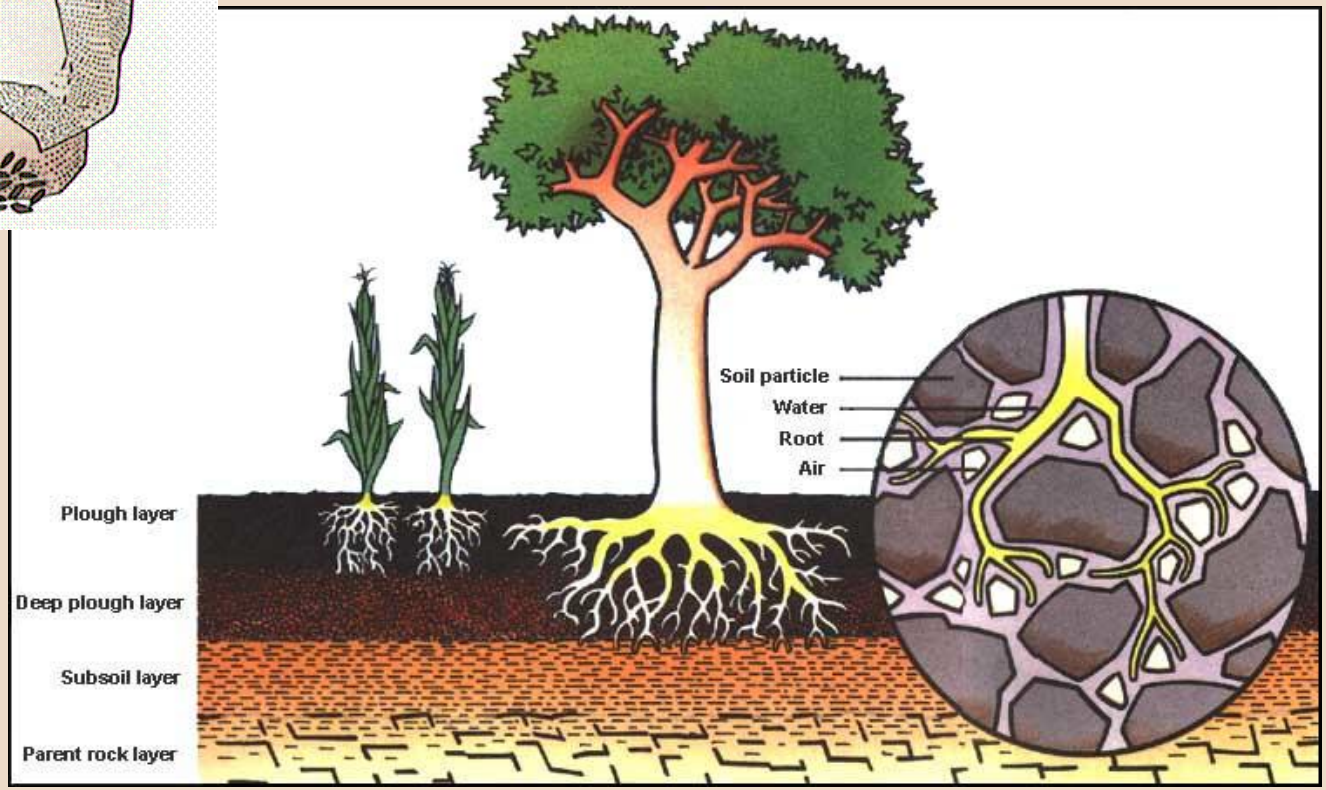


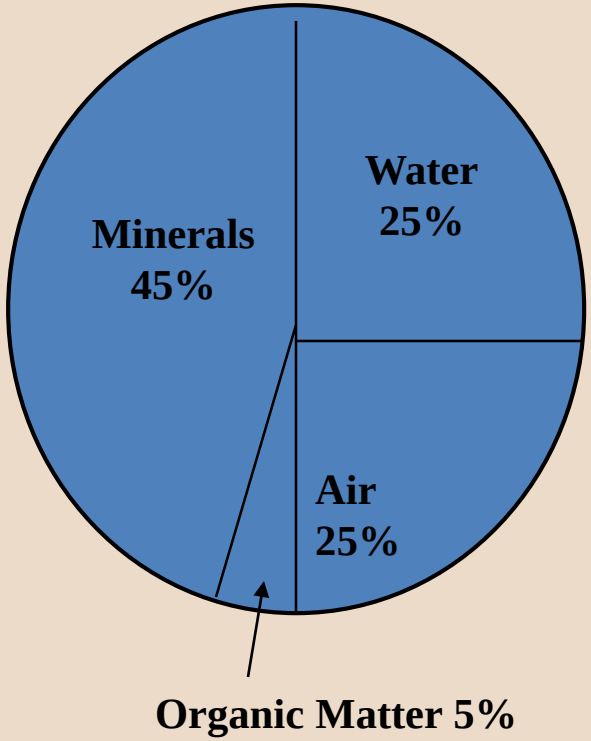
SOILS –

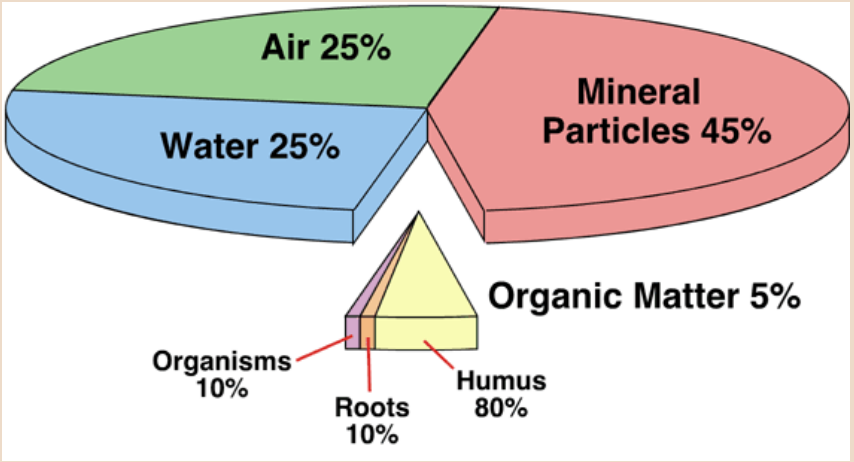


FROM THE GROUND UP

Soils defined: (simple)

- A mixture of mineral matter, organic matter, water, and air that support plant growth.





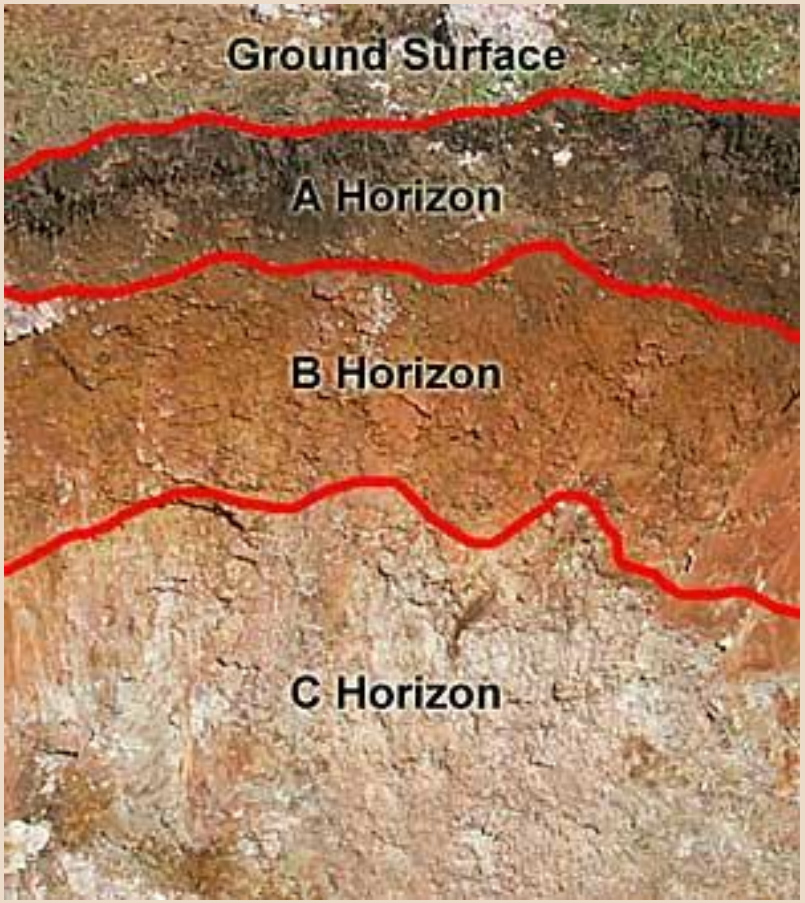
Composition of a Mineral Soil

Soil Horizons

- A **soil horizon** is a specific layer in the soil which measures parallel to the soil surface and possesses physical characteristics which differ from the layers above and beneath.

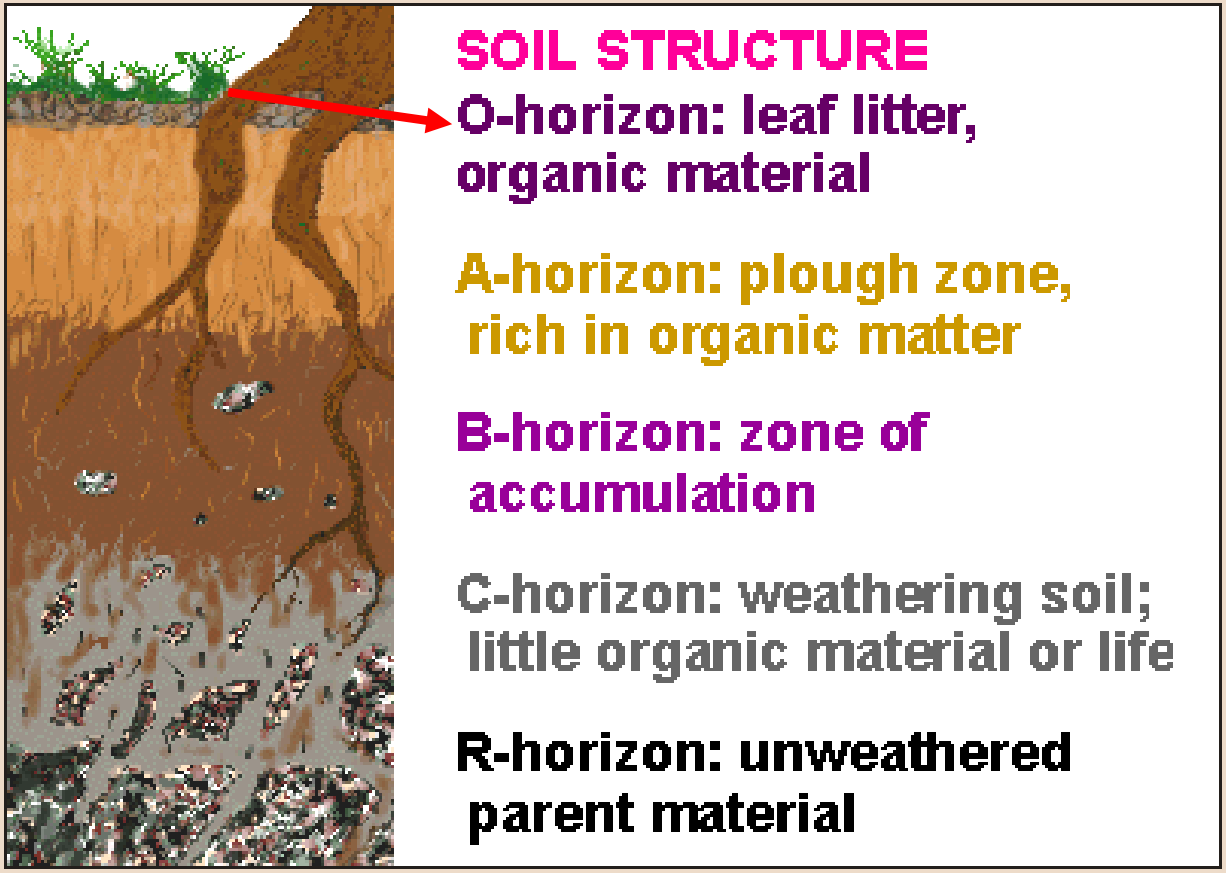
- Horizon formation is a function of a range of geological, chemical, and biological processes and occurs over long time periods. Soils vary in the degree to which horizons are expressed.

- As the age of a soil increases, horizons generally are more easily observed.



Soil Horizons – O Layer = Organic

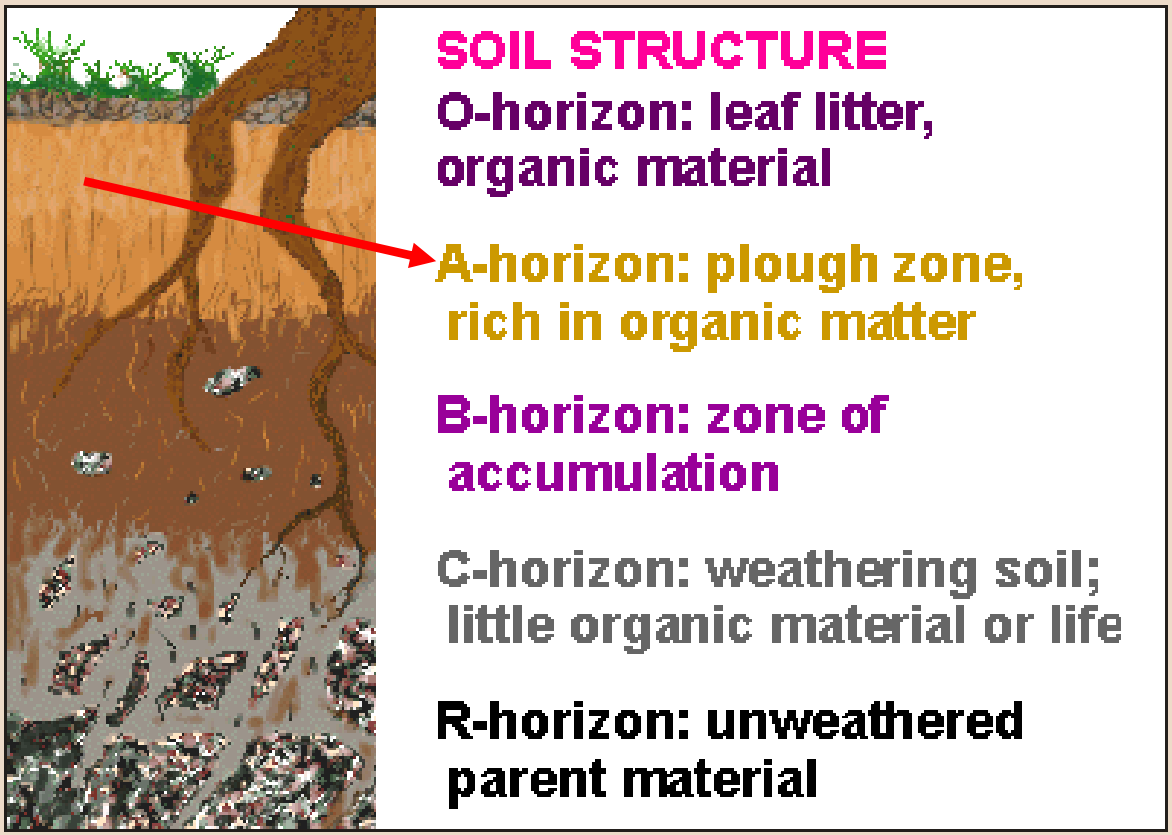
- This layer is also known as humus, with it's surface layer being dominated by the presence of large amounts of organic material in varying stages of decomposition.



Soil Horizons – A Layer = Topsoil

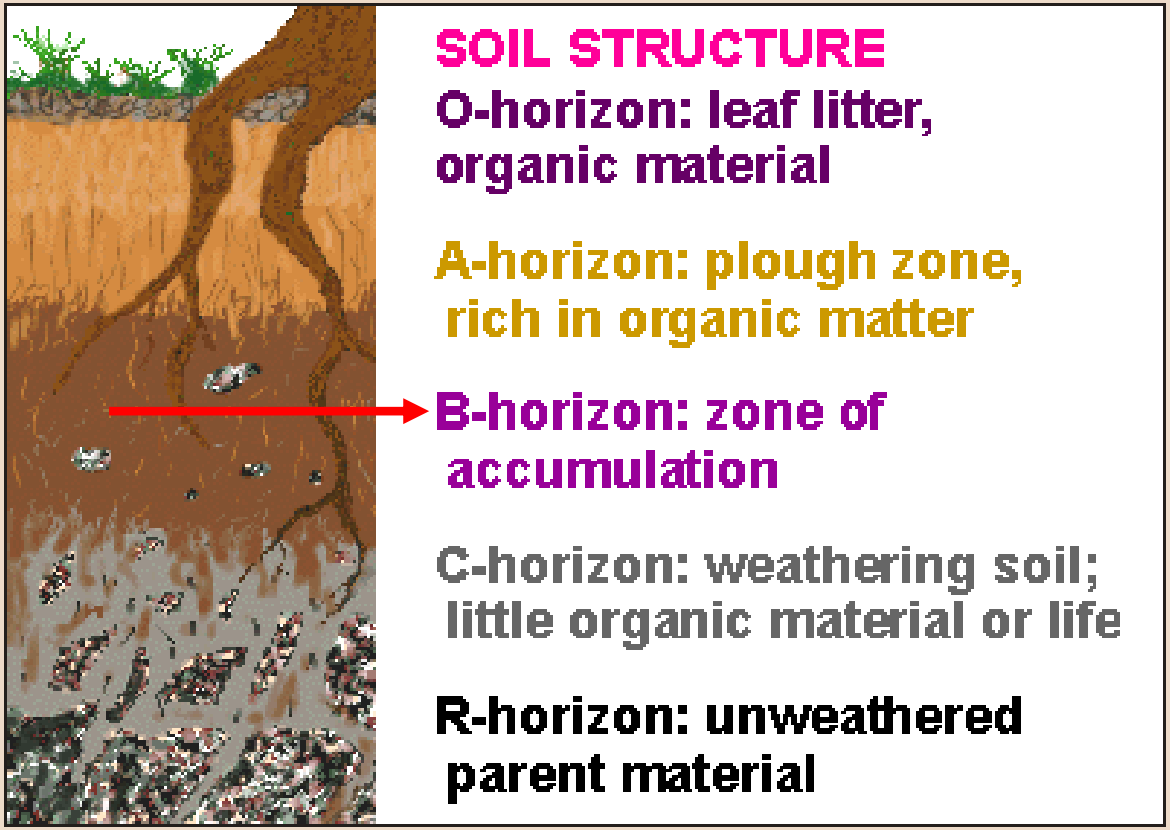
- **The A layer is a surface horizon, and as such is also known as the zone in which most biological activity occurs.**

- Soil organisms such as worms, nematodes, fungi, and many species of bacteria is concentrated here, often in close association with plant roots.



Soil Horizons – B Layer = Subsoil

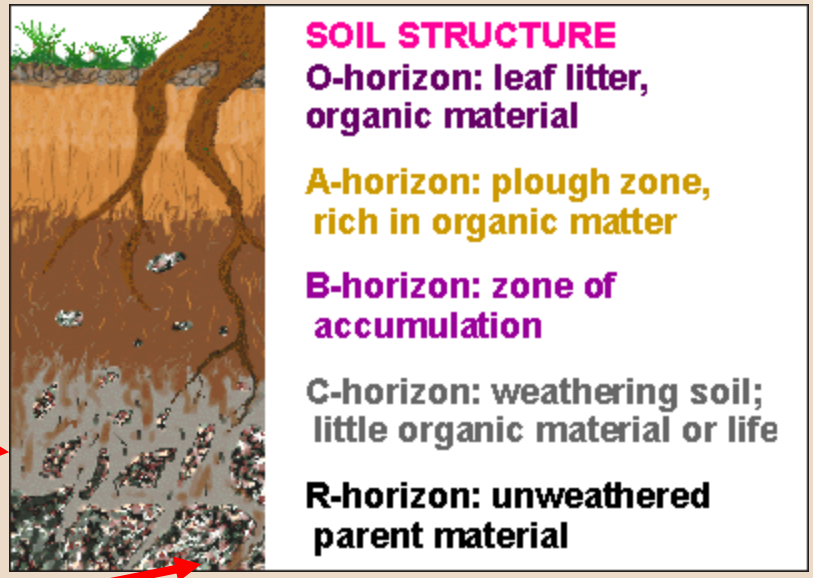
- The B Horizon is commonly referred to as 'subsoil', and consist of mineral layers which may contain concentrations of clay or minerals such as iron or aluminum, or organic material which get there by leaching.



- This layer is also known as the layer of accumulation.

Soil Horizons – C Layer = Broken Parent Material

- **This layer is little affected by soil forming processes.**
- The C Horizon may contain lumps or more likely large chunks of unweathered rock and contains bits of bedrock.



Soil Horizons – R Layer = Bedrock

- The R horizon basically denotes the layer of partially-weathered bedrock at the base of the soil profile.
- Unlike the above layers, R horizons largely comprise continuous masses (as opposed to boulders) of hard rock that cannot be excavated by hand.
- Soils formed in place will exhibit strong similarities to this bedrock layer, while depositional soils will often appear very distinct.

Soil Color

Based on it's color, a visual determination of the soil's fertility, origin, moisture, and horizons can be made.

As a rule:

- Dark soils are fertile.
- Light soils are less fertile.
- Mottled soils show poor drainage.
- Bright colors show iron or other elements.

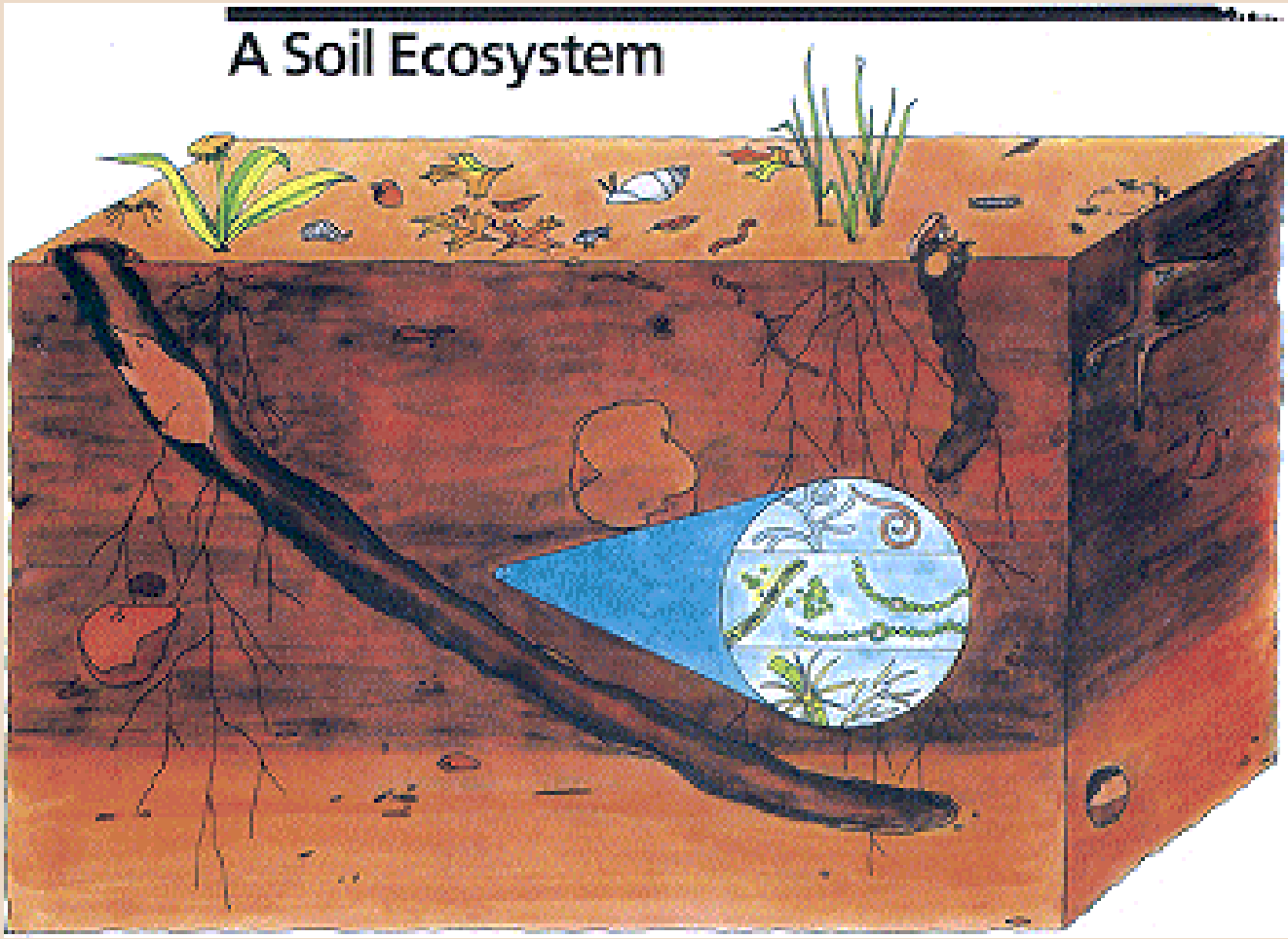
Soil Facts

- **It takes 100 to 600 years to form an inch of topsoil.**
- There are more organisms in one shovelful of dirt than there are people on the planet!
- The top 1 inch of the forest floor contains an average 1,400 living creatures for each square foot. Also, in one teaspoon of soil there are 2 billion bacteria and millions of fungi, protozoa and algae.
- There are 5000 to 7000 different species of bacteria in one gram of soil and the number of bacteria ranges from 100,000 to several billion.
- The total living matter in an acre of soil ranges from 5000 to 20,000 pounds.
- Each year, 15 tons of dry soil per acre pass through earthworms. Earthworms eat soil to get the organic materials in it. The rest passes through them.

The Soil as an Ecosystem

- The soil is a living, breathing ecosystem.

- The health of the plants in our soil is directly dependant on the health of the soil!



Plant Roots and Soil Horizons

- In order for plant roots to grow and survive, they **must** have a soil environment that has **the right balance of water and air**. Too much or not enough of either will result in root death.

- In addition, the soil must have a temperature and pH range that is within the plants tolerance.

- Roots on plants have 3 main functions:
  1. Anchorage
  2. Food Storage
  3. Absorption of water and nutrients = Feeder Roots

- Trees growing in urban areas **seldom** develop taproots. Root systems actually consist of larger perennial roots and smaller, short-lived, feeder roots. Large, woody tree roots and their primary branches increase in size and grow horizontally.

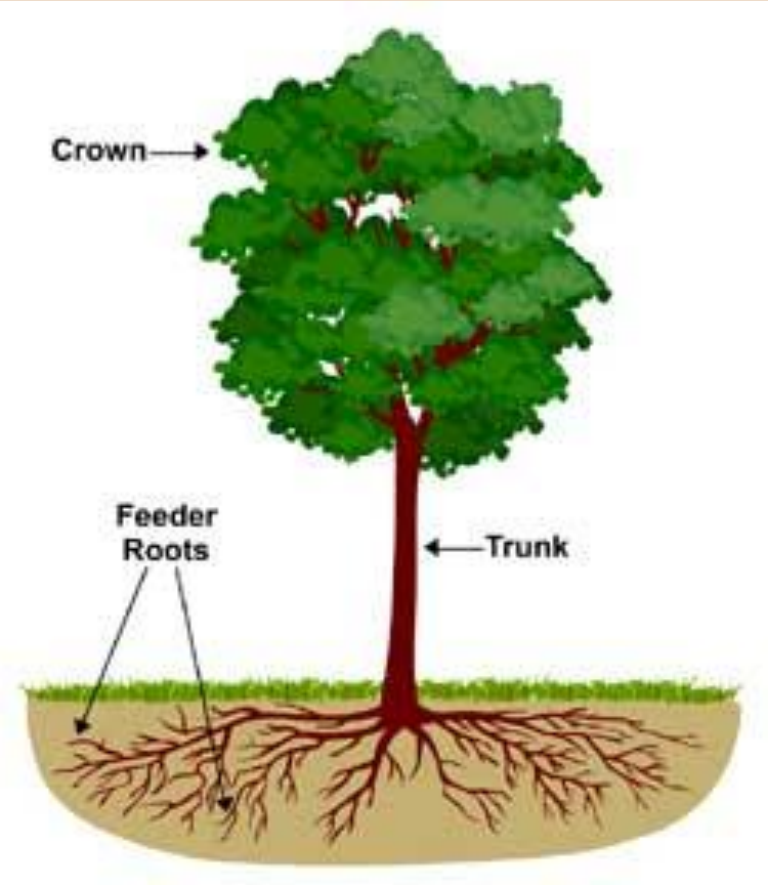
These roots are usually located in the top 6 to 36 inches of soil.

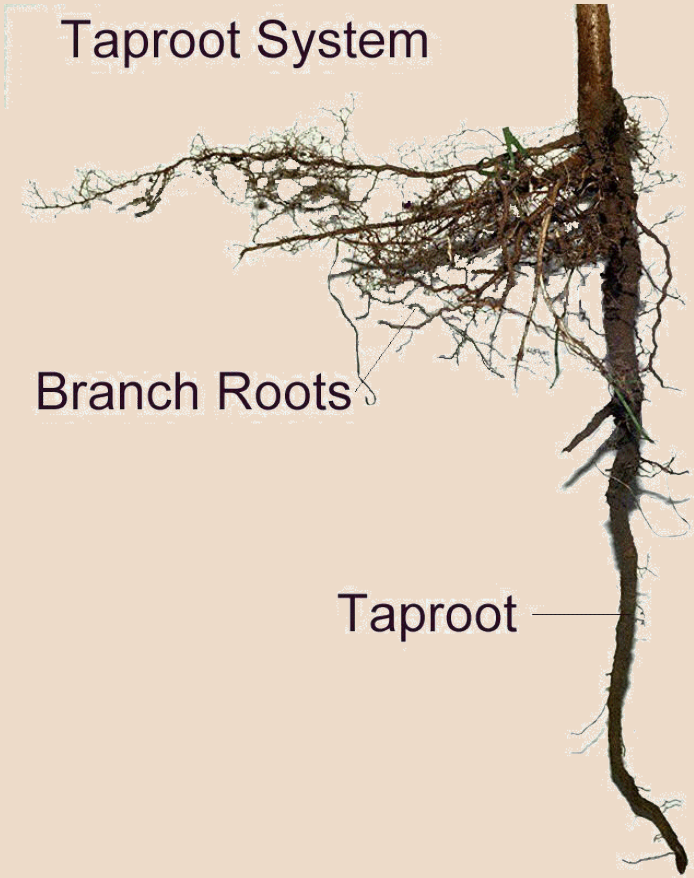
How Plant Roots Grow

- The small feeder roots constitute the major portion of the root system's surface area.

- **Feeder roots are located throughout the entire area under the canopy of a tree. As much as 50 percent of the root system grows beyond the drip line and may extend as far as two to three times the height of the tree.**

- A Trees **feeder roots** grow out from large woody roots and usually **grow up toward the soil surface.** At the surface, feeder roots mix with lawn and shrub roots and compete for the water, oxygen and minerals that are more abundant near the surface.





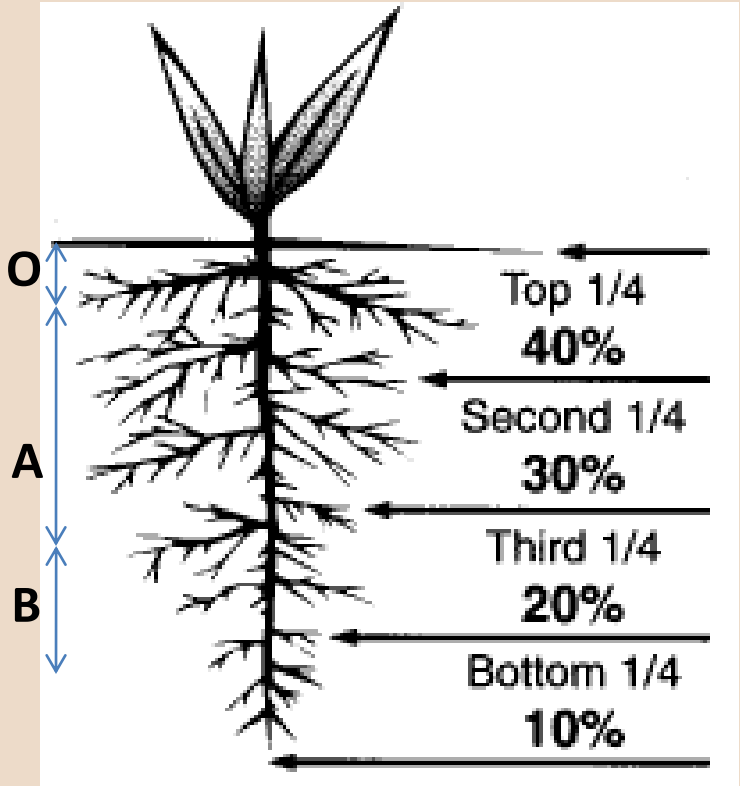
How Plant Roots Grow

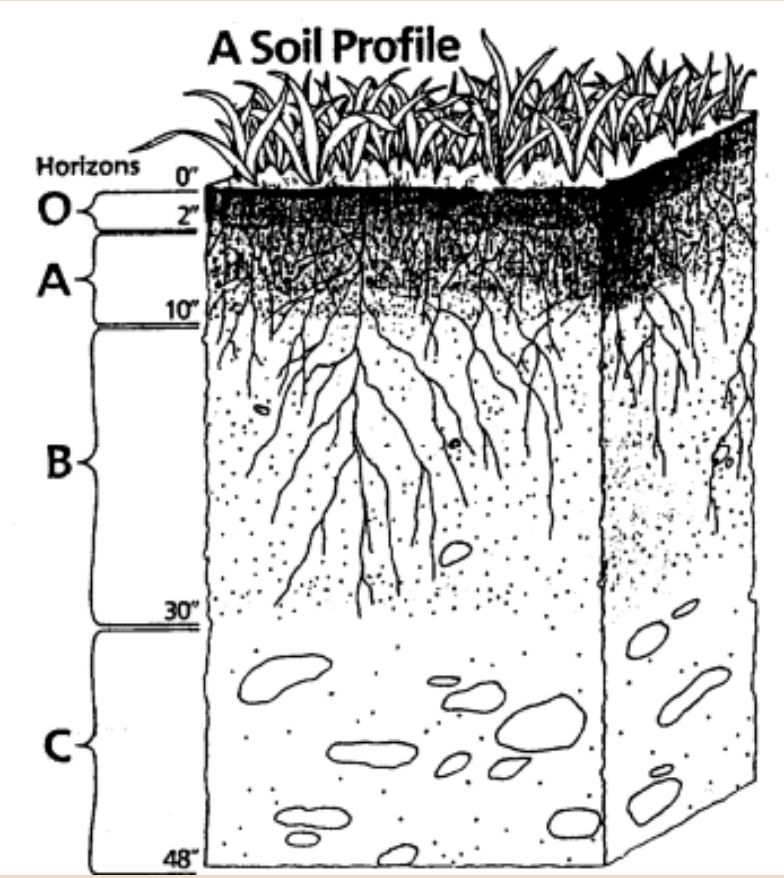
- The roots on shrubs and smaller annual and perennials plants serve the same function and behave in the same way as tree roots.
- Although tap roots sometimes develop on these smaller plants, it is the smaller and finer feeder roots (branch roots) that absorb the majority of water and nutrients from the soil.

Soil Horizons O, A and B

- Because we are most interested in soils as a growing environment, we will focus this discussion on the areas of root growth and how we can improve the soils to enhance the health and performance of the plants we grow.

- **Therefore the remainder of this discussion will pertain to the soil horizons O, A and to a small extent B.**





The Physical Characteristics of Soil

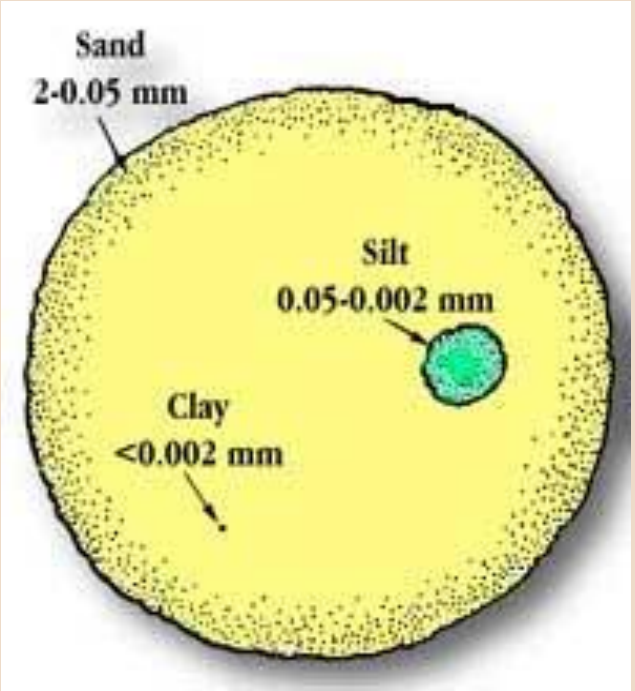
Soil Separates

Soil Texture

Soil Structure

Soil Separates – The Mineral Component

- The individual particles that make up a soil are defined as soil separates.
- These particles are classified by size, not by the origin or make-up of the particles.
- These particles are called sand, silt, and clay.
- Sand particles are the largest, silt particles are in-between, and clay particles are the smallest.

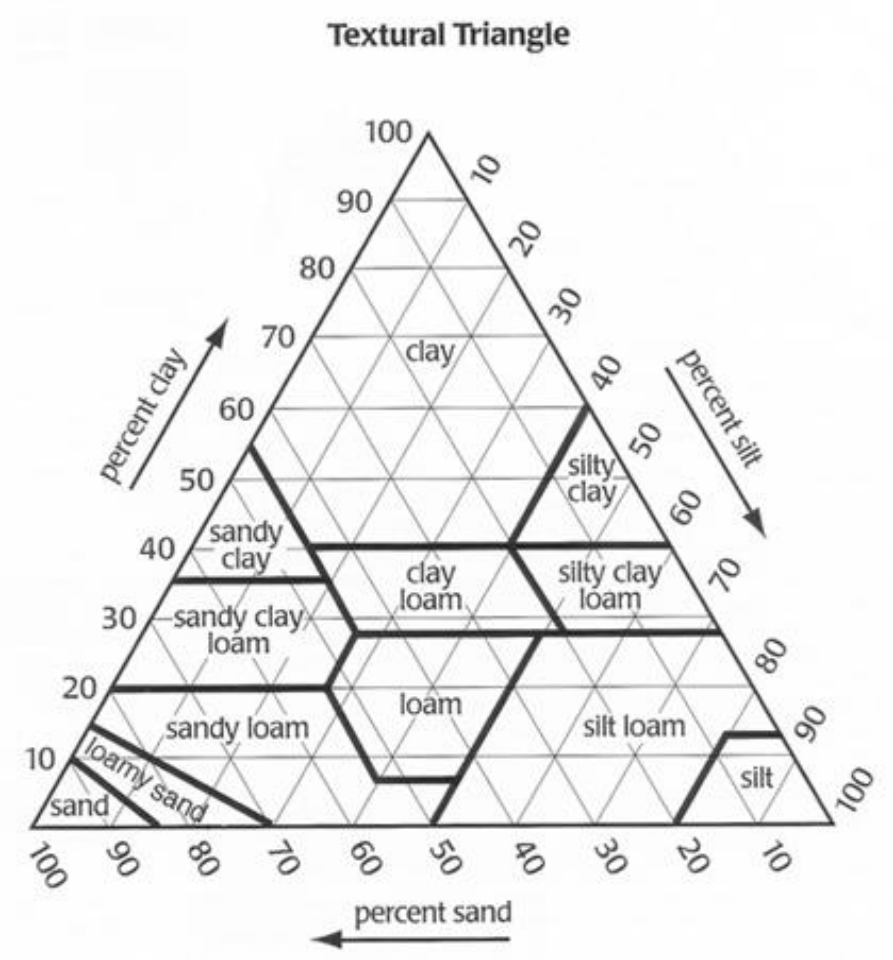


Soil Texture – The Mineral Component

- The relative percentages of the soil separates. In other words, the %'s of sand, silt, and clay in a soil sample.

- Includes 12 textural classes: sand, loamy sand, sandy loam, loam, silt loam, silt, silty clay loam, clay loam, silty clay, clay, sandy clay, and sandy clay loam.

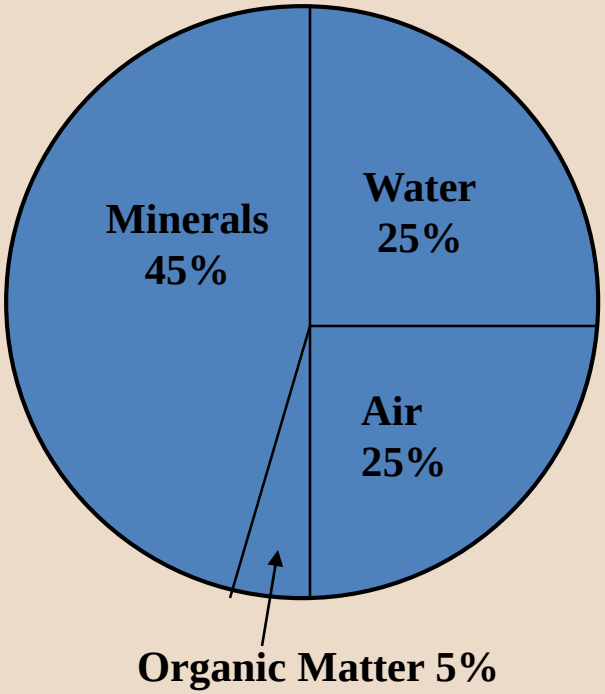
- Textural classes are determined by the use of a soil textural triangle.

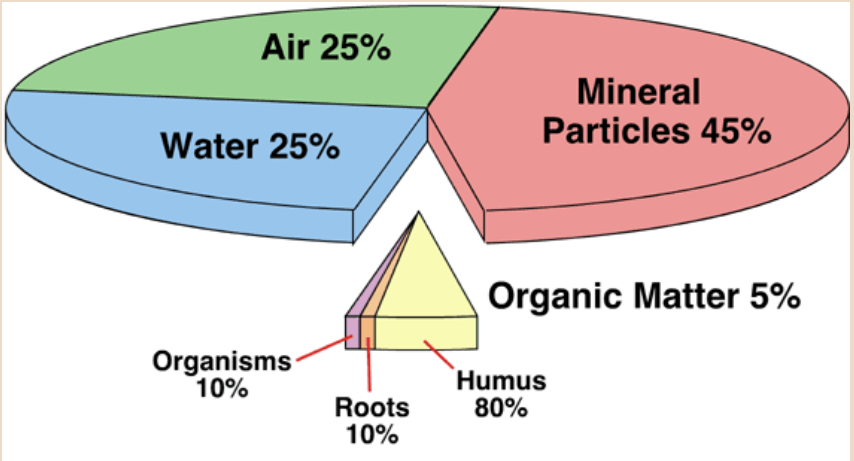


Soil texture

- Soil texture is determined by the size and type of solid particles that make up the soil.

- Soil particles may be either mineral or organic. In most soils, the largest proportion of particles are mineral and are referred to as "mineral soils.“





- **Soil texture classes may be modified if greater than 15% of the particles are organic.**

Sandy Soil Characteristics

- Large, open pore spaces.
- Good aeration to plant roots.
- Excellent drainage.
- Has low tendencies to compact.
- Tends to dry out rapidly.
- Often lacking in nutrients.
- Does not retain nutrients well. (Low cation holding capacity).
- Good for plant growth when fertilizer and water is frequently supplied.
- **Best improved with organic matter additions.**

Clay Soil Characteristics

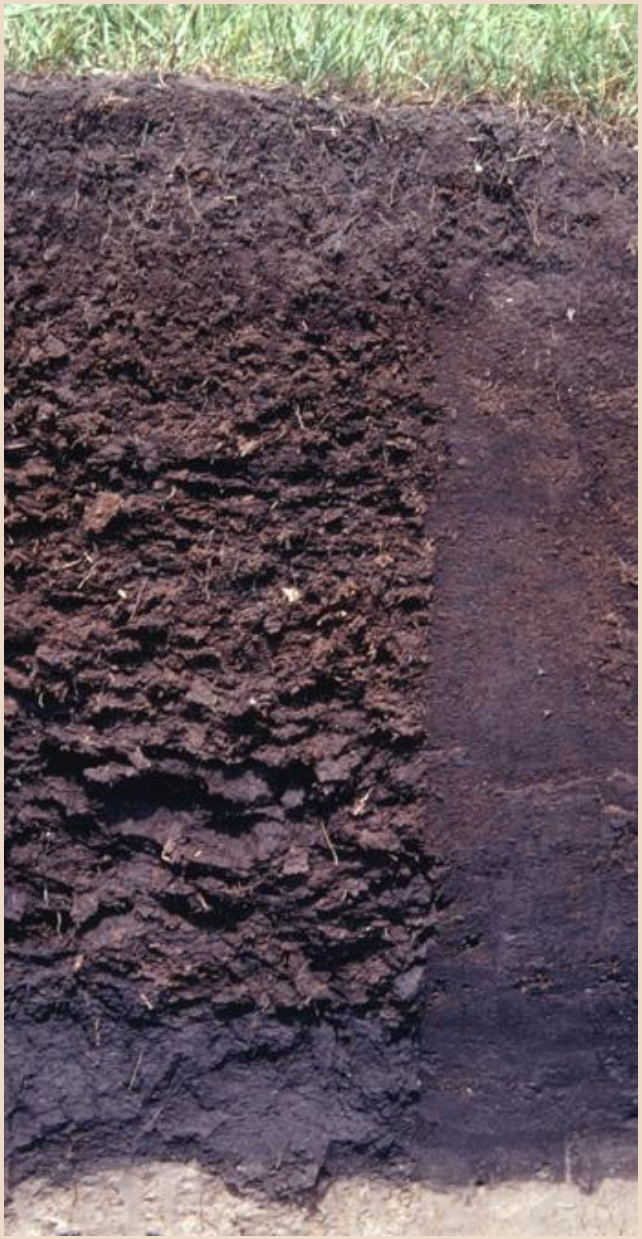
- Small, numerous pore spaces.
- Aeration to plant roots can be limited and slow.
- Drainage may be slow or poor. Water runoff may be a problem.
- Holds water well.
- Tends to hold nutrients better than other soil textures.
- Can be difficult to manage, often compacts, and may stay soggy.
- **Best improved with organic matter additions.**

Loam Soil Characteristics

- Has both small, medium, and large pore spaces.
- Aeration is usually adequate to good.
- Usually has good drainage.
- Good water and air balance.
- Considered best of all soil textures.
- **Additions of organic matter can only make a loam even better!**

Organic Soils

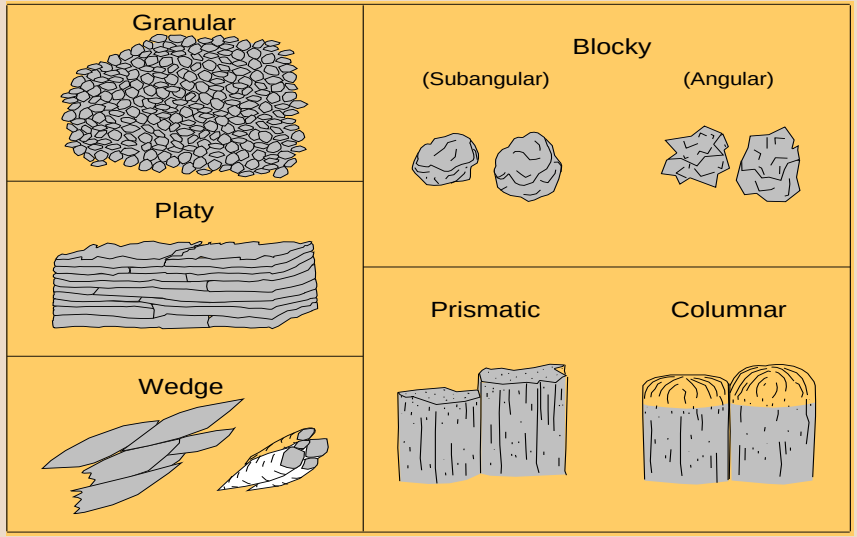
- Organic Soils have more than 20% Organic Matter.
- They have high water retention and are frequently low in Potassium and Copper.
- They **must** be drained to be productive.
- **Soil texture, structure, pH, nutrient availability, water holding ability, aeration, drainage, and health of the soil ecosystem are all affected by the organic components of the soil.**
- Settling and compaction is a big problem as the organic components are decomposed and digested by various soil organisms.



Soil Structure

- Soil structure refers to the grouping of particles of sand, silt, and clay into larger aggregates of various sizes and shapes.

- **Aggregates are granules composed of many soil separates bounded or cemented together by organic substances, iron oxides, carbonates, clays, or silicas.**



- Good soil structure provides pathways for roots, water, and air.

- **Bad soil structure can be hard, resist water and air infiltration, and result in weak, shallow roots.**

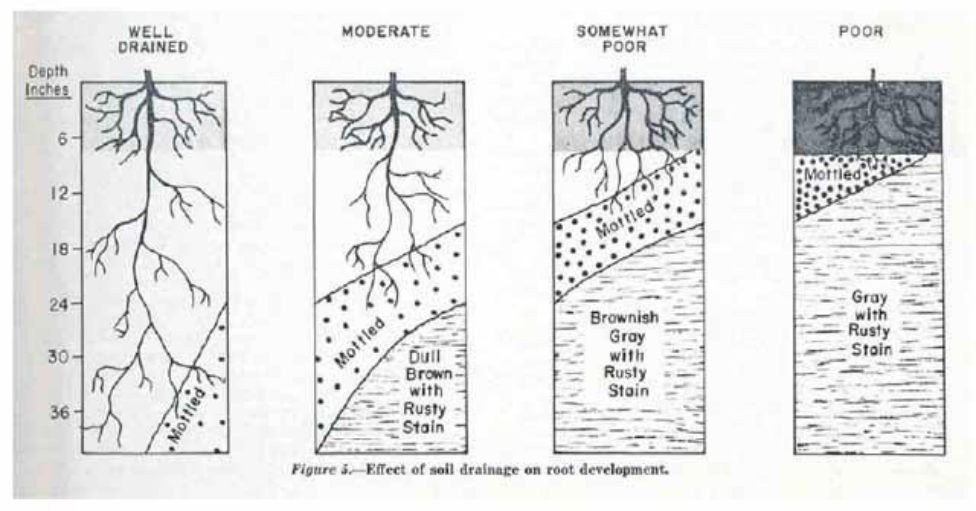
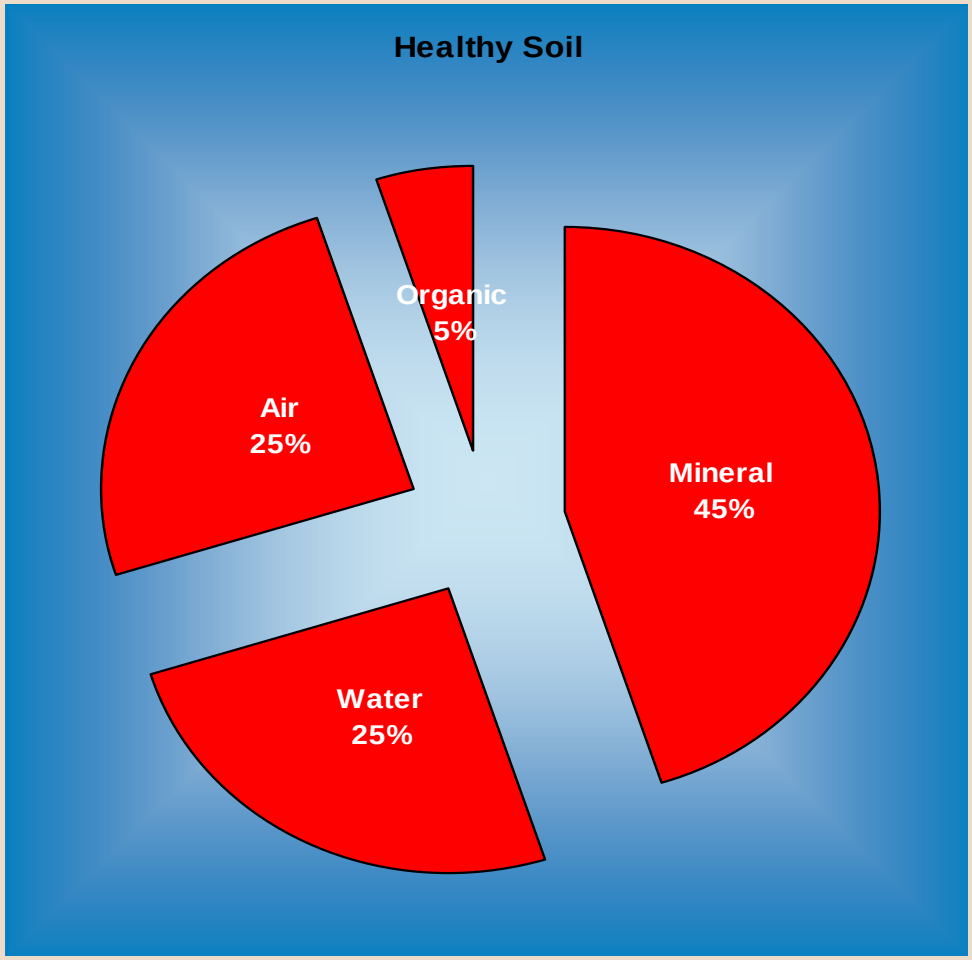


Figure 5.—Effect of soil drainage on root development.

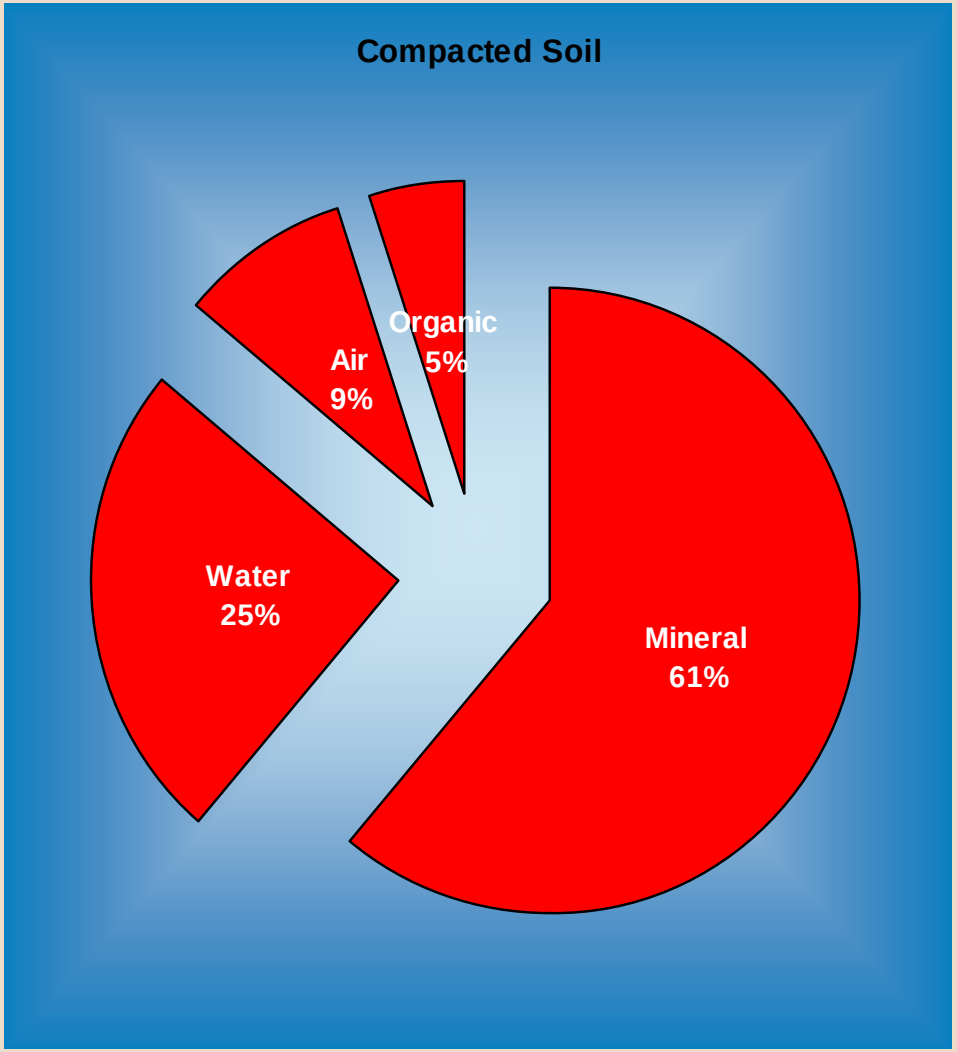
Proper Soil Structure

- Soils with good soil structure contain 50% solid and 50% pore space.
- The pore space will have half of the area filled with water and the other half with air.
- Saturated soils have no air as all pore spaces are filled with water.

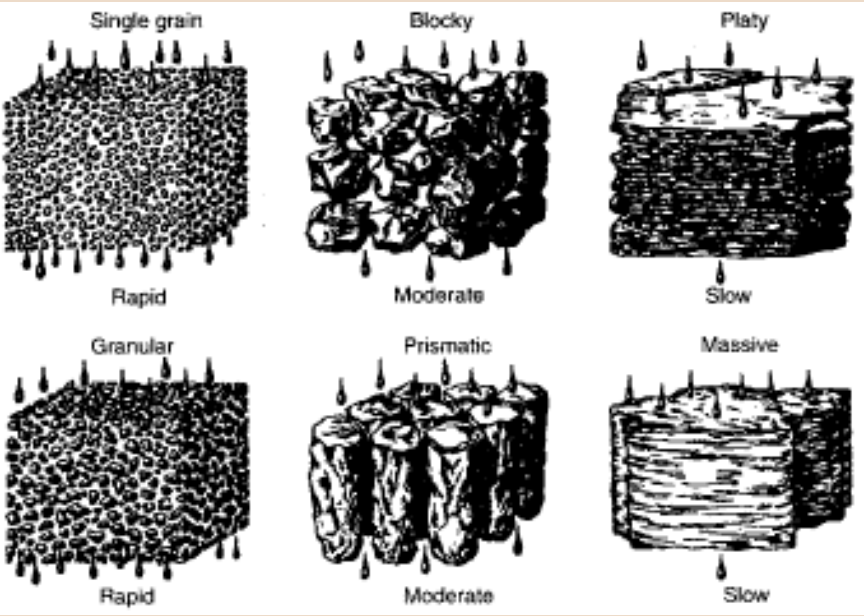


Compacted Soil Structure

- Compacted soil has more soil particles crammed into the same space.
- **Smaller pore spaces hold water well but prohibit air from entering soil. Water must be applied to the soil at a slower rate to avoid run-off.**
- **Roots do not penetrate well.**



Soil Structure



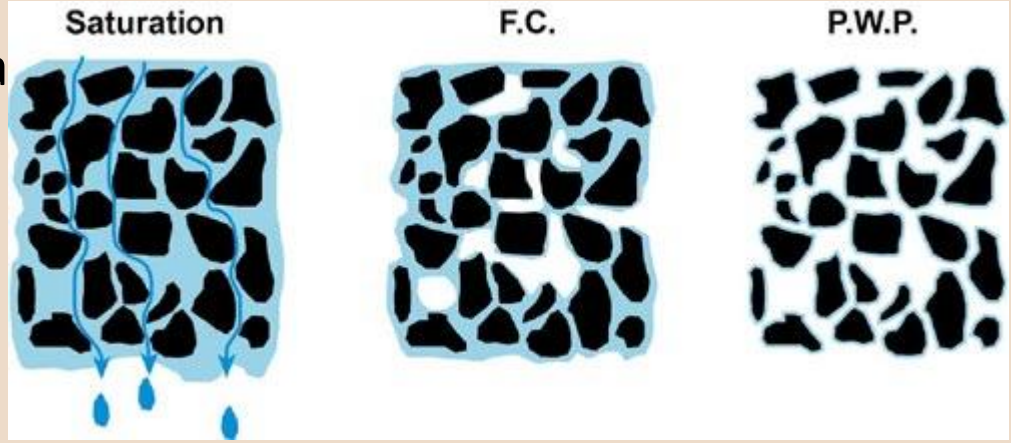
- The processes of root penetration, wetting and drying cycles, freezing and thawing, animal activity and soil organic matter **combined with inorganic and organic cementing agents** produce soil structure.
- Stable aggregates result in a network of soil pores that allow rapid exchange of air and water with plant roots.
- Practices such as excessive cultivation or tillage of wet soils disrupt aggregates and accelerate **the loss of organic matter, causing decreased aggregate stability**.

Soil Structure and Texture – Water & Air Relationships

- All soils have voids between the individual aggregates and particles called pore spaces.

- When water enters a soil, it fills up some or all of the pore spaces.

- **The proper balance of water and air in a soil is critical to healthy root and plant growth.**

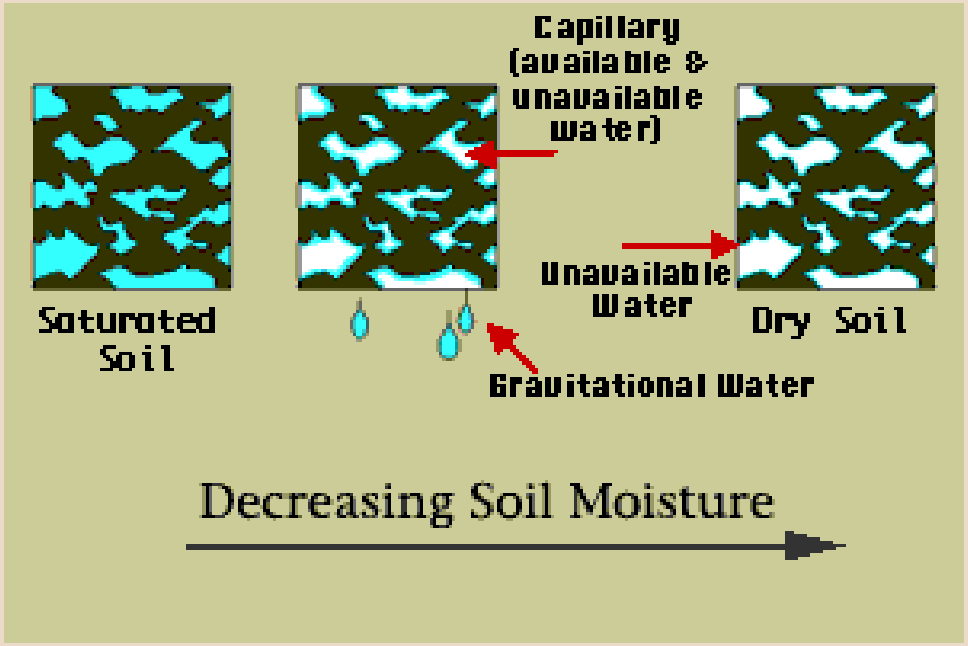
- Various terms a  f water in a soil.

Saturation

- The soil moisture level at which all soil pore spaces are filled with water. This condition occurs when water is 1st applied to the soil.

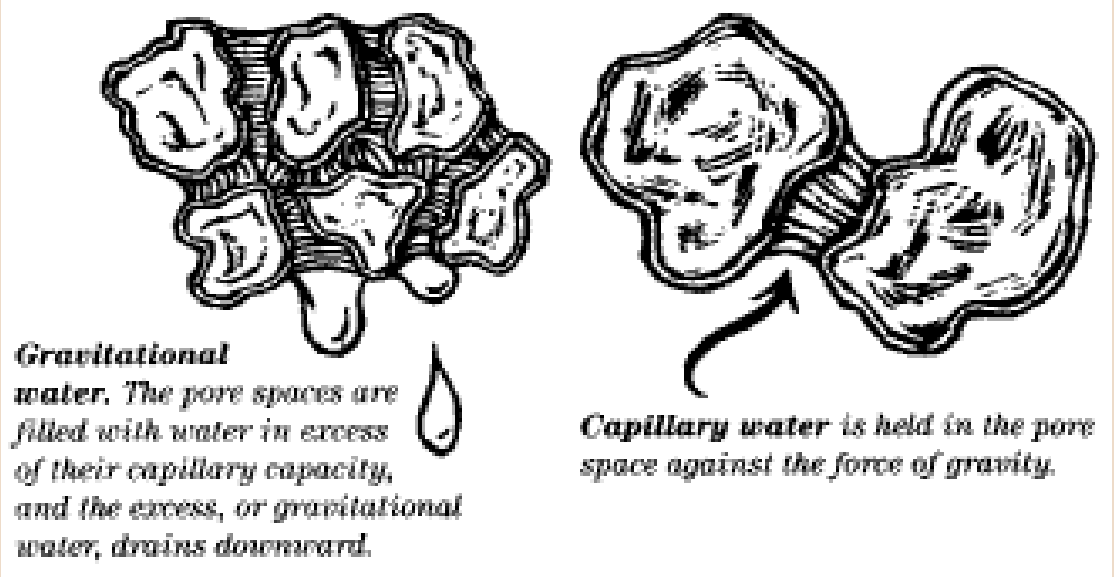
- No air is remaining as it has "bubbled" to the soil surface.

- **If soils are saturated for too long, roots will die to lack of oxygen needed by the roots for the process of respiration.**



Gravitational Water

- The water which drains out of a soil layer due to the force of gravity.
- In other words, water that is pulled below the root zone by gravity.
- Some water is “held” by the soil particles (both mineral and organic) against the force of gravity due to adhesive and cohesive forces.



Field Capacity

- Definition: the maximum amount of water that a soil can hold against the force of gravity.

- **This soil moisture level provides water and air to plant roots.**

Field capacity. *The capillary pores are full and the remaining pore space is filled with air.*

Wilting point. *The water available to plants is exhausted.*

Wilting Point

- The soil moisture level when plants first show signs of wilting.

- Although water does exist in the soil at the wilting point, it is held too tightly for plant roots to extract.

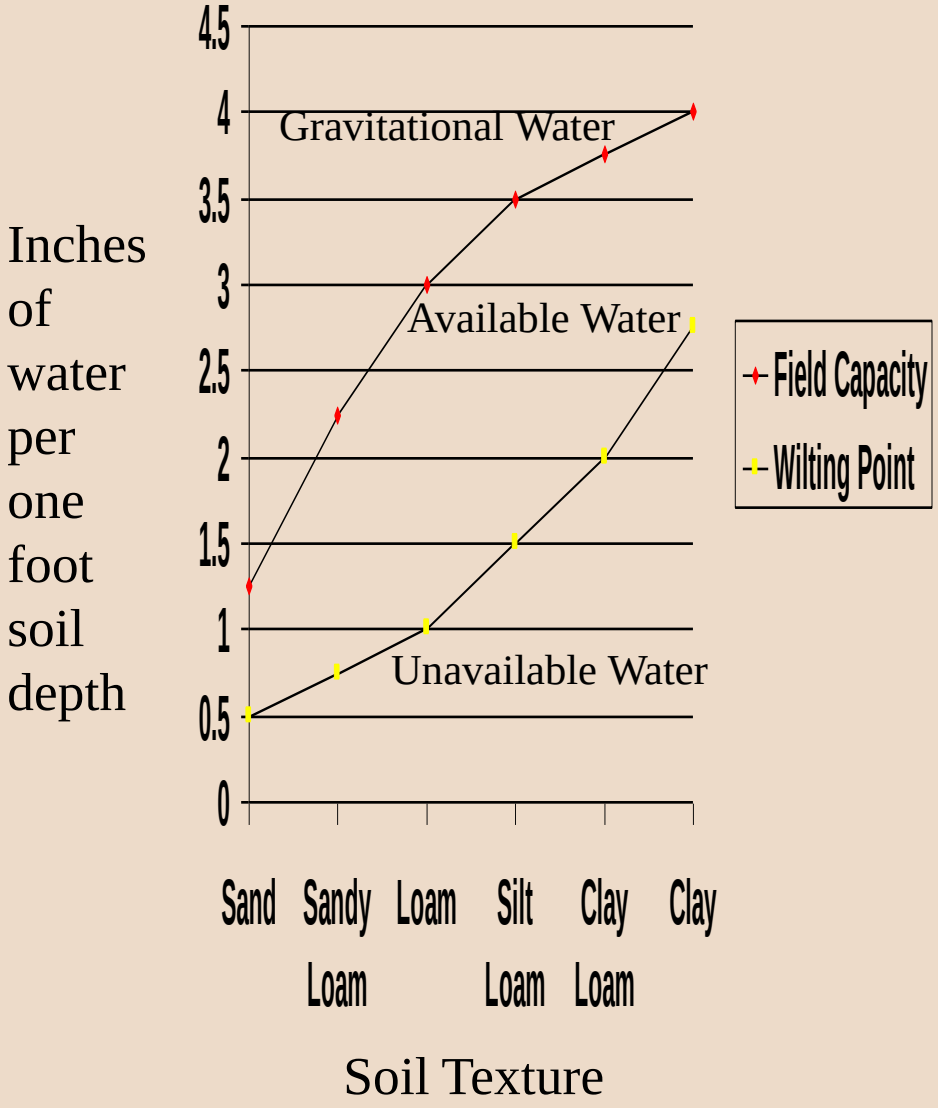
- **Ideally, an irrigator will add water to soil just before the soil reaches the wilting point.**

Available Water

- Definition: the water that is available to plant roots; **it is the soil moisture levels between field capacity and wilting point.**

- Available water is the water that plants are able to extract from the soil and the water that irrigators need to replace with each irrigation.

- **Different soil textures hold different amounts of available water.**



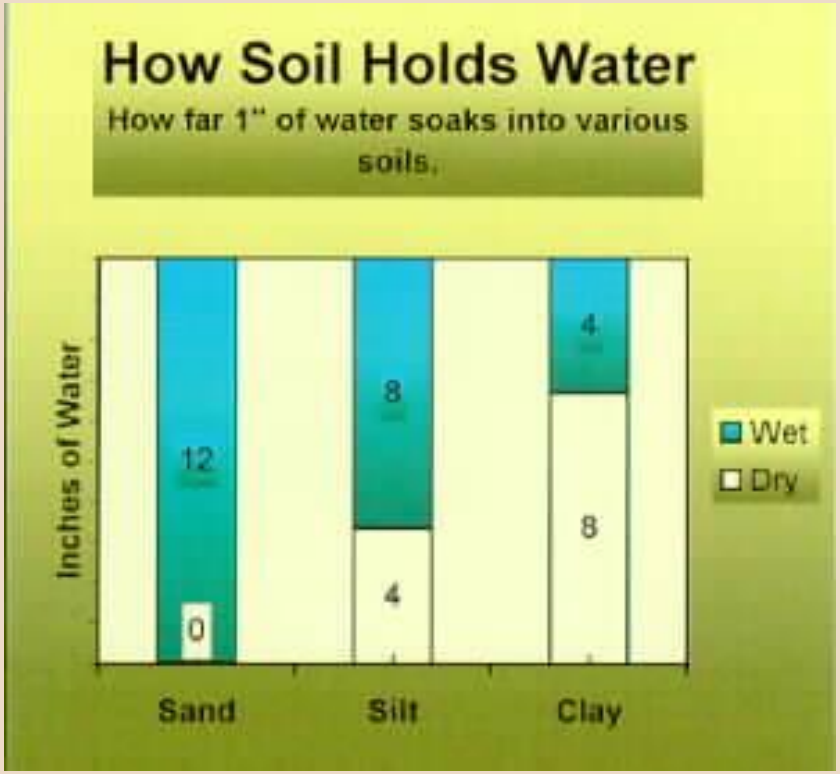
Unavailable Water

- Definition: water that remains in the soil that is not available to plant roots; this water is held too tightly for plant roots to extract.

Soil texture and Water Penetration

Inches of water per one foot soil depth:

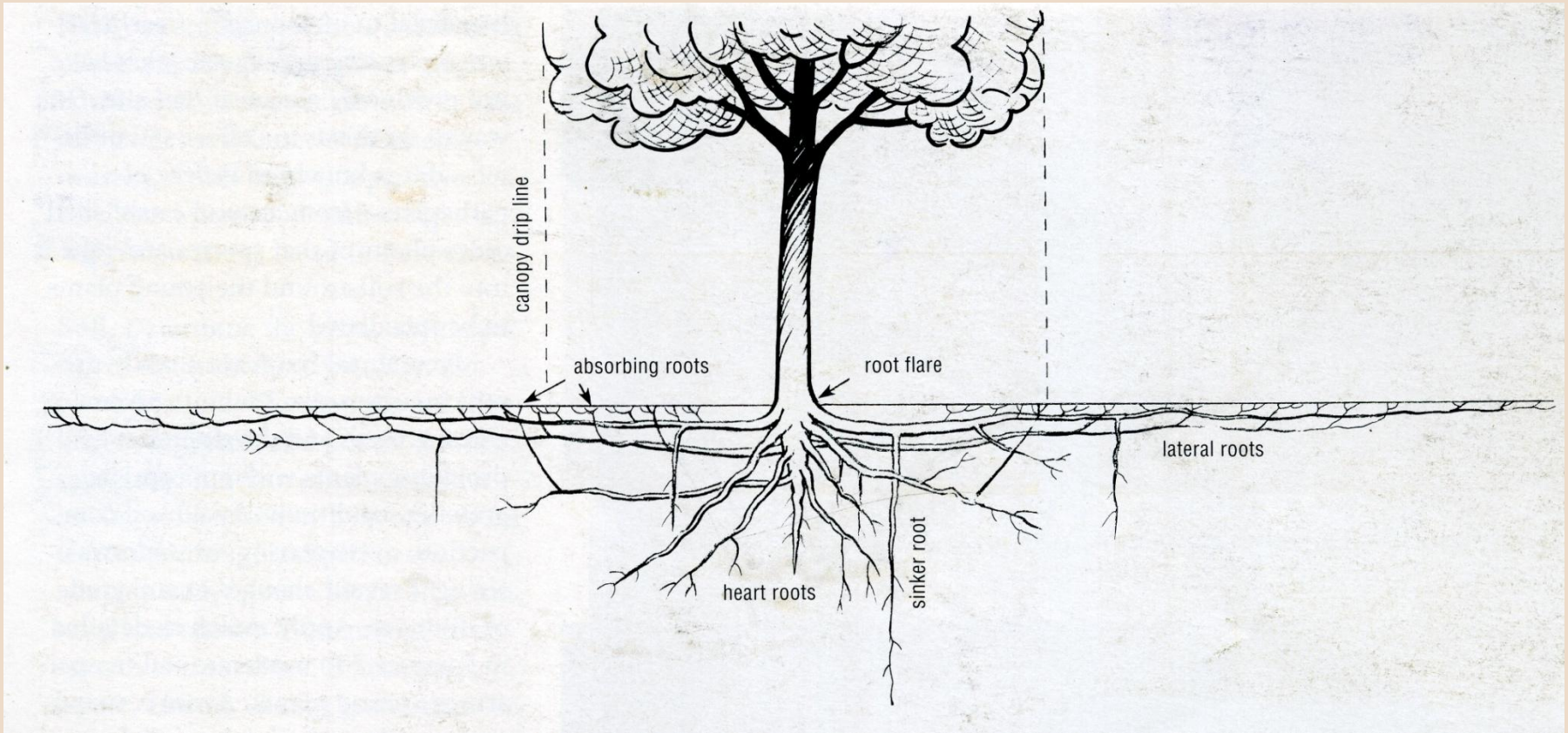
- 1” of water penetrates the ground 1’ in sandy soil.
- It takes 2”-3” of water to penetrate the ground 1’in clay soil.



Textural Class	Available Water Capacity (Inches/Foot of Depth)
Coarse sand	0.25–0.75
Fine sand	0.75–1.00
Loamy sand	1.10–1.20
Sandy loam	1.25–1.40
Fine sandy loam	1.50–2.00
Silt loam	2.00–2.50
Silty clay loam	1.80–2.00
Silty clay	1.80–2.25
Clay	2.25-3.00

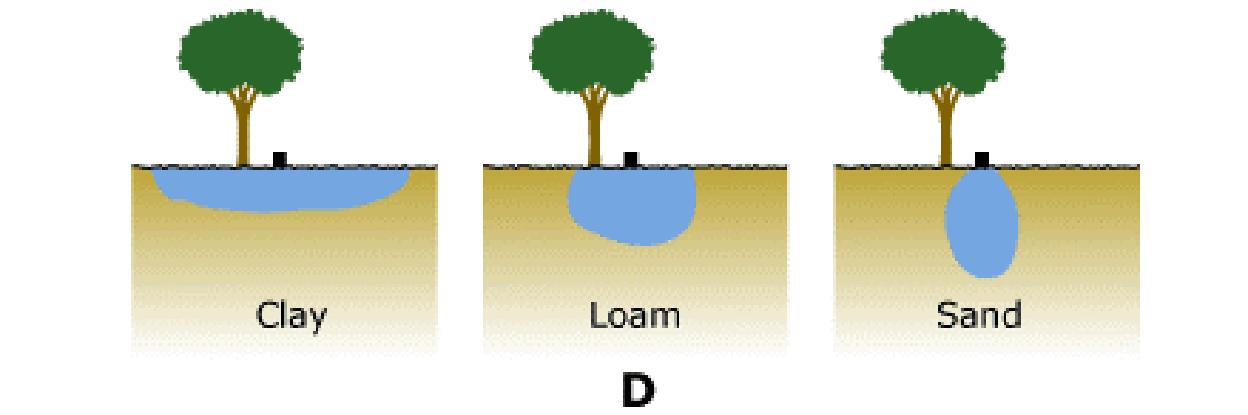
Depth of Water Extraction by Roots

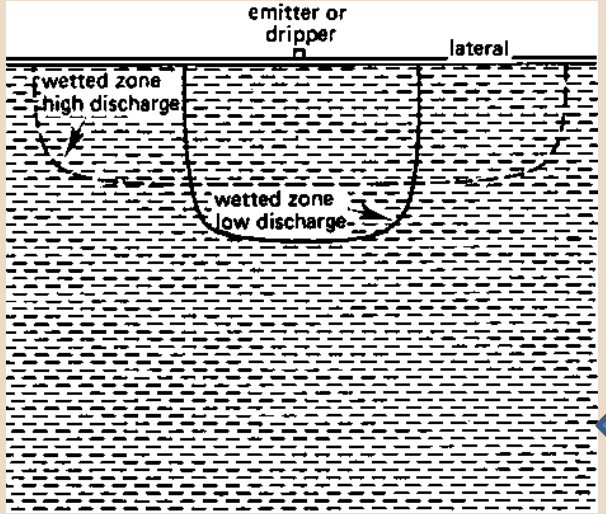
- Most water is taken up by roots from the top 12” of soil (40% - 70% or more).
- Up to 90% of the roots that take up water and nutrients are located in the top 36” of soil.
- Watering methods can determine root depth:
  - Light, shallow watering encourages shallow roots. This results in plants that dry out easily and can blow over in storms.
  - Deep, infrequent watering is best to encourage roots to penetrate deeply in the soil.



How water disperses in the soil

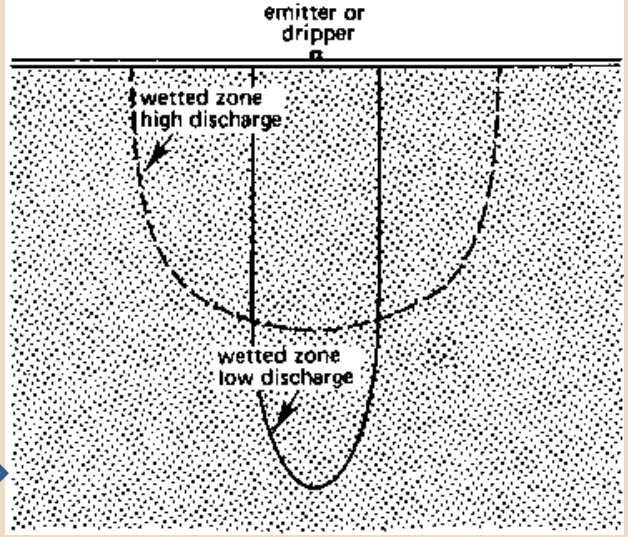
- The wetting patterns of irrigation water in clayey, loamy, and sandy soils.





Water applied to clay or organic soils

Water applied to sandy soils or soils low in organic materials



- **Soil texture and structure directly affects the movement of water through the soil. Water spreads out more horizontally when traveling through a soil higher in clay or organic components and travels more vertically though a soil higher in sand or lower in organic materials.**

KEYS TO PROPER WATERING

Water the proper area – the Feeder Root Zone!

Water near the trunk or stem on newly planted plants so that you wet the original root ball.

Water at the dripline **and beyond** on plants which are established in the ground. (The plant may take from a few weeks to a one year or more to become established depending on the type and size of the plant, the time of year that it was planted, soil conditions, cultural practices and other variables.)

Water further away from the trunk or stem as time progresses and as the plant grows larger in diameter.

Cover a significant area of the plants feeder root zone with water to maintain a strong and healthy root system.

KEYS TO PROPER WATERING

Water with sufficient amount of water – enough to thoroughly wet the entire depth of the Feeder Root Zone.

1” of water penetrates the ground 1’ in sandy soil, it takes 2” of water to penetrate the ground in clay soil.

90% of feeder roots are found in the top 3’ of soil! (70% are in the top 1’ of soil.)

Water to an average depth of 1’ to 3’ at each watering for plants that have been established in the ground. Smaller plants generally have shallower root systems than larger plants. As a general rule, water to a depth of 6” to 1 foot for plants 1’ or less in height, to a depth of 2 foot for plants 1’ to 4-5 feet in height and to a depth of 3’ for plants larger than 5 feet in height.

For plants in containers, water with enough water to leach excess salts out of the container and to thoroughly wet the entire root ball at each watering.

KEYS TO PROPER WATERING

Water at the correct interval – often enough to keep the plant from wilting, but infrequently enough to allow air to penetrate the soil.

Roots can drown if the soil is kept constantly wet!

Watering frequency will vary with the time of year, location, size of the plants, soil, weather conditions and many other variables.

On average:

Water new plants in the ground 1-2 times per week.

Water older established plants in the ground 1 time per week to 1 time per month depending on the variables.

Water plants in containers 1-3 times per week.

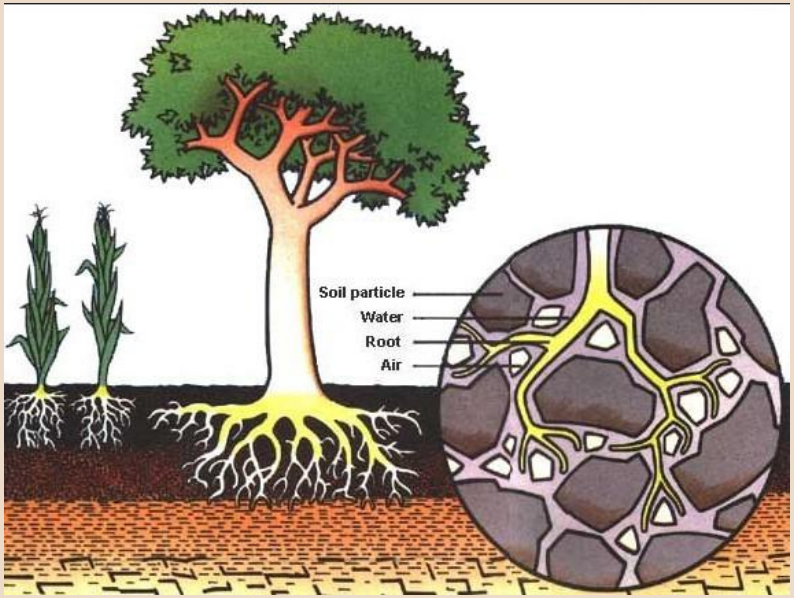
There are <u>very few</u> exceptions where plants should be watered every day! Watering too frequently will exclude oxygen from the soil and cause roots to drown as well as promote diseases!

Soil Structure – Water - Air & Plant Root Relationships

- The movement of air, water, **and plant roots** through a soil is affected by soil structure.

- Stable aggregates result in a network of soil pores that allow rapid exchange of air and water with plant roots. Plant growth depends on rapid rates of exchange.

- Good soil structure can be maintained by practicing beneficial soil management such as crop rotations, **organic matter additions**, and timely tillage practices.



- In sandy soils, aggregate stability is often difficult to maintain due to low organic matter, clay content and resistance of sand particles to cementing processes.

- **Organic matter can affect soil structure and can improve the water holding capacity of soil as well as increase the porosity of soil improving the availability of oxygen to plant roots.**

Alkaline Soils

- Besides affecting life in the soil, Alkaline soils have three problems that can result in poor plant growth:
  - **excessive salts**
    - A soil may be rich in salts because the parent rock from which it was formed contains salts. Sea water is another source of salts in low-lying areas along the coast. A very common source of salts in irrigated soils is the irrigation water itself. Most irrigation water contains some salts. **Most alkaline soils have problems with excessive salt accumulation due to low rainfall in the area as they are not leached from the soil.**
  - **soils which "seal off"**
    - Soils with excessive sodium can break down soil aggregates and result in a dispersed, sealed-off soil surface.
  - **high pH which ties up certain nutrients**

Reclaiming Salty Soils

- **Mulches on the surface slow upward evaporation which can aid in reducing the surface salts. As organic mulches decompose, they form humic acid which helps to lower the soil pH, therefore making salts more soluable.**

- Leaching
  - Soil is flooded with water and the salts are leached through the root zone. This is only practical if water low in salt is available & the soil drainage is moderate to fast. Unfortunately, most saline soils are clay-like and have poor drainage.

  - For leaching, 12" of water is needed to remove about 70-80% of the salt in the top 12" of soil.

- Gypsum $CaSO_4$
  - Gypsum works like this: $CaSO_4 + H_2O + 2Na^+ = Ca^{++} + Na_2SO_4 + H_2O$

  - **gypsum will slowly replace the sodium and over time will improve soil structure - the calcium cations bond together soil particles into larger aggregates.**

  - **the sodium sulfate is now more easily leached from the soil.**

Liquid "Gypsum" and "Liquid Thrive"

- **Liquid "Gypsum"** and **"Liquid Thrive"** contains a high level of soluble calcium which displaces the sodium. This then creates pore spaces in the soil. The effectiveness of the calcium is compounded by the use of a polyacrylamide (PAM) that attaches to the soil particle and remains in the soil for years, helping the soil structure to resist collapsing. The effect of the PAM is cumulative and long lasting.

- **Benefits:**
- Improves clay soils by displacing sodium immediately.

- Releases salts, lowering soil EC

- Improves soil drainage

- Reduces crusting and improves infiltration of water and nutrients

- 32 oz. = 200 lbs. dry gypsum

The Organic Component

- Organic matter is an important soil component because it:
- a) holds soil particles together and stabilizes the soil, thus reducing the risk of erosion;
- b) aids crop growth by modifying soil structure and improving the soil's ability to store and transmit air and water;
- c) stores and supplies many nutrients needed for the growth of plants and soil organisms;
- d) prevents or minimizes soil compaction;
- e) retains carbon from the atmosphere;
- f) reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants;
- g) can affect soil pH, making a soil more acidic or alkaline. is responsible for most of the soil N, 5-60% of the soil P, up to 80% of the soil S, and a large portion of the B, Mo, and K.

The Organic Component

- **Soil organic matter is in a constant state of flux, decomposing and being added to the soil by natural and human processes.**

- **In order to maintain the benefits of the soil organic materials and the nutrient cycling system, the rate of addition from plant and animal residues and manures must equal the rate of decomposition.**

- Soil organic matter (SOM) includes **primary components** that are inherited from plant and animal residues entering the soil. These primary components may be dead plants, dropped leaves and stems of plants, composts, manures, dead animals or animal products .

- Primary components are relatively easily decomposed by microorganisms and they persist in soil for a brief time (e.g. several months or years). They make about 20-30% of total SOM.

- Primary components can be classified either as mulches or soil amendments.

Organic Mulches

- Organic material which falls or is applied to the surface of the soil and decomposes is all considered organic mulch.

- There, organisms feed on them and mix the organic material with the upper soil layers; these organic compounds become part of the soil formation process, ultimately shaping the type of soil formed.

- **Mulches gradually incorporate into the soil profile from the top down. Applying organic mulches to the entire surface of a soil can affect the soil in the entire growing environment.**

- Mulches can also help to moderate the soil environment by affecting soil surface temperature and moisture level.

Organic Amendments

- Animals and micro-organisms mix soils and organic matter to form burrows and pores allowing moisture and gases to seep into deeper layers.

- Humans can also mix the different soil layers, restarting the soil formation process as less-weathered material is mixed with and diluting the more developed upper layers.

- Organic amendments only affect the soil environment in the area of the soil that they are mixed. **To be beneficial to plant growth, amendments must be mixed into a large enough area to support a substantial portion of the root system of the mature plant or plants.**

- **Turning or mixing soil can disrupt the soil ecosystem and have detrimental effects on the organisms living in the soil.**

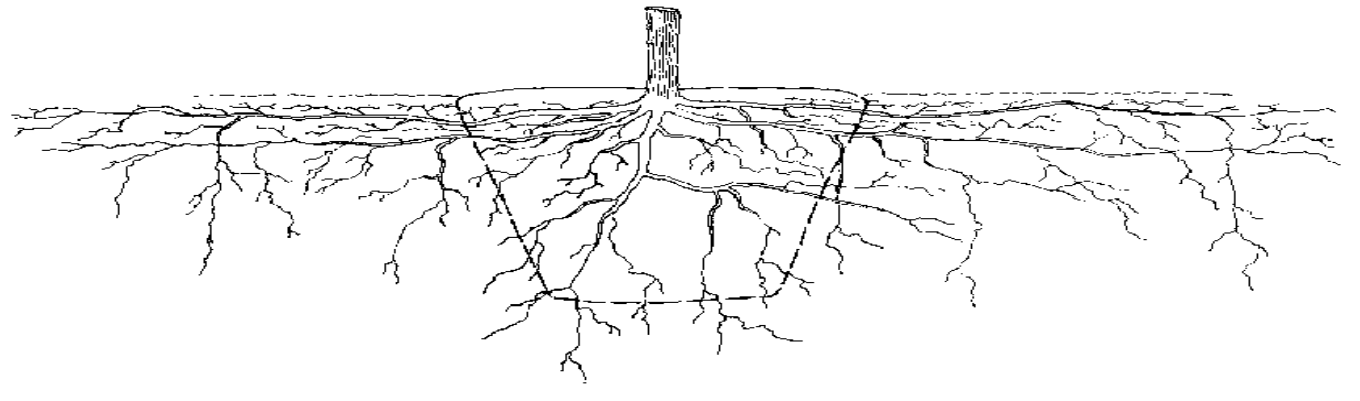
- **Organic amendments are only recommended or useful when preparing an area for planting annuals and small perennials.**

Organic Amendments

Mixing organic amendments into planting holes for trees and shrubs is generally <u>not</u> recommended or beneficial.

- At best, these amendments do no good as the root system on healthy plants will develop well beyond the amended planting hole.

- At worst, amendments in a planting hole can:
  - Restrict or inhibit the development of roots into the non-amended “native” soil.
  - Restrict the movement of water into the non-amended soil, forming a perched water table and causing the soil in the planting hole to become saturated and soggy.
  - Will decompose over time, causing the amended soil to compact and the crown of the plant to settle below surface of the non-amended soil. This settling frequently causes crown rot and can kill the plant.



The Carbon: Nitrogen Ratio

When organic amendments are added to a soil, the microorganisms begin to ingest the carbon as a food source. As they multiply, they take in soil nitrogen to aide in their life cycle. **This can deplete the soil nitrogen enough that plants growing in this soil are deprived of nitrogen. This is called "nitrogen tie-up".**

- Definition: The ratio of the weight of organic carbon (C) to the weight of total nitrogen (N) in a soil or in organic matter.

- Importance:

  If an amendment has a high C/N ratio, it will result in nitrogen tie-up in the soil.

  - however, amendments with a low C/N ratio have enough nitrogen in the amendment to avoid having the microorganisms use the nearby soil nitrogen.

  - **amendments with C/N ratios of 30 or less are considered favorable and will not tie up soil nitrogen.**

C/N ratios of some Organic Materials

Material	C:N Ratio		Material	C:N Ratio
Soil Humus	10:1		Leaves	40-80:1
Poultry manure (fresh)	10:1		Newspaper	50-200:1
Alfalfa hay	13:1		Corn stalks	60:1
Grass clippings	12-25:1		Pine needles	60-110:1
Vegetable wastes	12-20:1		Oat straw	74:1
Coffee grounds	20:1		Wheat straw	80:1
Cow manure	20:1		Sawdust	100-500:1
Horse manure	25:1		Bark	100-130:1
Fruit wastes	35:1		Paper	150-200:1

The Organic Component

- SOM also includes **secondary compounds**, compounds formed within the soil by breaking down organic structures and synthesizing new ones. These secondary components include **humic substances**, which are rather different from most primary components.

- **Humic substances are products of biochemical decomposition.** They are complex substances of high molecular weight, which are resistant to further decomposition. Consequently they tend to accumulate in the soil. Most are dark and are hence responsible for the dark soil color that is commonly associated with soils of high organic matter content. Humic substances make up 60-80% of total SOM.

- The humic substances posses carboxyl groups (*R-COOH), which give them their acidic character and make them effective in buffering soil pH.

- Humic substances can also affect soil structure by causing soil particles to bind together into larger aggregates, thus increasing soil porosity.

Two Rules for Adding Soil Organic Matter

1. Use a lot.

- Recommendations for mulches are to keep 2-4 inches of SOM on the surface of the soil across the entire planting area or across a significant portion of the plants feeder root zone.
- Recommendations for soil amendments are to amend the mineral soil by 20-30%.

2. Keep doing it.

- Soil organic matter decomposes over time and as it decomposes the benefits are lost.

The Living Soil

There are four major areas of living organisms, both plant and animal, that live or have lived in or on the soil. These include:

- Macrofaunea - visible animals
- Microfaunea - microscopic animals
- Macroflorae - plants and plant roots
- Microflorae - microscopic plants

All living organisms contribute to the soil organic matter providing nutrients to the soil and food for other organisms either in the form of their waste products or from the organisms themselves as they die and decay.

Factors which affect the numbers of organisms in the soil:

- adequate aeration
- adequate moisture
- proper temperatures
- proper pH.
- adequate food (primarily organic material)

Soil Macrofaunea

- Burrowing animals
  - include moles, prairie dogs, gophers, mice, rabbits, badgers, woodchucks, armadillos, chipmunks, reptiles, etc.
  - role in the soil:
    - **aerate the soil.**
    - **alter soil structure**.
    - usually eat more than they produce so they tend to have a net negative effect on soils.

- Gastropods
  - belly-footed organisms
  - include snails and slugs

  - feed on decaying vegetation but can also eat live plants
  - **not considered a beneficial organism to plants and soils**

Soil Macrofaunea - Earthworms

- About 7000 species exist worldwide.
- **Don't eat existing vegetation but feed on organic matter.**
- **They release into the soil small granular aggregates which resist rupture and readily release nutrients.**
- **They aerate the soil.**
- Conditions best for earthworms are moisture, warm soil around 70 - 90 degrees, ample organic matter, low salts, and high calcium supply.

- Conditions not favorable are sandy, salty, barren soil and having predators such as mice, mites, millipedes and the use of insecticides.

Soil Macrofaunea (cont.)

- Arthropods
  - joint-footed invertebrate organisms
  - include mites, millipedes, centipedes, and insects
  - **mostly feed on decaying matter**
  - **help to aerate the soil**
  - some can be pathogenic (eat plants)
  - **most are beneficial**

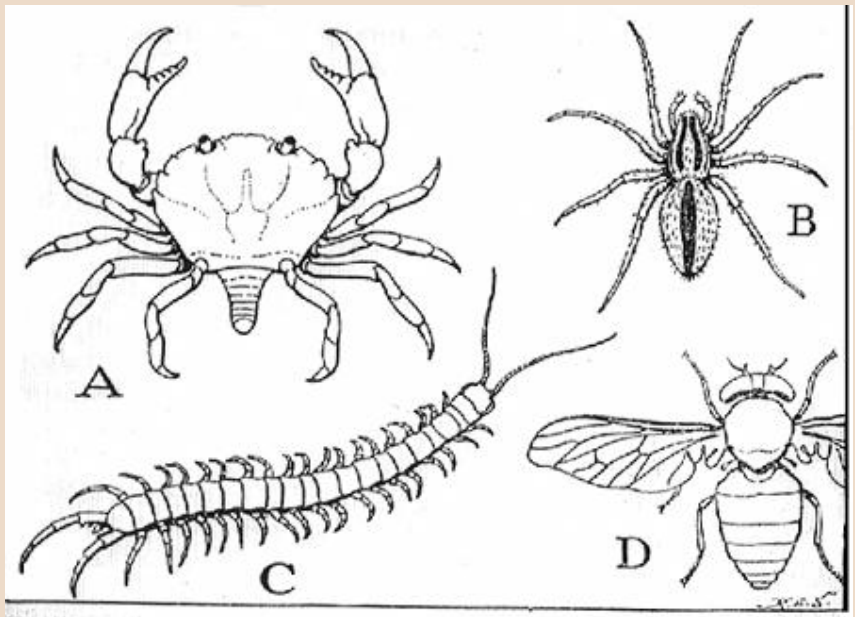
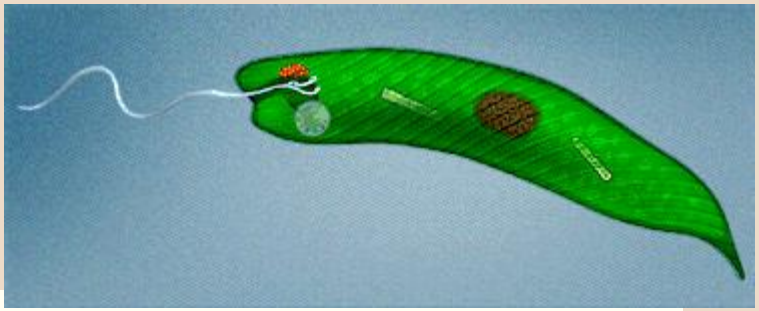


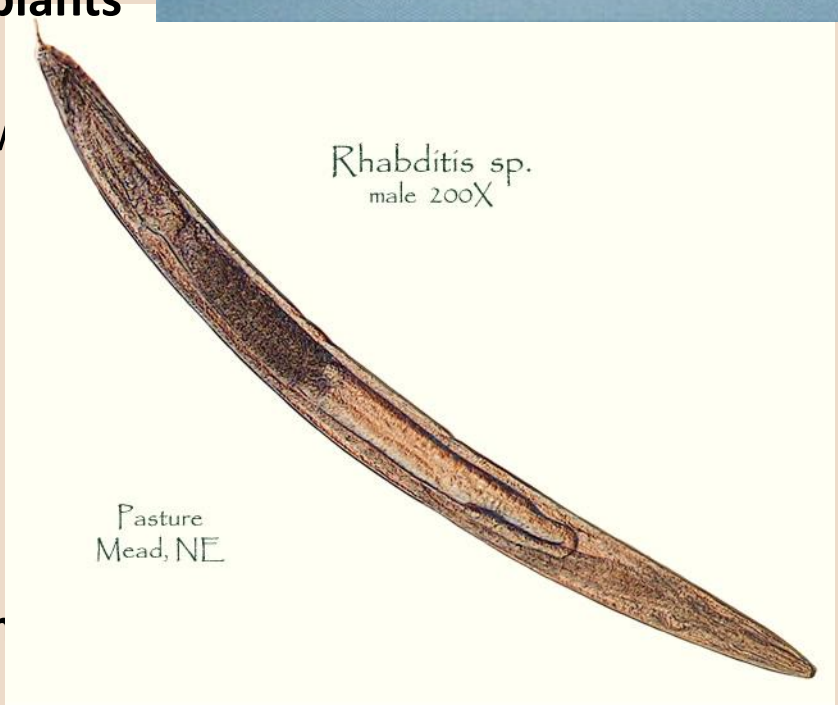
FIG. 15.—Principal types of animals evolved in the phylum Arthropoda by different groupings of the segments

Soil Microfaunea

- Protozoa - Single celled microscopic animals
  - feed on bacteria in soil water
  - **hasten the recycling of nutrients to plants**

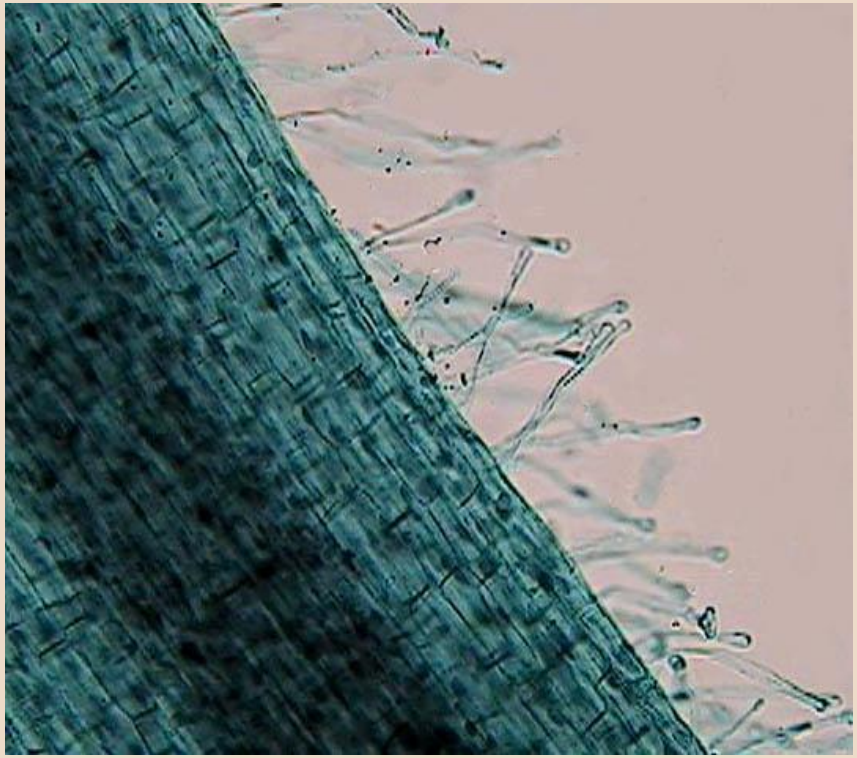


- Nematodes - microscopic thread-like w
  - three types
    - Omnivorous
      - **eat decaying organic matter**
      - most common
    - Predaceous
      - **eat soil faunae including other r**
    - Parasitic
      - attack plant roots and stunt the plant
      - suck plant juices and open wounds for disease



Soil Macroflorae

- The roots of plants and the decaying matter of dead leaves, roots, flowers, fruit, woody stems and other plant parts.
- New young root tips are constantly being extended into the soil.
- Along with dead roots left in the soil, root hairs are constantly being sheared off as roots expand.
- **All add valuable organic matter to the soil which recycles plant nutrients**.



Soil Microflorea

- The microscopic forms of plant life that include:
  - Bacteria - a unicellular microscopic plant that lacks chorophyll and multiplies by fission. A pH level of around 6.3-6.8 is also the optimum range preferred by most soil bacteria.
  - Fungi - an undifferentiated plant lacking chlorophyll and conductive tissues.
  - Actinomycetes - a group of microorganisms intermediate between fungi and bacteria.
  - Algae -simple rootless plants that grow in water or wet soils, they contain chlorophyll, and grow based on the nutrients available.
  - Viruses - a submicroscopic obligate parasite consisting of nucleic acid and protein.

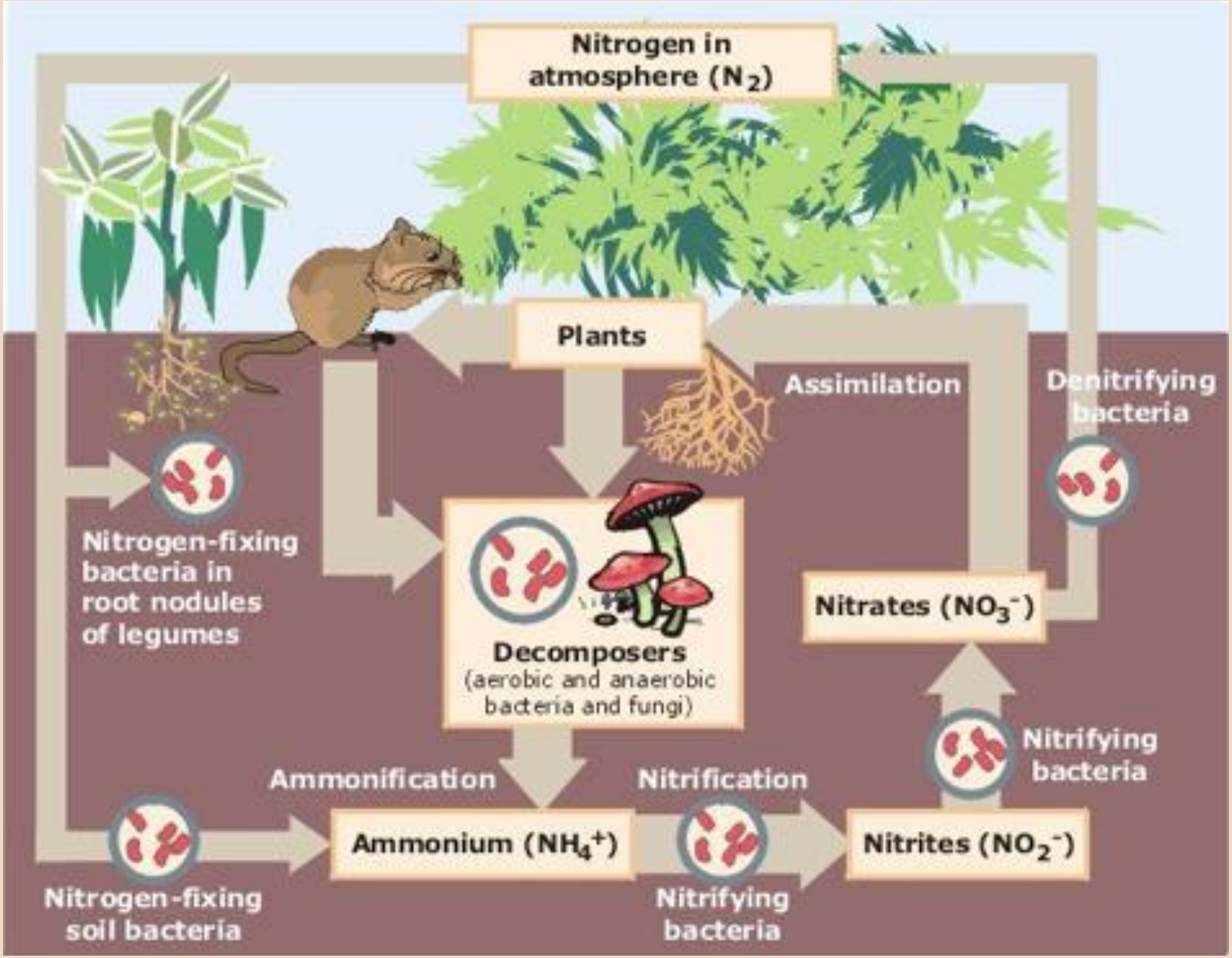
Soil Microflorea - Bacteria

- Heterotrophic bacteria
  - depend on organic matter (living and dead) for food.
  - are divided into two groups: non-symbiotic and symbiotic.
  - **Non-symbiotic bacteria** : depend on dead organic matter for food, they do not need a live host plant, and **they can fix atmospheric nitrogen N_2 and later release NH_4^+ into the soil when they die.**
  - **Symbiotic bacteria:** most legumes have a symbiotic relationship with bacteria in which the bacteria infect the root and create a nodule. The bacteria obtains some nutrients and sugars from the root and the bacteria fixes atmospheric nitrogen during growth and reproduction.
  - The life span of one bacteria equals about 2 hours, **upon death of bacteria they release NH4+ to the plant root** therefore, plant never runs out of nitrogen and the plant stays green.

Soil Microflorea - Bacteria

- Autotropic bacteria
  - are able to manufacture food from CO_2
  - cause **nitrification**: $NH_4^+ \longrightarrow NO_2^- \longrightarrow NO_3^-$
  - **Nitrification** is the change of ammonium form of nitrogen to the nitrate form of nitrogen.
  - **Nitrogen can be absorbed into roots in only two forms: NH_4+ (ammonium) & NO_3- (nitrate)**
  - also causes **denitrification**: $NO_3^- \longrightarrow N_2$
  - Denitrification is the change of nitrate nitrogen to ammonia gas which is lost to the atmosphere. It occurs in soggy or saturated soils.

Bacteria's role in the nitrogen cycle



Soil Microflorea - Fungi

- Role in soil is to break down cellulose, lignins, and gums. They release nutrients into soils upon their death.

- Three types:
  - parasitic - attack live plants for nutrients - bad!
  - **saprophytic - eat dead organic matter - good!**
  - **Mycorrhiza- live on plant roots – a symbiotic relationship where a fungus aids the host plant in absorbing nutrients and water - good!**

Mycorrhiza

- Mycorrhiza have formed associations with plant roots for over 400 million years.

- Mycorrhiza are present in 92% of plant families (80% of species).

- Present in most undisturbed soils, mycorrhiza may be missing from areas where the top layers of soil have been removed, where soils have been compacted, where fungicides or excess fertilizers have been applied or in container (soilless) soil mixes.

- **Mycorrhiza MUST come into direct contact with a plant's root to form a symbiotic association with the plant!**

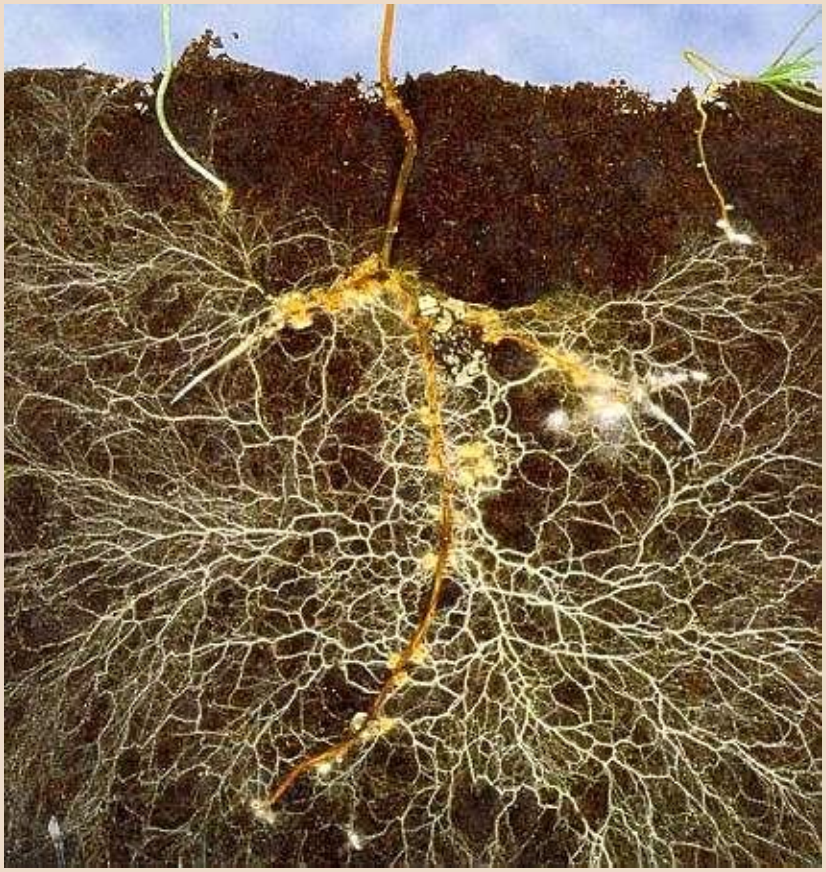
Types of Mycorrhiza symbiotic Fungi:

- **Ectotrophic** - fungal threads (mycelium) grow into root from soil and grow **between** the root cells. They take up nutrients from the soil and deposit them directly in the root.

- **Endotrophic** - same except fungal threads **penetrate directly into** the cell itself. Upon death of fungal threads, nutrients are deposited right in the cell protoplasm.

Benefits of Mycorrhiza:

- Enhanced plant efficiency in absorbing water and nutrients **(especially phosphorous)** from the soil.
- Reduces fertility and irrigation requirements.
- Enhances plant health, vigor and drought resistance and minimizes stress.
- Increased pathogen resistance/protection.
- Enhances seedling growth, rooting of cuttings, and plant transplant establishment.
- Improved phytoremediation of petroleum and heavy metal contaminated sites.



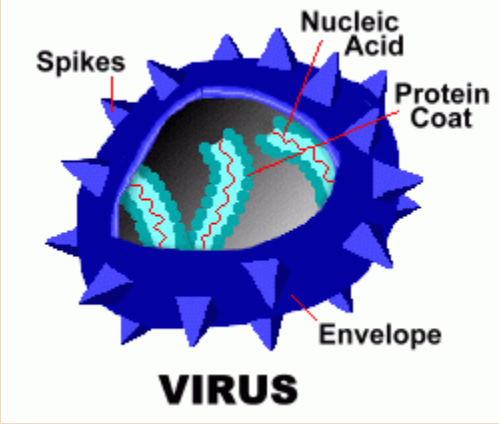
Soil Microflorea (cont.)

- Actinomycetes
  - related to both fungi and bacteria
  - in soils, **they decompose tough forms of organic matter such as cellulose and lignins**.
  - prefer moist, organic soils with a neutral to slightly acid pH. Can tolerate drier soils than fungi.
  - Can cause some plant diseases such a potato scab.

- Algae
  - microscopic, chlorophyll-bearing organisms.
  - types are green, blue-green, and yellow-green.
  - often show up on the soil surface when it is damp, shady, and when nitrogen fertilizer has been applied.
  - **some types can fix atmospheric nitrogen**.
  - generally, they prefer pH's of 7.0 - 8.5

Soil Microflorea (cont.)

- Viruses
  - non-cellular organisms that can only grow and reproduce inside living cells.
  - they must be transmitted by nematodes, soil insects, root grafts, and fungi attacks.
  - **not beneficial** although at times they may result in a plant variation such a variegated leaf or flower color.
  - no viruscides exist to control viruses.



Soil Temperature

- Warm Soils: (Temperatures 70-90 degrees F.)
  - Increases biological activity which increase nutrient availability to plants.
  - Aids in the germination of seeds.
  - Increases availability of nitrogen and phosphorus.
- Cool Soils: (Temperatures below 65 degrees F.)
  - Can slow or entirely stop biological activity.
  - Can tie up certain plant nutrients.
  - Can result in freezing and thawing which breaks up soil aggregates.

Soils and Plant Nutrition

- There are 17 elements that plants need in order to successfully grow and complete their life cycle. These elements are called the “Essential Elements”.

- 14 of the elements are minerals taken in by roots from the soil.

- These essential elements are broken down into two categories: macro elements and micro elements.

- All of these 14 elements are absorbed by the plant only when in solution with water and are taken into the plant in their ionic form. nitrogen(NO^-_3), phosphorous($H_2PO^-_4$), potassium(K^+), Calcium(Ca^{++}), magnesium(Mg^{++}), sulfur(SO^-_4), Chlorine(Cl), iron(Fe^{+++}), zinc(Zn^{++}), and so on.

Macro Elements

- The macro elements that are minerals taken in by roots from the soil are nitrogen, phosphorus, potassium, calcium*, magnesium*, and sulfur*.
- These elements are needed in larger quantities by the plant than the micro elements.
- Macro elements are also know as major elements (* elements are sometimes referred to as secondary elements).

Micro elements

- The micro elements are Boron, Zinc, Manganese, Chlorine, Iron, Molybdenum, and Copper and Nickel.
- These elements are needed by the plant in smaller amounts than the macro elements.
- Micro elements are also know as trace or minor elements.
- **The availability of these nutrients for plants to absorb from the soil is affected by the soil pH and the microorganisms which live in the soil.**

The Effect of Micro-organisms on Nutrient Absorption by Plants

- Micro-organisms can directly affect nutrient absorption by plants. The nutrients that are most affected include **Nitrogen and Phosphorous**.

- Sulfur (S) is usually found in low levels in soils and it is frequently obtained by decomposing organic matter.

- **The application of soil amendments or fertilizers that are high in salts, release high levels of nutrients too quickly, modify soil pH outside a desirable pH range, or cause soils to become too soggy, excluding adequate aeration, can kill soil micro-organisms!**

Nitrogen (N)

- The most critical element in plant growth. **This is the nutrient that is most commonly lacking in soils and most frequently needs to be added to soils.**

- Can be absorbed into roots in only two forms: NH_4+ (ammonium) & NO_3- (nitrate). **The nitrate form of nitrogen is very prone to leaching.**

- Sands and well drained soils tend to lose NO3- very easily during high rainfall or frequent irrigation.

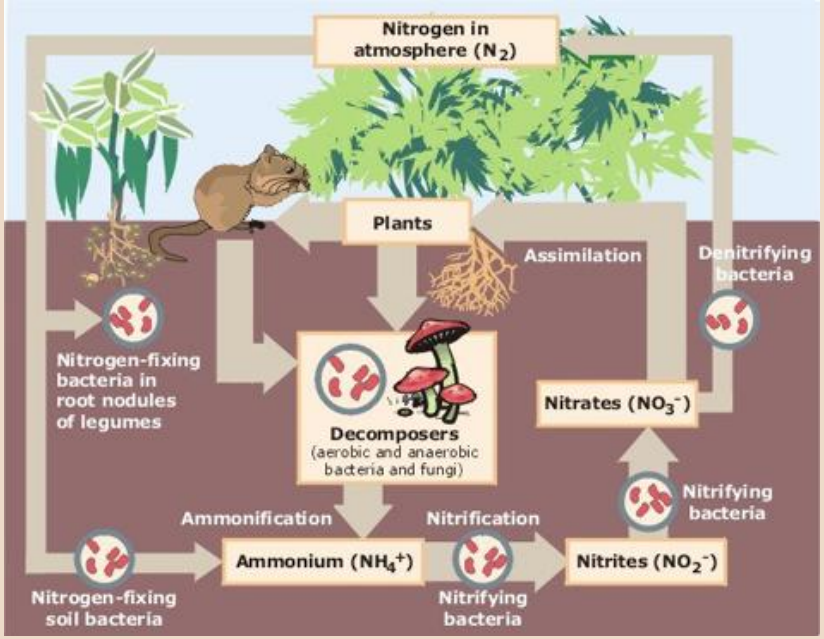
- Fertilizing with the ammonium form of nitrogen (NH4+) is less prone to leaching as the + charge tends to bond with the negatively charged clay particles.

- **Ammonium Volatilization** occurs when ammonium fertilizers are applied to the surface of alkaline soils. These soils, typically high in calcium and carbonate, can react with the ammonium fertilizer and result in losses of up to 30% to the atmosphere. **Ammonium fertilizers should be incorporated into the soil to lessen this loss.**

- **The addition of some form of nitrogen type fertilizer is most often needed to maintain plant health on most types of plants!**

Nitrogen - the nitrogen cycle.

- Nitrogen is both added to the soil environment and lost from the soil environment by natural processes. This is known as the Nitrogen Cycle.



The Nitrogen Cycle – Nitrification

- Nitrogen Fixation is the change of atmospheric nitrogen (N_2 gas) into NH_4+ **by bacteria and some algae.** This NH_4+ is now or will soon be available to plant roots.

- The decomposition of organic matter releases NH4+ into the soil for absorption by plant roots. The amount of NH4+ depends on the origin of the organic matter.

The Nitrogen Cycle - Denitrification

- Nitrate (NO_3-) can be changed to N_2 gas by certain **bacteria** in the soil. This occurs when soils are saturated and the bacteria are in need of oxygen.

- The bacteria take the oxygen from the nitrate and release it as N_2 gas. **This gas bubbles to the surface and the nitrogen is lost.**

- Tends to be worse in soils high in manures and in soils with poor drainage.

The Nitrogen Cycle - Immobilization

- **Bacteria, fungi, and algae** take up ammonium and nitrates from the soil for their own growth and therefore make it unavailable for plants.

- This tends to occur when large amounts of organic matter are introduced to the soil and is worse when the organic matter has a high C/N ratio.

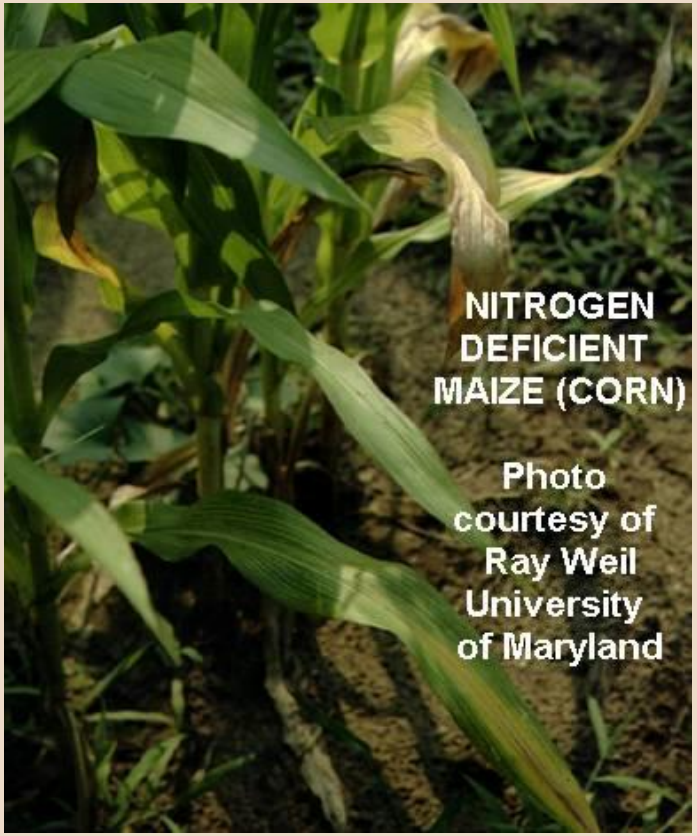
- **All of the nitrogen will be released to the soil upon the death of the microorganisms.**

Nitrogen Deficiency Symptoms

- Light green to yellow color on leaves. Older leaves show symptoms first

- Leaves may go completely yellow but still be alive. Yellowing occurs from the tip of the leaf downward and may later dry up.

- Plants are spindly and stunted



Phosphorus (P)

- The second most needed plant nutrient. It is the least mobile in soil and minimally affected by the leaching processes.

- **Most plants get phosphorus by organic matter breakdown near the roots.**

- Even though phosphorus may be present in the soil, it can be easily tied up by iron, aluminum, and calcium depending on the pH of the soil.

- **Mycorrhiza which have formed associations with plant roots can greatly increase the ability of the plant to absorb phosphorous.**

- Addition of phosphorus fertilizer is often necessary due to the high need of plants and the ease of phosphorus tie-up. It is best when it is worked lightly into the soil.

Soil Nutrients

The Physical or Chemical Properties of Soil can also affect the availability of certain soil nutrients. These include:

- Potassium (K) is usually very present in soils in the mineral form of feldspar but **is very insoluble resulting in a very small amount available to plants. Therefore, fertilizers are often needed**.

- Calcium (Ca) is very seldom deficient, except in very sandy soils. Calcium is very soluble and **wet, rapidly draining soils may leach out calcium.**

- Iron (Fe) is generally found in most soils but can be tied up on alkaline soils.

- Manganese (Mn) is usually readily available to plants except in highly alkaline soils. Can be a toxic element in highly acidic soils.

- Zinc (Zn) is tied up in highly alkaline soils and can also be leached in sandy soils.

Improving Soils

- Disadvantages of Sandy soils include:
  - the lack of nutrients and the lack of nutrient holding ability
  - lack of moisture holding ability

- Sand also has advantages. These include:
  - large, open pore spaces which provides excellent drainage and good aeration to plant roots.
  - low tendencies to compact.

- Gardening in clay soils tends to be difficult but it can have some advantages:
  - Clays tend to be fertile
  - Clays hold water and nutrients
  - Clays anchor plants securely

Goals for improving clay soils are to:

- Increase the porosity of the soil and thereby increase air and water penetration into the soil.
- Prevent soil compaction.

Adding organic matter can solve these problems.

Inorganic Additives to Improve a Clay Soil:

- Gypsum
  - helps the clay form into larger aggregates.
- Sand
  - Use sand that is rough and sharp.
  - River sand which is smooth tends to stick too easily to the clay resulting in bricks **(or concrete).**
  - **All sand, regardless of type, must have organic matter added with it to avoid clay "bricks"**
- Perlite
  - Helps keep soil loose but tends to migrate to the surface.
- Oyster Shell
  - Adds calcium which helps bind the soil but not good for alkaline soils.

Organic Amendments & Mulches

- Particle size, texture and degree of decomposition all affect the physical and chemical properties of organic material.
  - Coarse materials tend to
    - Last longer
    - Have better ability to hold open soil pore space thus increasing aeration and water penetration as well as reduce soil compaction
  - Fine materials tend to
    - Decompose more quickly
    - Have better moisture holding ability as well as provide more nutrients to the soil as the decompose
    - Hold onto nutrients reducing the effects of leaching
    - act as binding agents

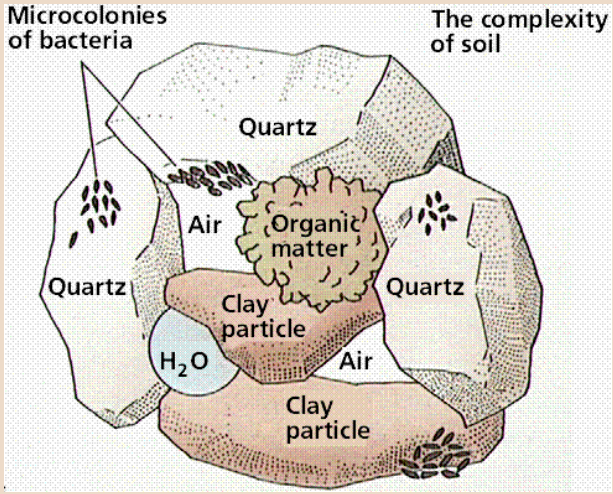
Container Soils

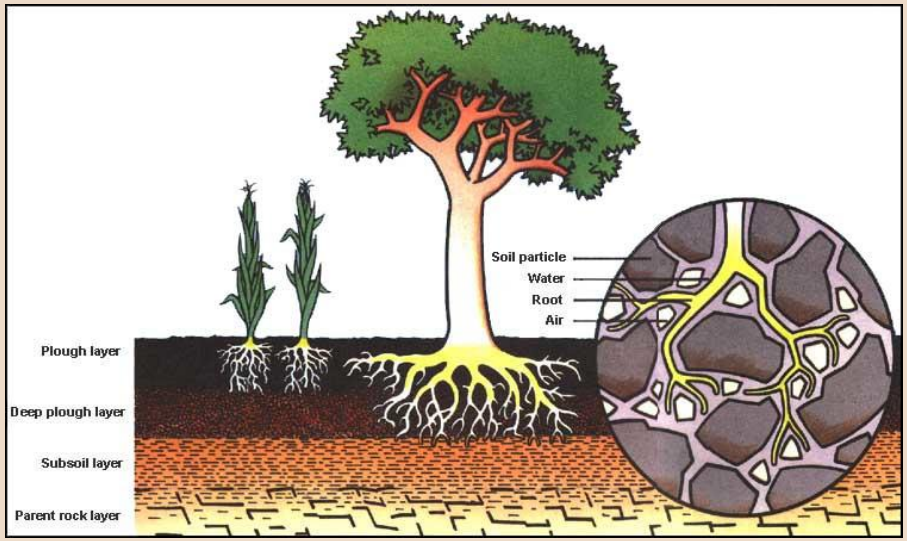
- Potting or container soils are mixtures of organic and inorganic components designed to provide optimum water, air and nutrients for plant root growth.
- Primarily organic soils, container soils are subject to the same processes of decomposition and compaction as in-ground soils.
- Container soils high in wood and bark products decompose more quickly than those with a higher mineral content .
- Container soils should be considered as **temporary** and need to be refreshed as they decompose and compact.
- Always add fresh soil to the bottom of a root ball and never bury the crown of a plant by adding more soil to the top of a potted plant unless the roots of the plant are exposed.

Container Soils

- Commercially available “cactus soils” are low in organic materials. They decompose less and they decompose more slowly than soils with a high wood and bark content.

- Mix cactus soil 50-50 with a potting soil that has rice hulls (which decompose much more slowly than wood and bark products) and organic nutrients, such as Kellogg’s ‘Patio Plus’, for a long lasting container soil.





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