Lecture 3: Soil Microclimatology

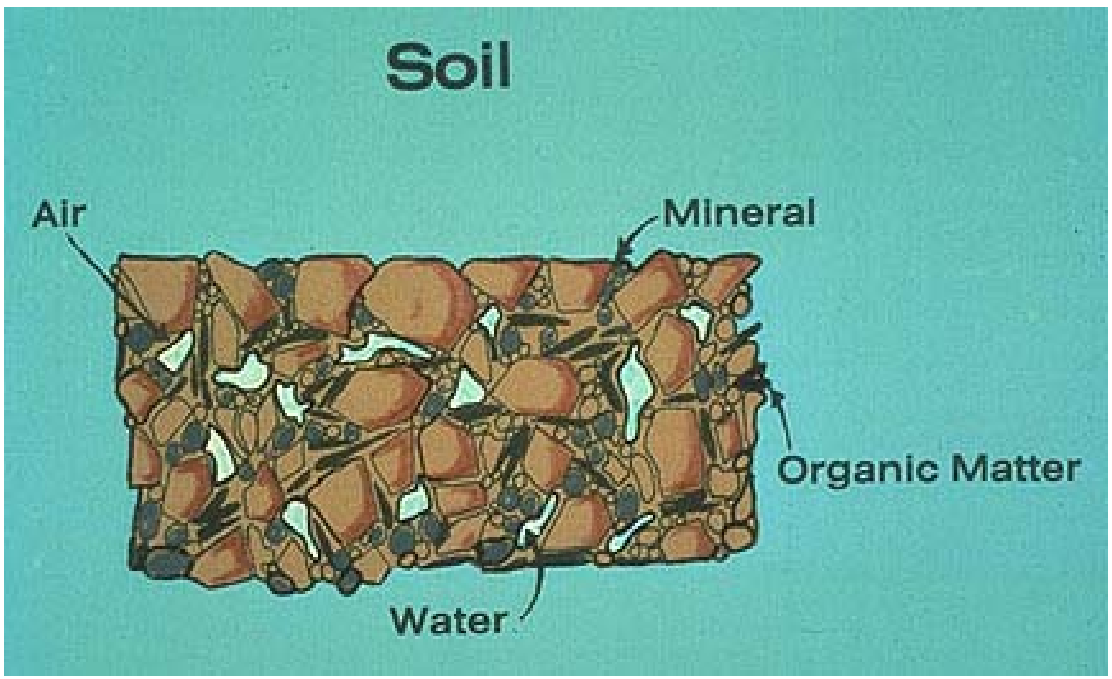
- Introduction to Soils

- Heat Transfer Through Soils

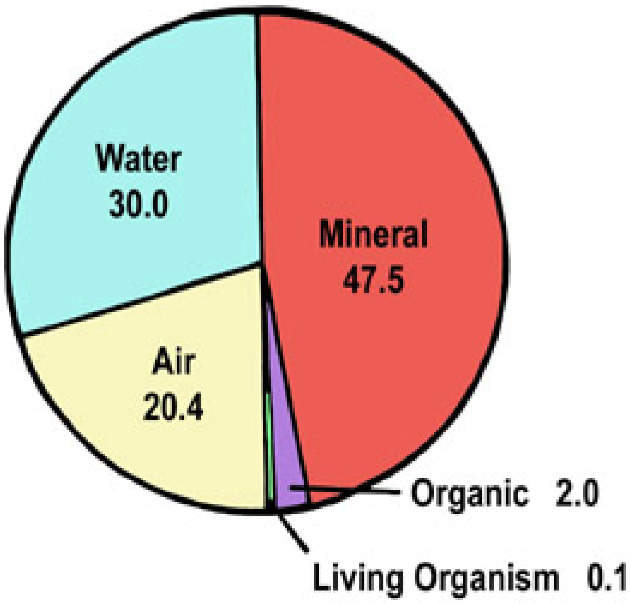
- Water Transfer Through Soils

What is a Soil?

Soil is a complex mixture of mineral matter, organic matter and living organisms



What Does Soil Contain?



Inorganic Substances

- mineral particles, affect texture

Gases

- found in pores (nitrogen, oxygen and carbon dioxide)

Water

- occupies pore spaces; is an effective regulator of soil temperature

Organic Substances

- decomposed remains of plants, animals and their waste; provides nutrients to soil; affects fertility and water-holding capacity

Humus and Soil Formation

- well decomposed matter is called humus ("organic decay forming a rich finely-divided substance")

- organic decay is essential for soil formation and the recycling of soil nutrients

- humus is in top layer of soil immediately below accumulated plant litter

- as content of organic matter increases, soil becomes darker in color

- organic matter tends to have low strength, drains excess water freely, readily holds plant water, and is very chemically reactive

Microflora - including fungi, bacteria and algae decompose plant/animal residues, synthesize humus, and cycle nutrients

Soil Forming Variables

Parent Material - surface deposits undergoing weathering (soil structure, texture, porosity, mineral content and water-holding capacity)

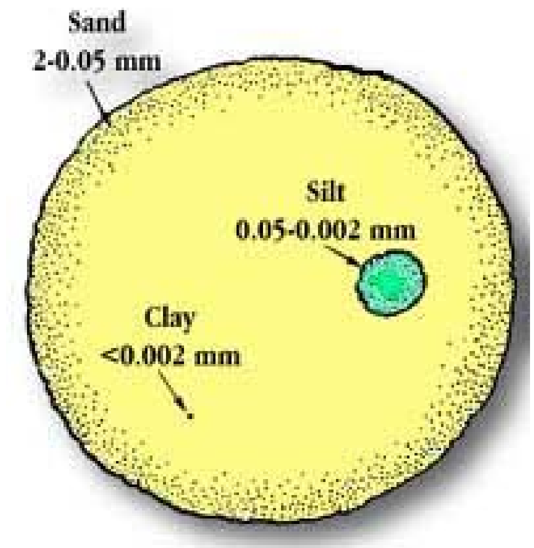
Climate - temperature, precipitation, wind; weathering may be increased by warmer temperatures and higher moisture levels (leaching)

Topography - hill tops versus valleys (water-logging); mediated by microclimate (temperature, precipitation); hillside slopes

Time - longer that parent material is altered by erosion, the more developed the soil profile becomes

Humans - good management can improve poor soils, although erosion is by far the most predominant effect of human disturbance

Soil Texture and Classification



Texture = %sand + %silt + %clay = 100%

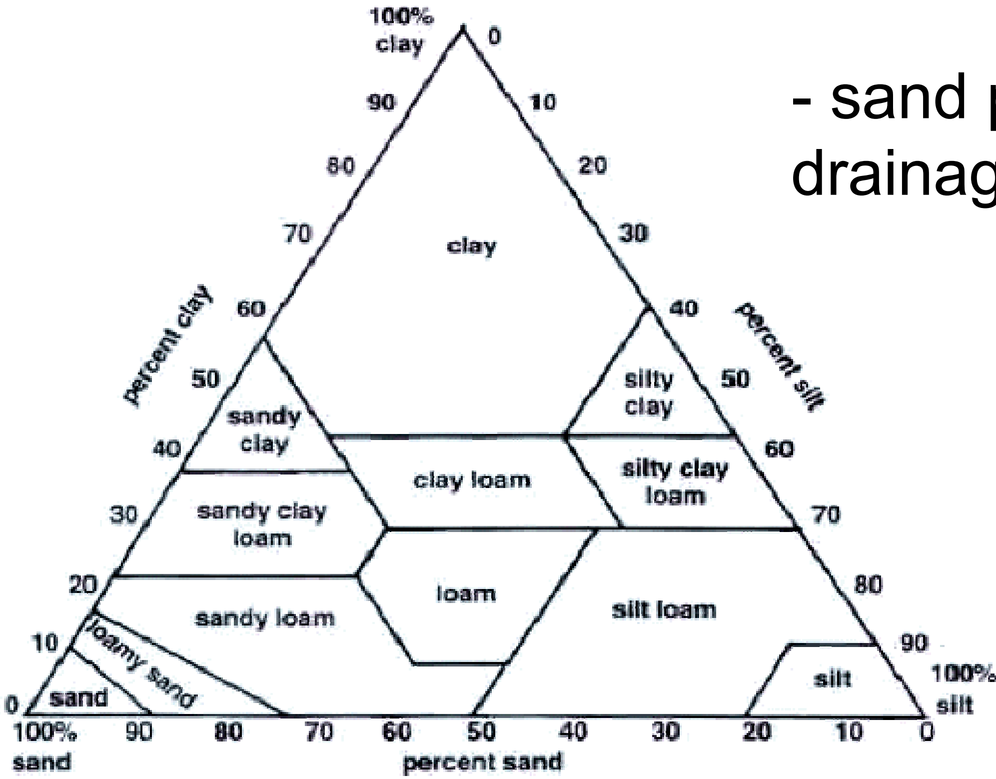
- silt particles are more cohesive than sandy soils but less than clayey soils

- clayey soils have smallest soil particles and the most small pore spaces (thus will have a high water-holding capacity)

Loams

- a balanced soil that contains ~ 40% sand, 40% silt, 20% clay

Soil Classification



- sand particles: influence water drainage and aeration

- silt particles: influence soil's ability to maintain plant available water

- clay particles: have low soil strength when wet and tend to inhibit drainage and aeration (but they are chemically active)

Soil Porosity

- refers to the size and number of air spaces (pores) found in soils (effected by texture, structure and organic matter content of soil)

- allows for movement of air, water and nutrients

- also allows for HEAT FLOW

Soil Density

Bulk Density: density of a volume of soil as it occurs naturally (i.e. including air spaces and organic matter)

- mass of soil sample/total volume of soil sample

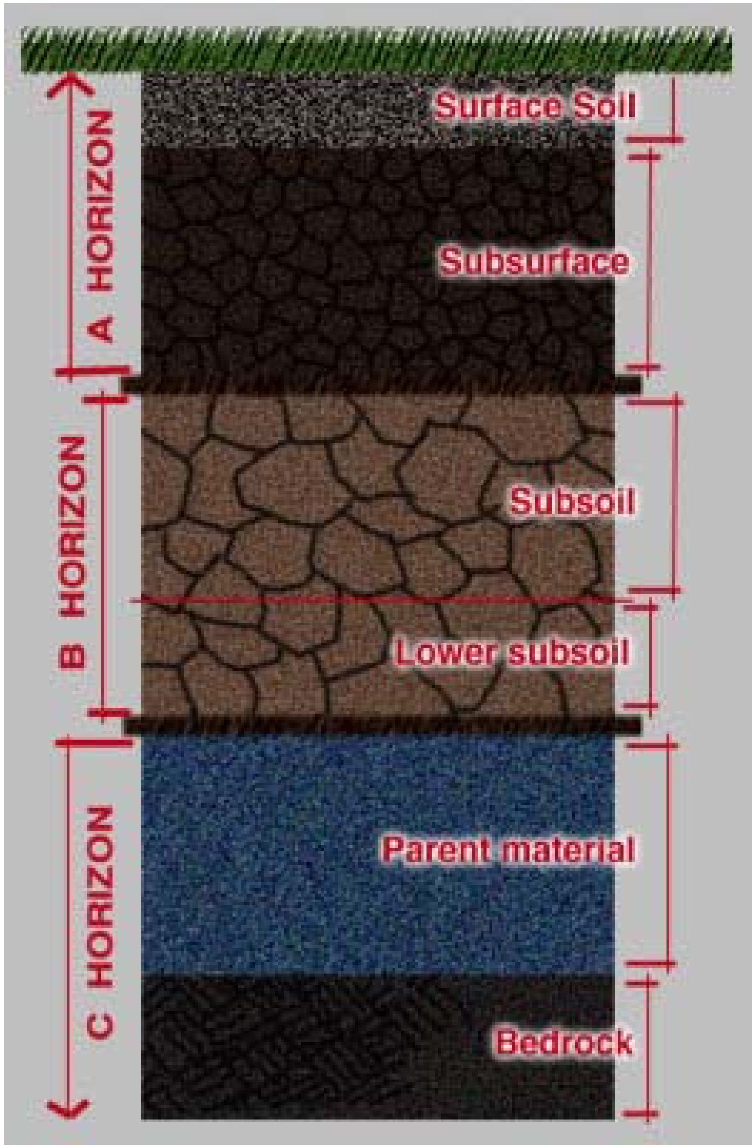
- ranges from 0.8 to 1.9 g/cm^3

- ideal bulk density for plants: 1.35 g/cm^3

- low bulk density = high porosity and/or high organic matter

- is an important influence on soil water-holding capacity

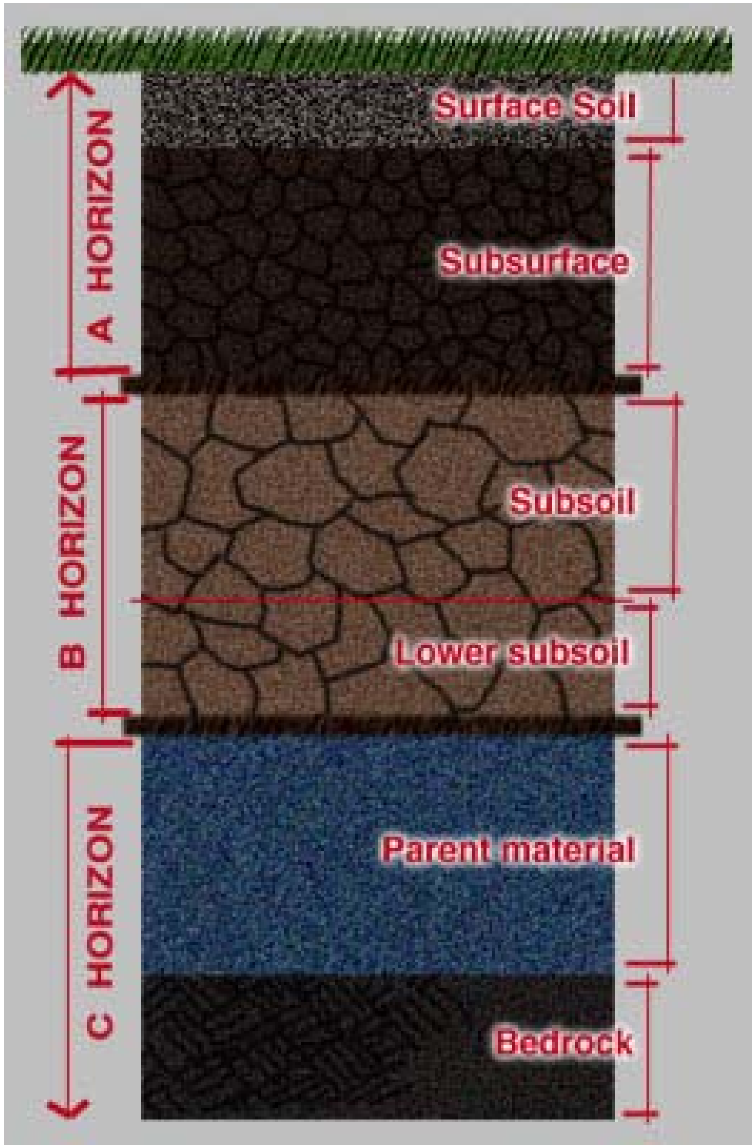
Soil Horizon Development



A-Horizon

- top layer of soil (topsoil)
- typically thin (< 20 cm)
- most fertile (organic matter)
- easily eroded by water and wind
- most leaching occurs
- "eluviation": percolating water moves small mineral particles and salts downward

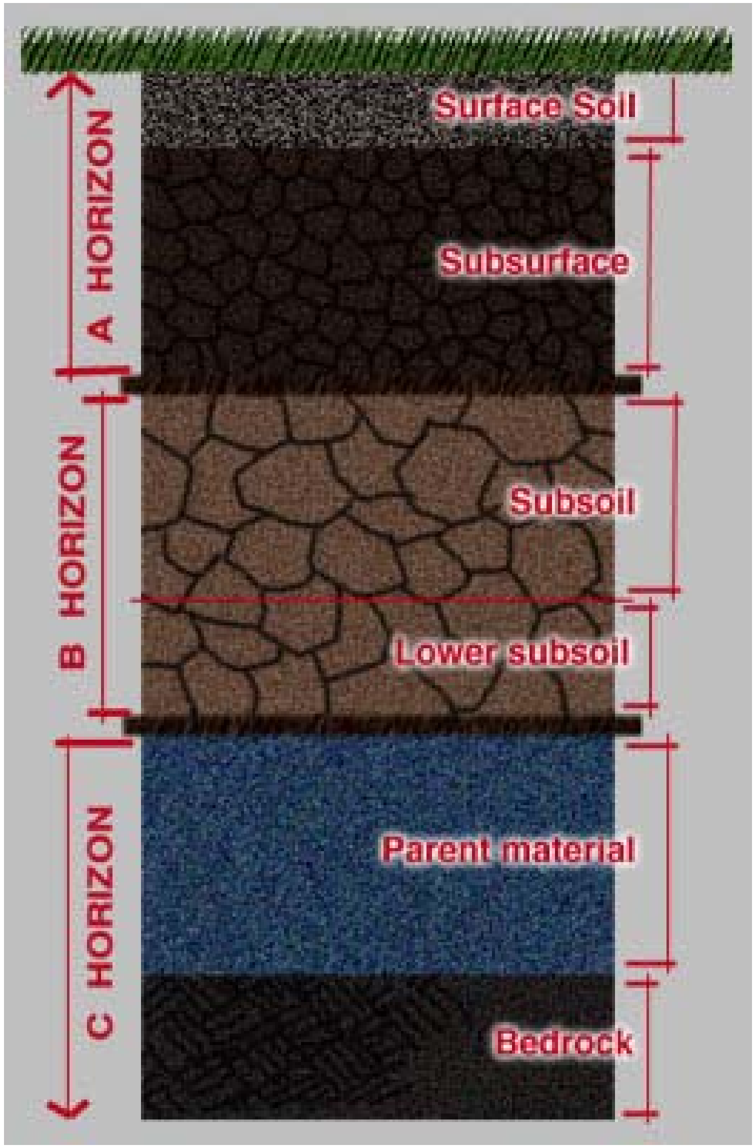
Soil Horizon Development



B-Horizon

- called sub-soil
- usually lighter in colour because less organic matter
- varies in thickness (cm to m)
- accumulation of mineral particles due to leaching of topsoil ("illuviation")

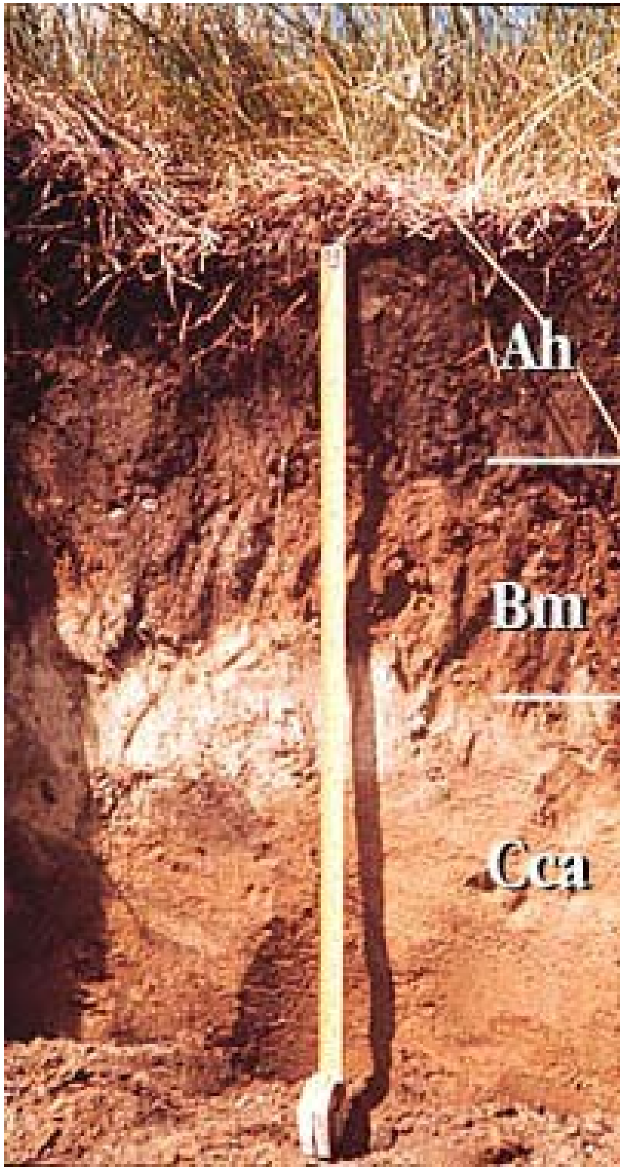
Soil Horizon Development



C-Horizon

- also called "parent material"; which is the original material from which the soil was created

- could be deposits from glacial activity (till), from sand/silt carried by the wind (aolean) or sediments carried by water (fluvial)



Summary: Physical Properties of Soils

Texture

Structure

Density

Porosity

Colour

Temperature

Factors Affecting Heat Transfer in Soils

Energy input into the root zone is influenced by following energy transfer processes:

- absorbed **radiation** (insolation, surface albedo)
- **convection** (movement of a heat-carrying mass) – air mass warmer than soil surface, rain warmer than surface, condensation of water vapour
- **conduction** (movement of heat within a body) – heat conduction from warm to cold soil

Conduction of Heat in Soils

Heat flux (q_h) is proportional to temperature gradient $\Delta T/\Delta z$, with the proportionality constant called "thermal conductivity" (K_T)

$$q_h = K_T (\Delta T/ \Delta z)$$

Thermal Conductivity

- defined as the quantity of heat flowing through a unit cross-sectional area in unit time (i.e. a measure of the ability of soil to conduct heat)

- is not constant, not even for a given soil type, and varies with both depth and time

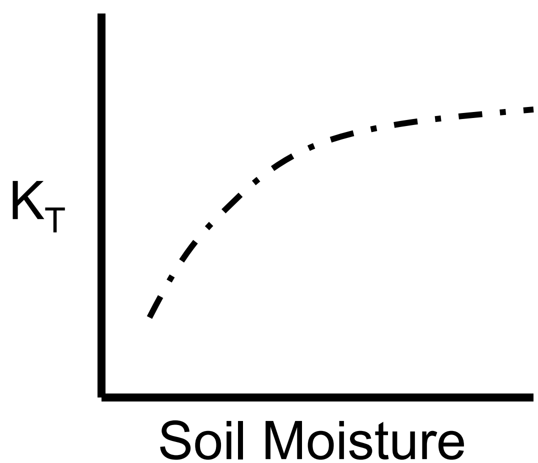
Factors Influencing Soil Conductivity

(1) conductivity of individual soil particles

(2) soil porosity

(3) soil bulk density

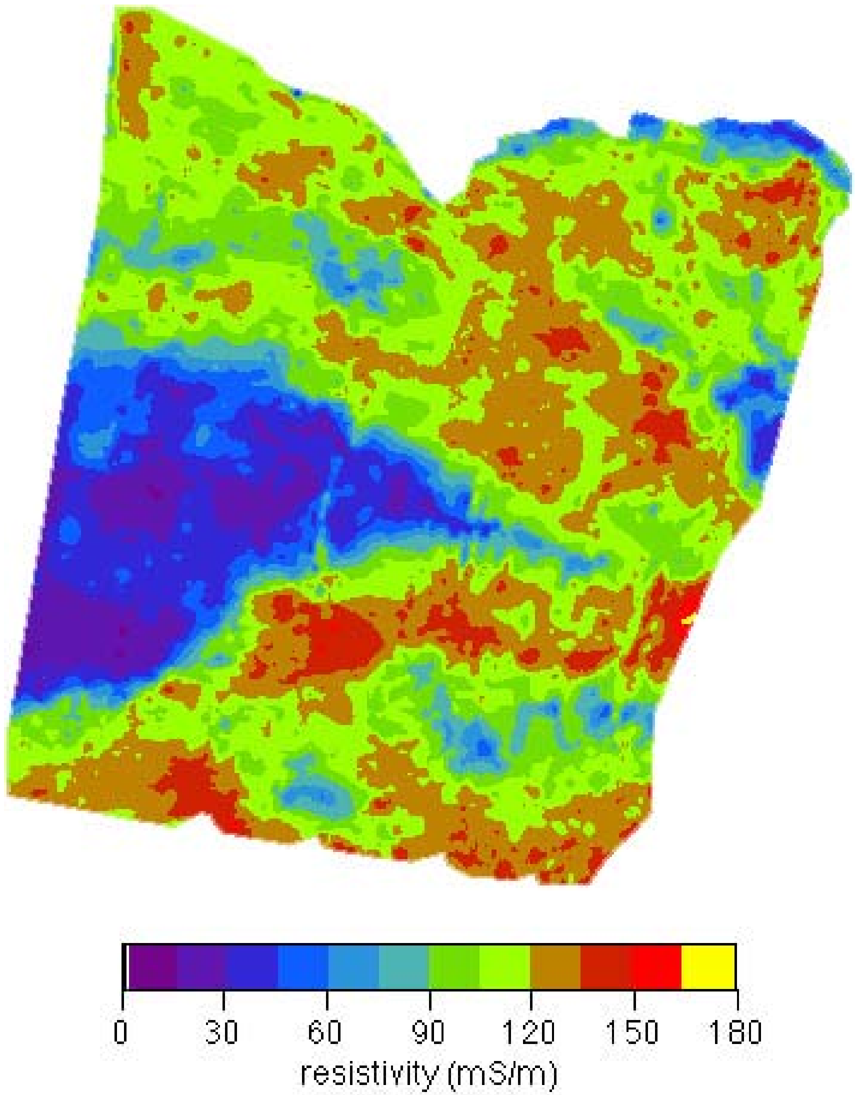
(4) soil moisture content



Soil moisture is the only factor that changes in the short-term.

Addition of moisture to initially dry soil increases soil conductivity.

Measuring Soil Conductivity



- electrical probes can be inserted into soil at defined level below the surface

- resistance to electrical flow is measured

- resistance is inversely related to conductance

Heat Capacity (C_v)

- amount of heat (J) necessary to raise a unit volume (m^3) of a substance through a temperature change of one degree Kelvin (K)

- value for a given soil is strongly (and linearly) dependent on soil moisture

Thermal Diffusivity (D_T)

- ability to diffuse thermal heat; which in turn controls the speed at which temperature waves move below the surface

- it can also refer to time required for temperature changes to travel through the soil

$$D_T = K_T/C_v$$

Factors Affecting Thermal Diffusivity

Thermal diffusivitiy is influenced most by soil moisture:

- when soil moisture is low, addition of water strongly increases thermal diffusivity

- after about 20% soil moisture content (by volume), thermal diffusivity begins to decline

Characteristics of soils with high diffusivities:

- rapid changes in surface temperature
- greater penetration of temperature change to lower soil layers

Characteristics of soils with low diffusivities:

- thermal exchanges are concentrated near the uppermost surface
- experience relatively extreme diurnal temperature fluctuations

<u>Examples</u>: wet clay (0.51) -- conservative thermal climate

dry peat (0.10) -- extreme thermal climate

Thermal Properties of Natural Materials

TABLE 2.1 Thermal properties of natural materials

Material	Remarks	ρ Density ($kg\ m^{-3} \times 10^3$)	c Specific heat ($J\ kg^{-1}\ K^{-1} \times 10^3$)	C Heat capacity ($J\ m^{-3}\ K^{-1} \times 10^6$)	k Thermal conductivity ($W\ m^{-1}\ K^{-1}$)	κ Thermal diffusivity ($m^2\ s^{-1} \times 10^{-6}$)
Sandy soil (40% pore space)	Dry	1·60	0·80	1·28	0·30	0·24
	Saturated	2·00	1·48	2·96	2·20	0·74
Clay soil (40% pore space)	Dry	1·60	0·89	1·42	0·25	0·18
	Saturated	2·00	1·55	3·10	1·58	0·51
Peat soil (80% pore space)	Dry	0·30	1·92	0·58	0·06	0·10
	Saturated	1·10	3·65	4·02	0·50	0·12
Snow	Fresh	0·10	2·09	0·21	0·08	0·10
	Old	0·48	2·09	0·84	0·42	0·40
Ice	0°C, pure	0·92	2·10	1·93	2·24	1·16
Water*	4°C, still	1·00	4·18	4·18	0·57	0·14
Air*	10°C, still	0·0012	1·01	0·0012	0·025	20·50
	Turbulent	0·0012	1·01	0·0012	~125	$\sim 10 \times 10^6$

* Properties depend on temperature, see Appendix A3.

Sources: van Wijk and de Vries (1963), List (1966).

Soil Temperature Profiles

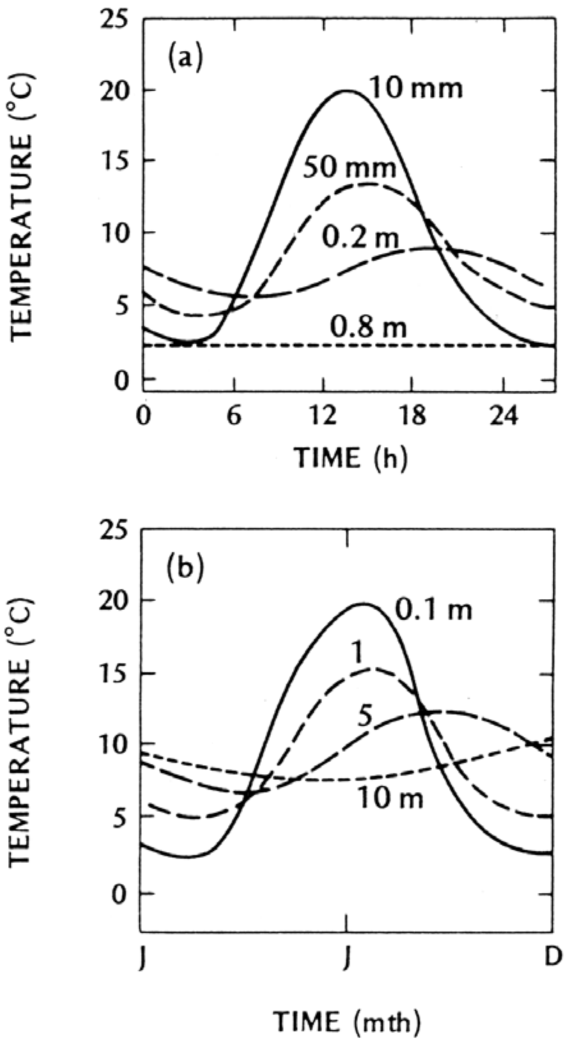


Figure 2.6 Generalized cycles of soil temperature at different depths for (a) daily and (b) annual periods.

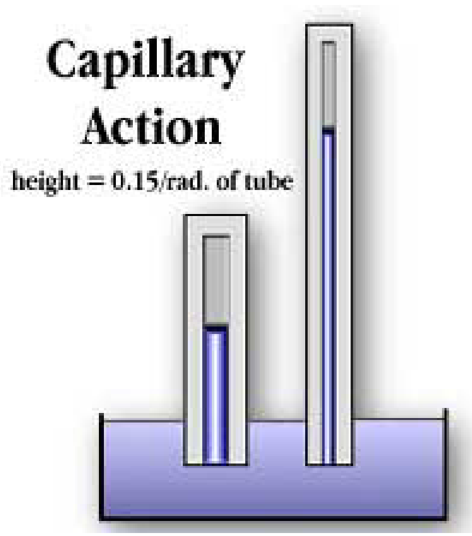
- diurnal variations in soil temperature decrease exponentially with depth

- in most soils, daily surface temperature wave is discernible only to a depth of about 0.75 m

- annual fluctuations in soil temperature usually does not extend below 10m

Soil Water

1. **Gravitational Water**: excess water that drains from soil after a rainfall or irrigation



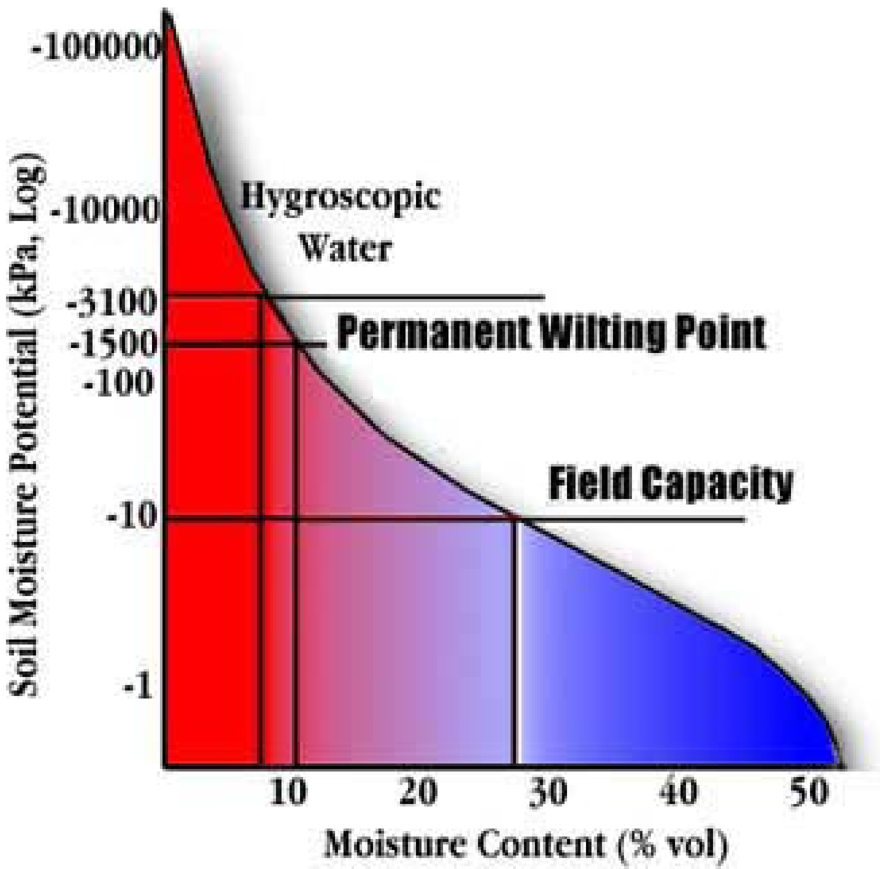
2. **Capillary Water**: contained in small pores or as films around soil particles

3. **Hygroscopic Water**: in air-dry soils, water found in thin layers around minerals (several molecules thick)

Available vs Total Water Content

Available Water	- amount of water held by soil; an amount falling between field capacity and wilting point
Field Capacity	- matic potential of soil (-30 kPa) following gravitational water movement downward; measure of the greatest amount of water that soil can hold after gravitational drainage
Wilting Point	- matric potential of soil (-1500 kPa) at which plants can no longer remover water (plants will not recover until soil moisture is restored)

Soil Moisture Retention Curve



Relationship between water content and soil water pressure is called the soil moisture retention curve.

Water Retention in Soils

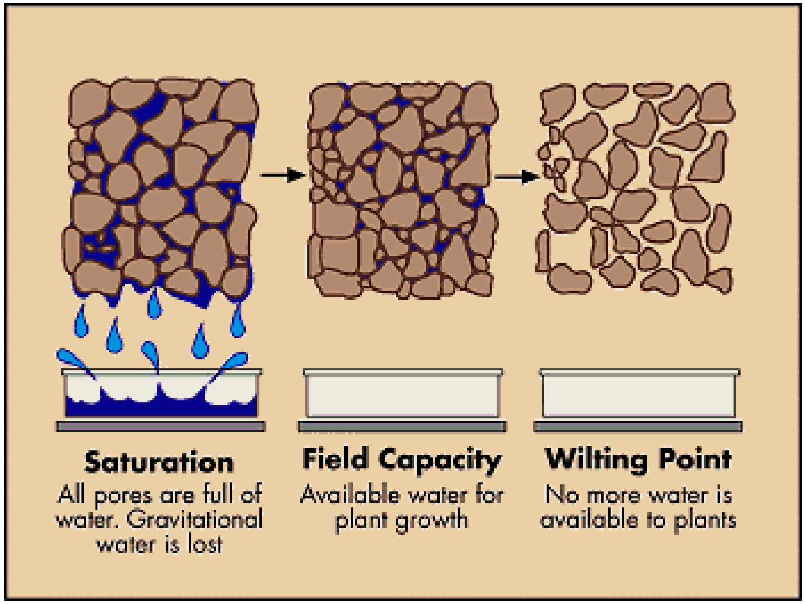
Soil Moisture Content

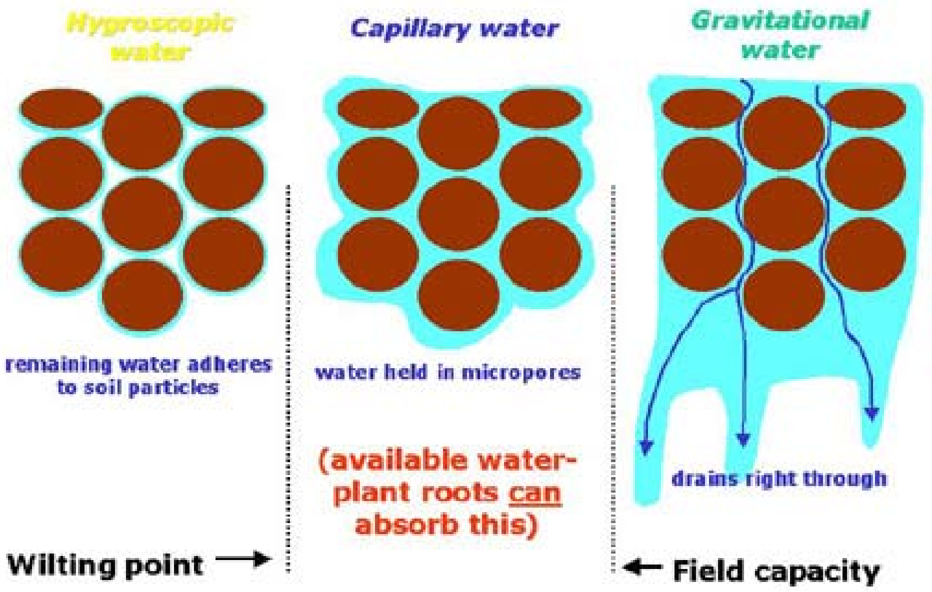
- defined as percentage volume of moist soil occupied by water

- simply a measure of actual soil water content

- is a function of soil texture and organic matter

- greater clay/organic matter content in soil increases water retention



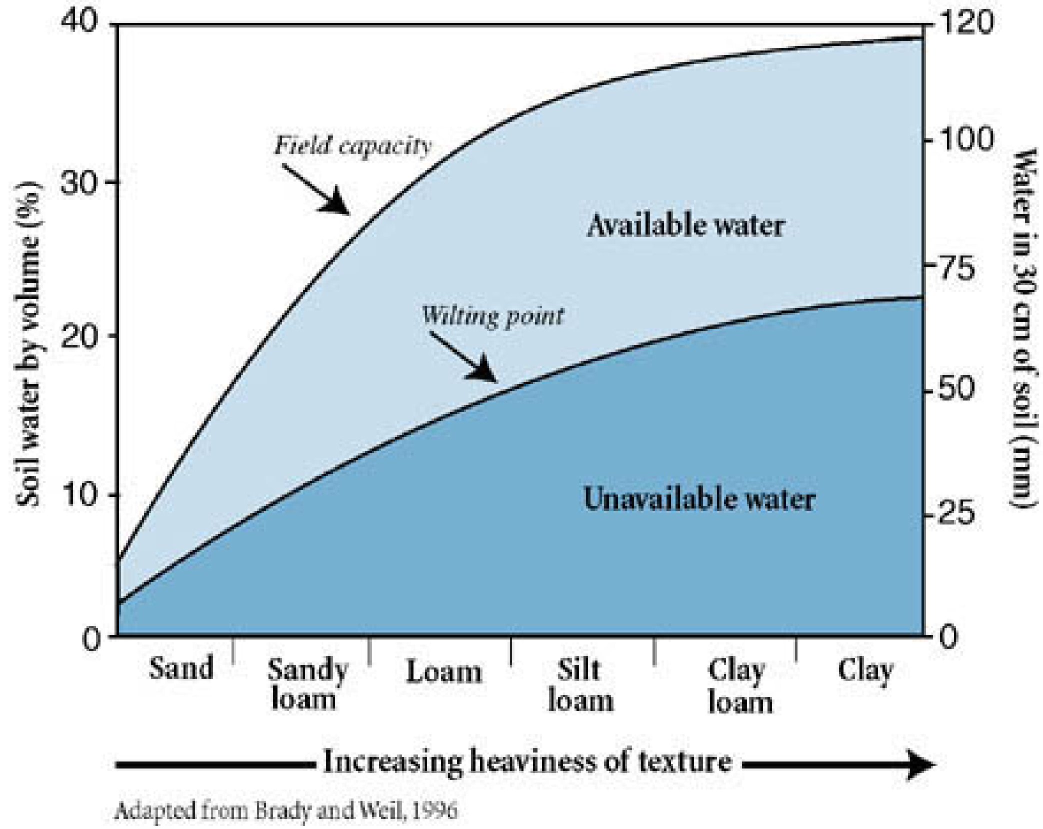


Soil water-holding capacity $= D \times \theta_{fc}$

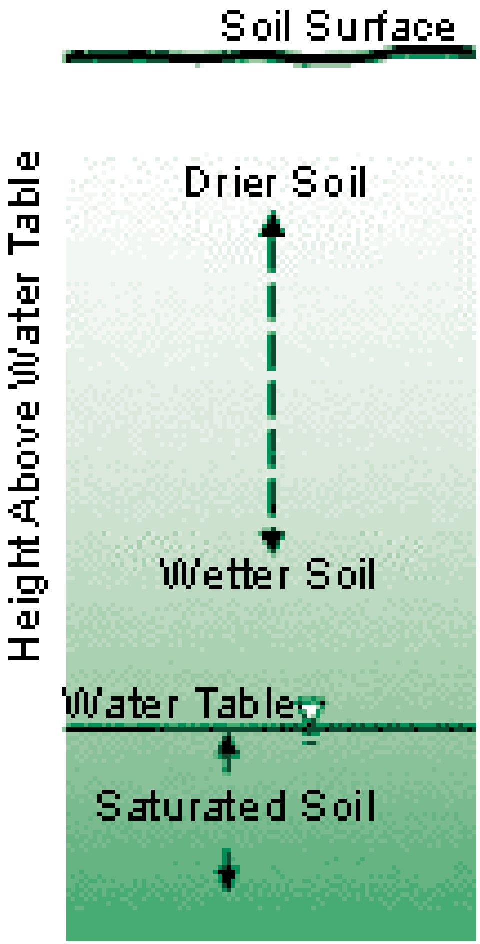
D = rooting depth zone (m)

θ_{fc} = field capacity of the soil (m^3/m^3)

Effects of Soil Texture on Moisture Availability



Identify trends:

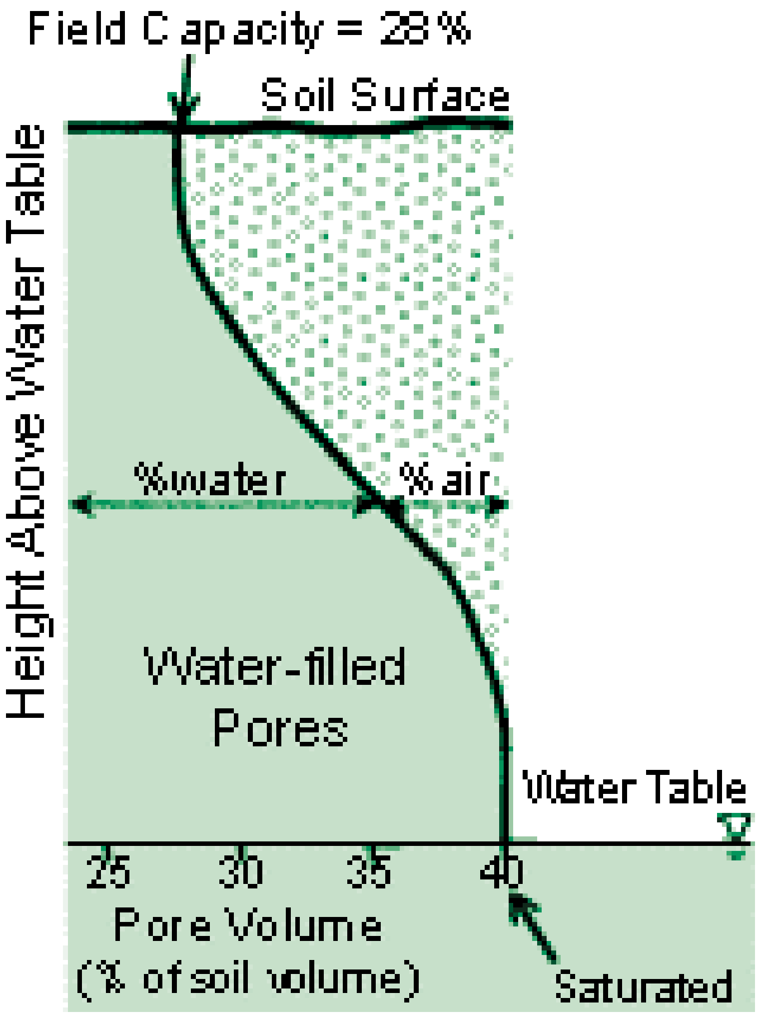


Water Table

- the upper surface of groundwater; the level below which the soil is saturated with water

Saturation

- maximum amount of moisture the soil can hold if every space between soil grains is filled with water



Unsaturated Water Flow

- movement of water in a soil that is not filled to capacity

- water moves because of suction differences and moves towards areas of greater suction (i.e. drier soil)

Soil Water Energy

- rather than thinking of water in terms of tension or suction, can discuss water being held by soil particles in terms of ENERGY

- important consideration when talking about water transfer – as water will move from areas of high to low energy (potential)

Ψ_g (positive) - gravitational potential

Ψ_o (negative) - osmotic potential

Ψ_m (negative) - matric potential

Soil Water Energy

Ψ_g - gravitational potential

- a positive energy that flows out of the soil through large pores

Ψ_o - osmotic potential

- due to attraction that salts have for water through the process of osmosis

Ψ_m - matric potential

- potential energy of water attracted to soil solid particles

Soil Water Potential (Ψ_T)

$$\Psi_T = \Psi_g + \Psi_o + \Psi_m$$

- total energy needed to extract water from soil matrix (measured as negative potentials)

- generally, Ψ_T varies as the inverse of soil moisture content (but the relationship is not linear)

- in other words, it is easy to extract water from wet soil

Coarse sand < loams < clays

Hydraulic Conductivity

- flux of water per unit gradient of the hydraulic potential (i.e. describes the capacity of soils to conduct water vertically upward)

- for water to move vertically, soil water potential must be greater than the opposing gravitational gradient downward

- as soils dry, hydraulic conductivity declines

Effects of Vegetation on Soil Formation

- protects soil from wind and water erosion

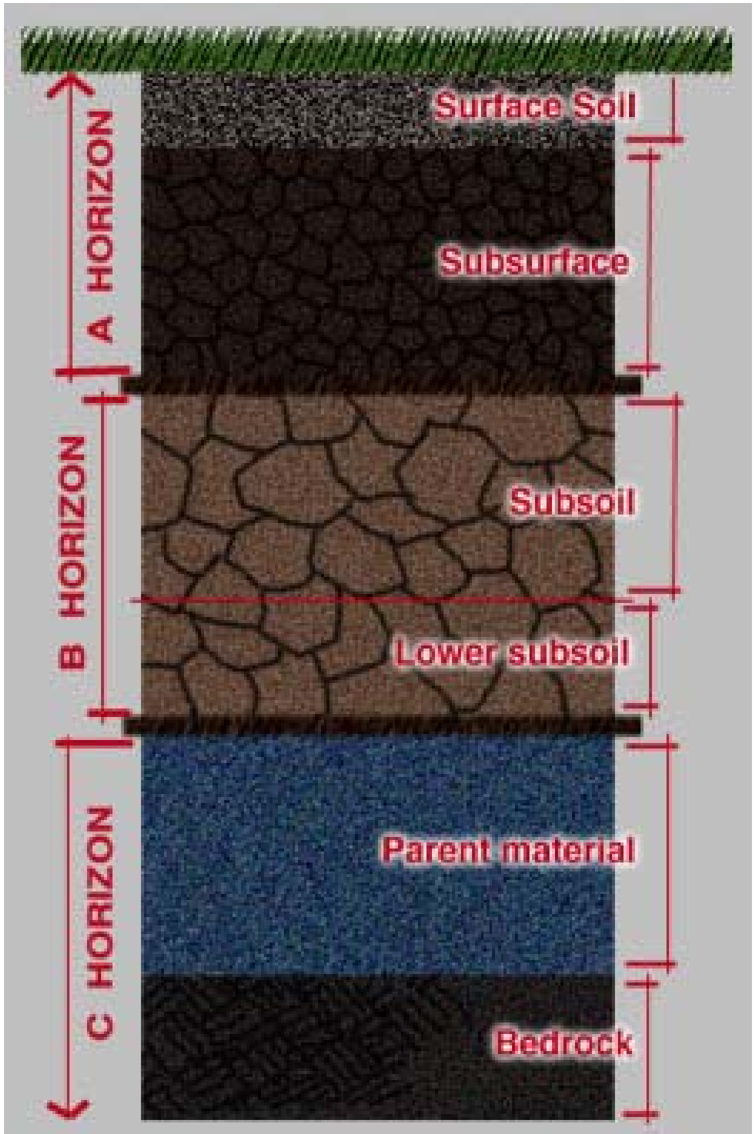
- roots of grasses/trees penetrate soil to break up parent material and add structure (i.e. compactness of soil)

- provide organic matter which improves structure and ability of soil to hold water

- roots provide nutrient-rich environment for micro-organisms ("rhizosphere effect")

- cycling of nutrients that would otherwise be leached out of the upper soil profile

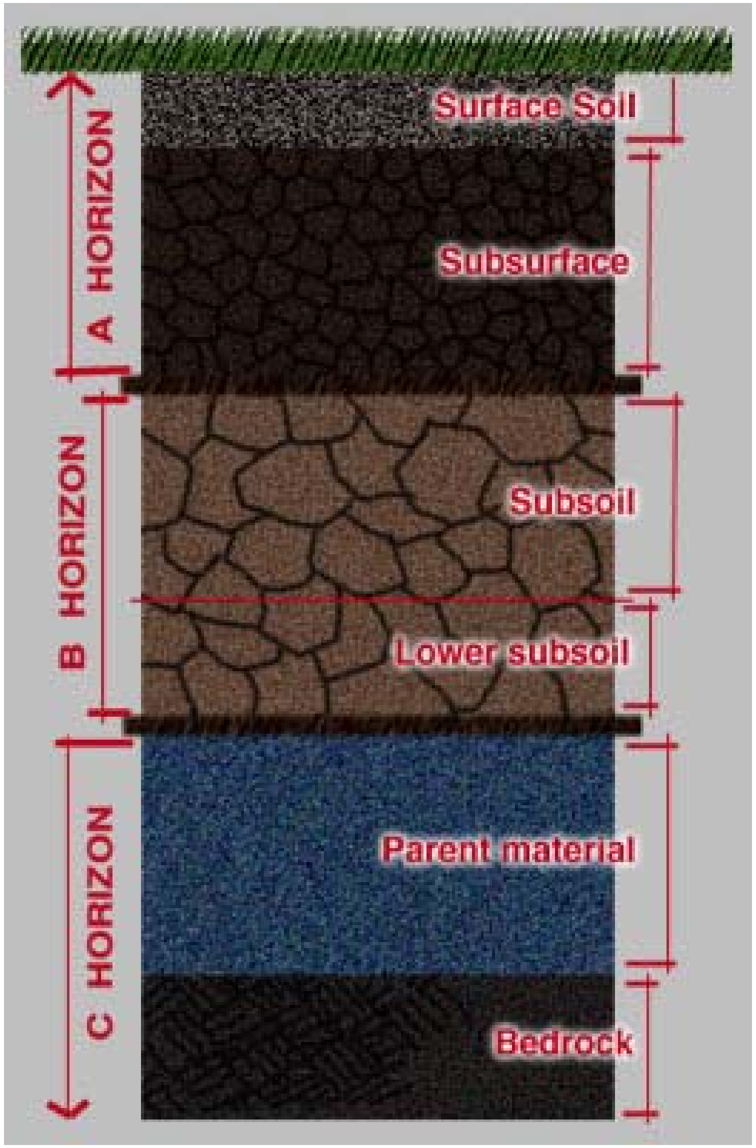
Soil-Root Interactions



A-Horizon

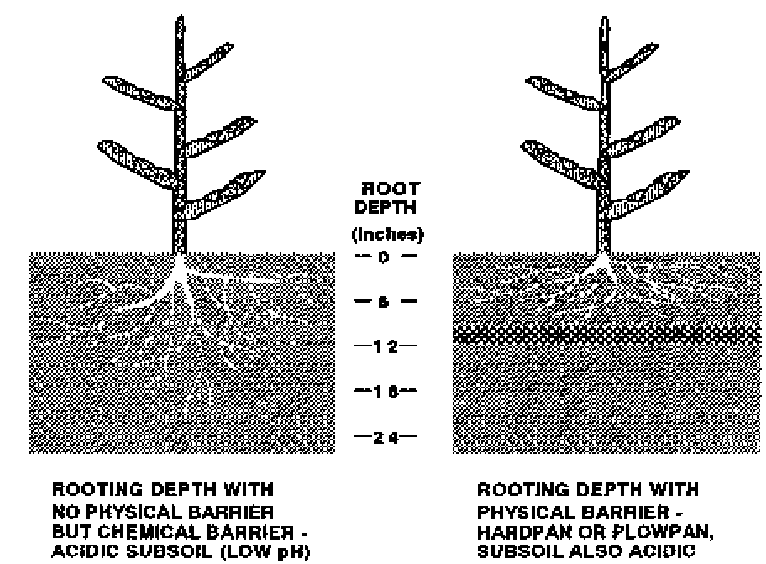
- roots are most dense
- exude nutrients which stimulate microorganisms
- high biological activity

Soil-Root Interactions



B-Horizon

- usually denser than A-horizon so roots have difficulty extending into this zone



Depth of Root Water Extraction

- most plant roots are in the upper soil horizons (50-100 cm from the surface)

- tundra, boreal forest and temperate grasslands have the shallowest root profiles (83-93% of root mass in the top 30 cm of soil)

- deserts have the deepest root profiles (with only 50% of root mass in the top 30 cm)

- on average, trees can have roots up to 7.0 m deep, shrubs 5.1 m and herbaceous perennials 2.6 m

Douglas Fir

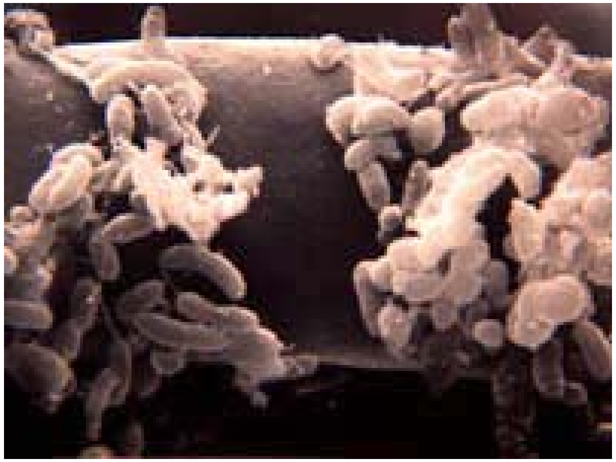
Tap Root

- large central root that is particularly important in anchoring tree in soil

Feeder Roots

- are only a few hundred μm in diameter

- responsible for most water and nutrient absorption



Rhizosphere

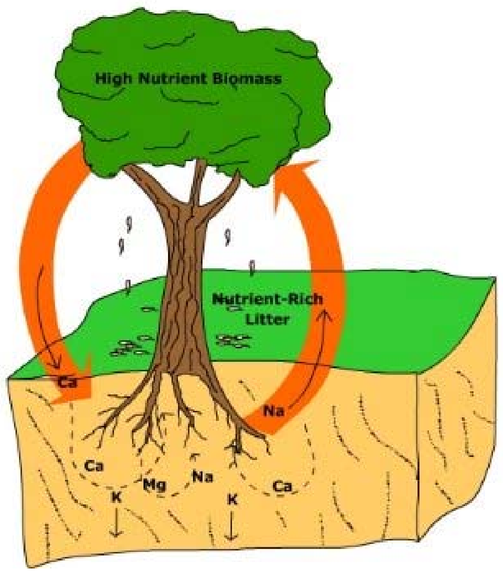
- zone found a few mm around active roots

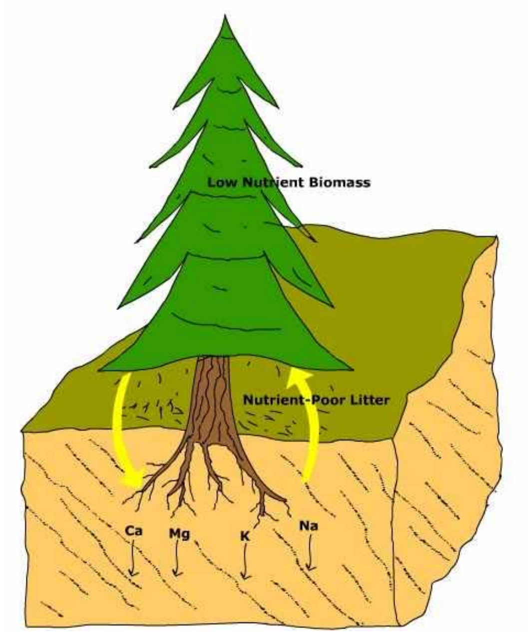
- root exudates create rich environment for growth of micro-organisms (photo above)

- secretion of polysaccarides by roots are important for binding of soil particles (aggregates), thereby affecting soil texture and soil moisture content

Grass Soils

- grasses cycle nutrients very effectively because they revive quickly in the spring
- developing root system can take advantage of spring snow meltwater
- under dormant trees, this melt water would leach nutrients out of the soil profile
- soils are rich in humic organic matter





Forest Soils

- more discernable soil horizons
- highly leached surface layer
- less decomposed organic matter
- nutrient cycling depends on type of forest – conifer versus deciduous

Role of Roots in Chemical Weathering

1. High rates of biological activity that often results in the secretion of organic acids
2. High CO_2 production (carbonic acid)

Example

- lichens are usually the first plants to be established on bare rock (cling to rock with tiny hair-like roots)
- to get nutrients they need, lichens secrete chemicals on surface of rock