2. Soil-water content & water potential relation

Introduction

- Soil-Water-Plant Relationships relate the properties of the soil that affect the movement, retention and use of water
- It can be divided & treated as:
  - Soil-Water relation
  - Soil-Plant relation
  - Plant- Water relation
- Irrigation water and rainwater is stored in different classes of soil pores (fine, medium and large pores)

2. Soil-water content…

- The water stored in the soil pores constitutes the soil water
- Only 1.0 to 1.5% of the volume of water absorbed by roots is used for building vegetative structures, performing physiological & biochemical activities
- The rest of water is lost through ***transpiration*** of plants
- “when to irrigate and how much to irrigate” depends on *soil-water-plant-atmosphere relationships*
- *Both excess and deficit of soil water affects the plant growth and results in yield reduction*

2.2 Classification of soil water

(i) Gravitational water

- Soon after irrigation (or rainfall), the soil pores are completely saturated
- The portion of water which drains down under the influence of gravity is called gravitational water
- It is not useful for plants as it flows out rapidly

(ii) Capillary water

- Water content retained in the soil after the gravitational water has drained off
- Held within soil pores due to the surface tension forces against gravity
- Useful for plants & goes on reducing due to evaporation & transpiration
- Influenced by structure, texture and organic matter content of soil

2. Soil-water content …

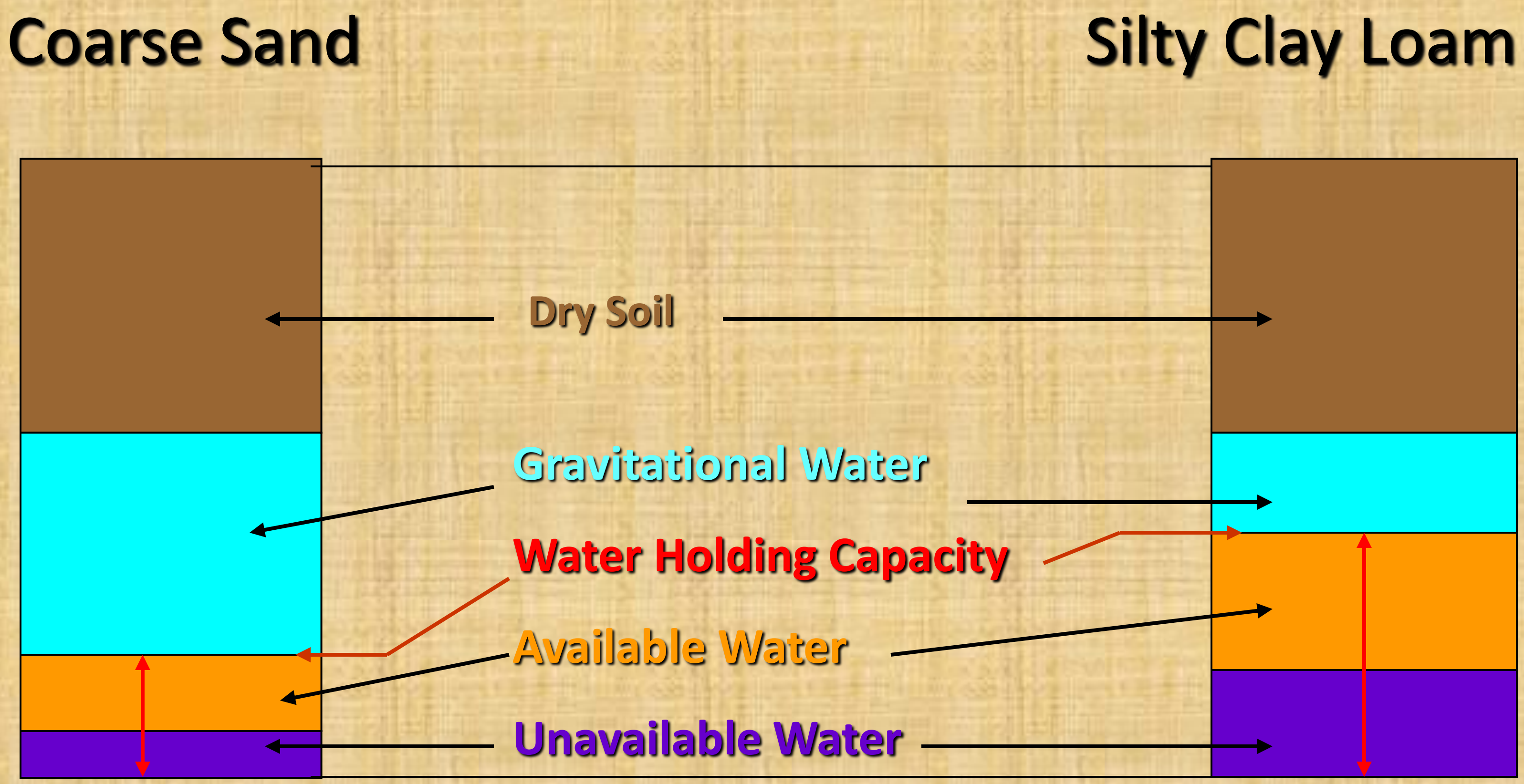
(iii) Hygroscopic water

- Water held as a very thin film on the surface of the soil particles due to adhesion
- Cannot be extracted by plants & can be removed only by heat
- Water content below permanent wilting point

Field capacity (FC):

- Maximum amount of moisture that can be held by the soil against gravity
- Soil water at field capacity is **available** to plants and allows sufficient air circulation & microbial respiration
- FC is upper limit of moisture content that a soil can hold

2.2 Classification of soil water…



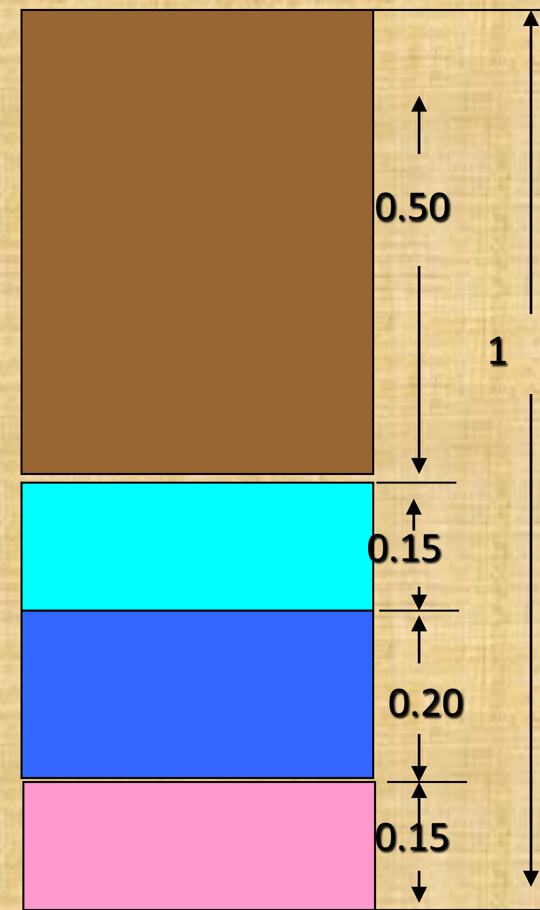
2.2 Classification of soil water…

soil water _ pore relation

Soil Solids (Particles & organic matter): 50%

Total Pore Space: 50%

- Very Large Pores: 15% (Gravitational Water)
- Medium-sized Pores: 20% (Plant Available Water)
- Very Small Pores: 15% (Unavailable Water)



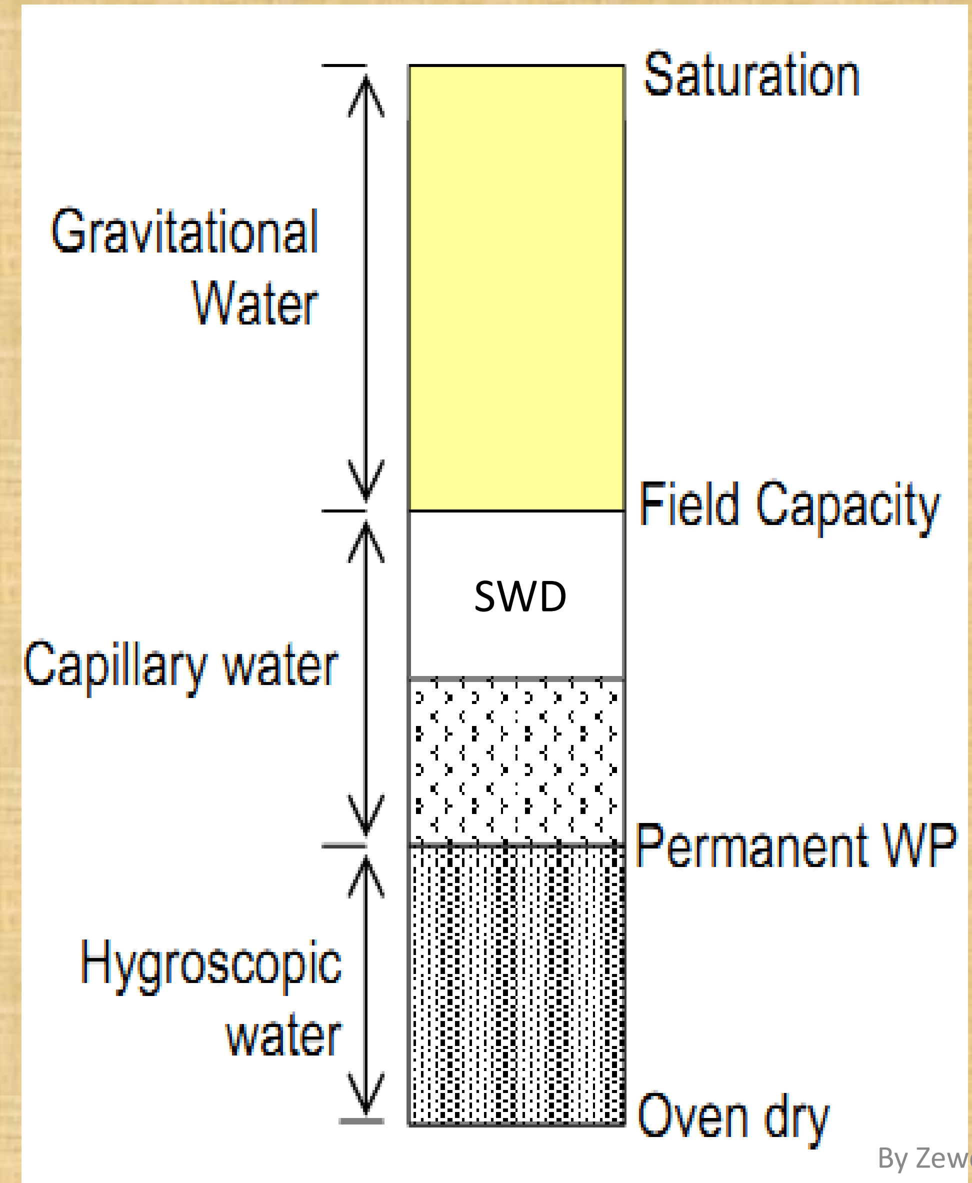
2.2 Classification of soil water…

Permanent wilting point (WP)

- Moisture content level at which the plants are water stressed and irreversibly wilt
- Plants can no longer exert enough force to extract moisture at PWP
- Applying additional water after this stage will not relieve the wilted condition
- The soil moisture tension at this condition is around -15 bars of soil water potential
- Depends upon the nature of crop

2.2 Classification of soil water…

Classification of soil water



➢ ***Available water***

- Water held in the soil b/n FC and PWP

Readily available water

- Portion of available water which is most easily extracted by roots
- It is approximately 75%-80% of the available water

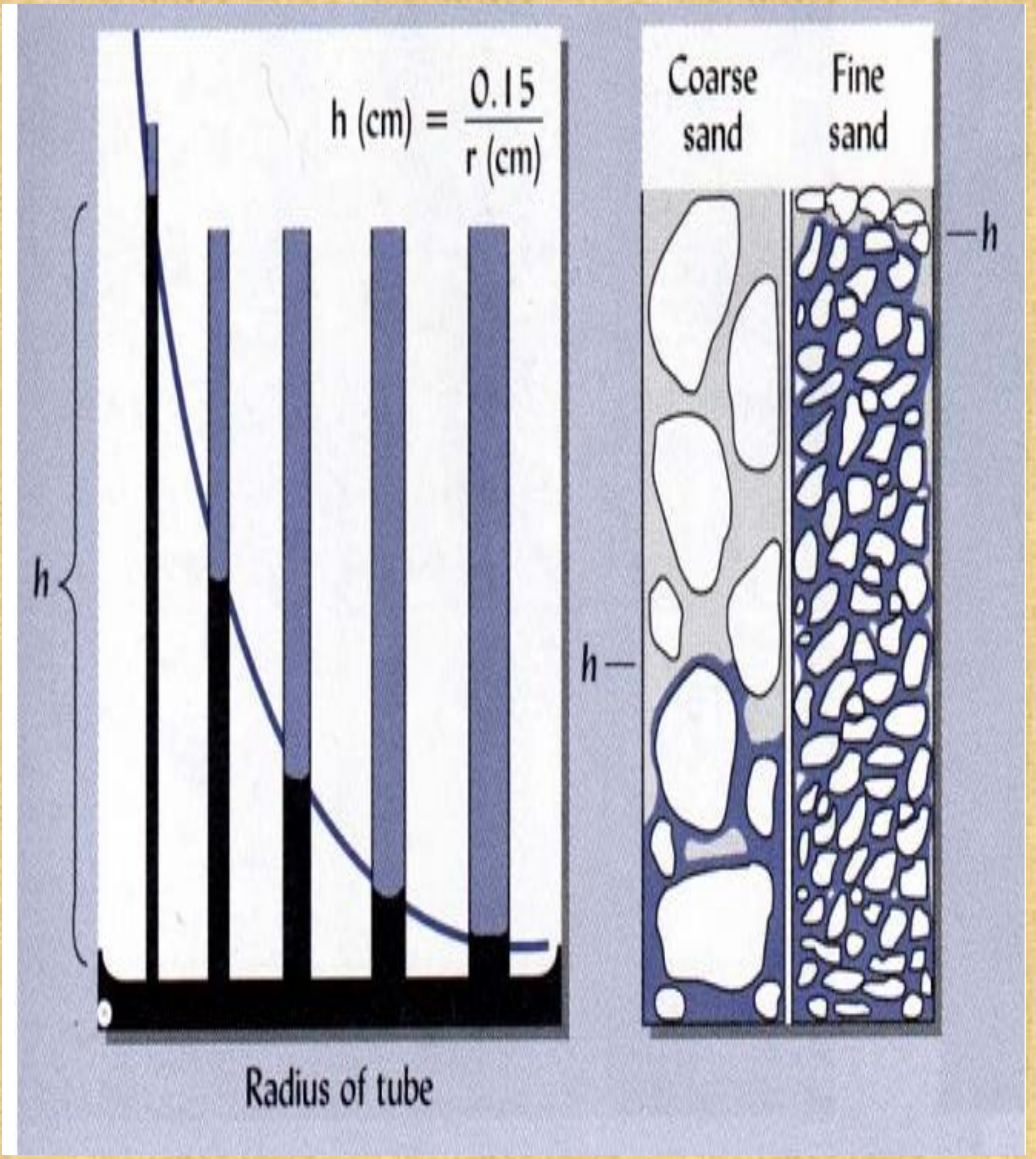
Capillary rise

- The rise in height **'h'** of soil water due to capillarity is given by:

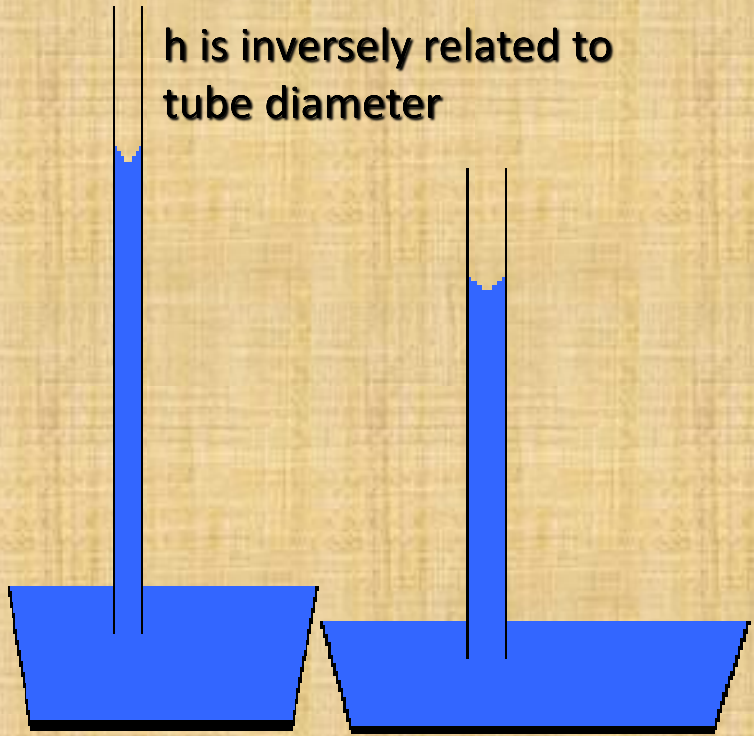
$$\frac{0.15\,(cm^2)}{r\,(cm)}$$

- The smaller the tube diameter, the higher the capillary rise of soil water
- The tension or suction created by small soil pores is greater than that created by large soil pores

Capillary rise



h is inversely related to tube diameter



Forces acting on soil water

- Soil water is subject to matric, osmotic & gravitational forces

a) Matric forces

- resulting from interactions of the **solid phase with the liquid and gaseous phases**
- Have the greatest effect on release of water from soil to roots
- Consist of adsorptive & capillary forces
- Adsorptive forces cause water molecules adsorbed on soil particles
- Capillarity is the adhesive force that acts in the boundary layers between phases

Forces acting on soil water…

b) Osmotic force

- Soil water contains certain amount of dissolved salts and other solutes
- When a solution is separated by a semi permeable membrane from pure water or form a solution of lower concentration, water tends to diffuse into the concentrated solution through the membrane.
- The force exerted on soil water due to the difference in concentration across a semi-permeable membrane, are osmotic forces

Forces acting on soil water…

c) Gravitational force

- The force acted by gravity on soil water
- It will have effect on soil water only if it exceeds the combined effects of matric & osmotic suctions
- When the soil gets wet after irrigation or rain, the

combined matric and osmotic forces decrease

- At saturation, gravity exceeds matric & osmotic forces holding water in the soil matrix $\rightarrow$ water moves downwards

2.3 Soil water potential (SWP)

Energy state of soil water

- Soil water, like other bodies in nature, can contain energy in different quantities and forms (kinetic and potential).
- Kinetic energy ($0.5MV^2$) is considered to be negligible b/c movement of water in the soil is quite slow
- Potential energy is of primary importance in determining the state and movement of water in the soil.
- Differences in potential energy of water between one point and another give rise to the tendency of water to flow within the soil.

2.3 Soil water potential…

SWP (ψ_t):

- The energy status of water is simply called 'water potential'
- Important because it reflects how hard plants must work to extract water
- Units of measure are normally bars or atmospheres
- Soil water potentials are negative pressures (tension or suction)
- Water flows from a higher (less negative) potential to a lower (more negative) potential

2.3 Soil water potential…

- The total soil water potential is the sum of potentials resulting from different force fields
- can be written as: $$\psi_t = \psi_m + \psi_O + \psi_g$$

where:

ψ_t	=total potential
ψ_m	=matric potential
ψ_O	=osmotic potential
ψ_g	=gravitational potential

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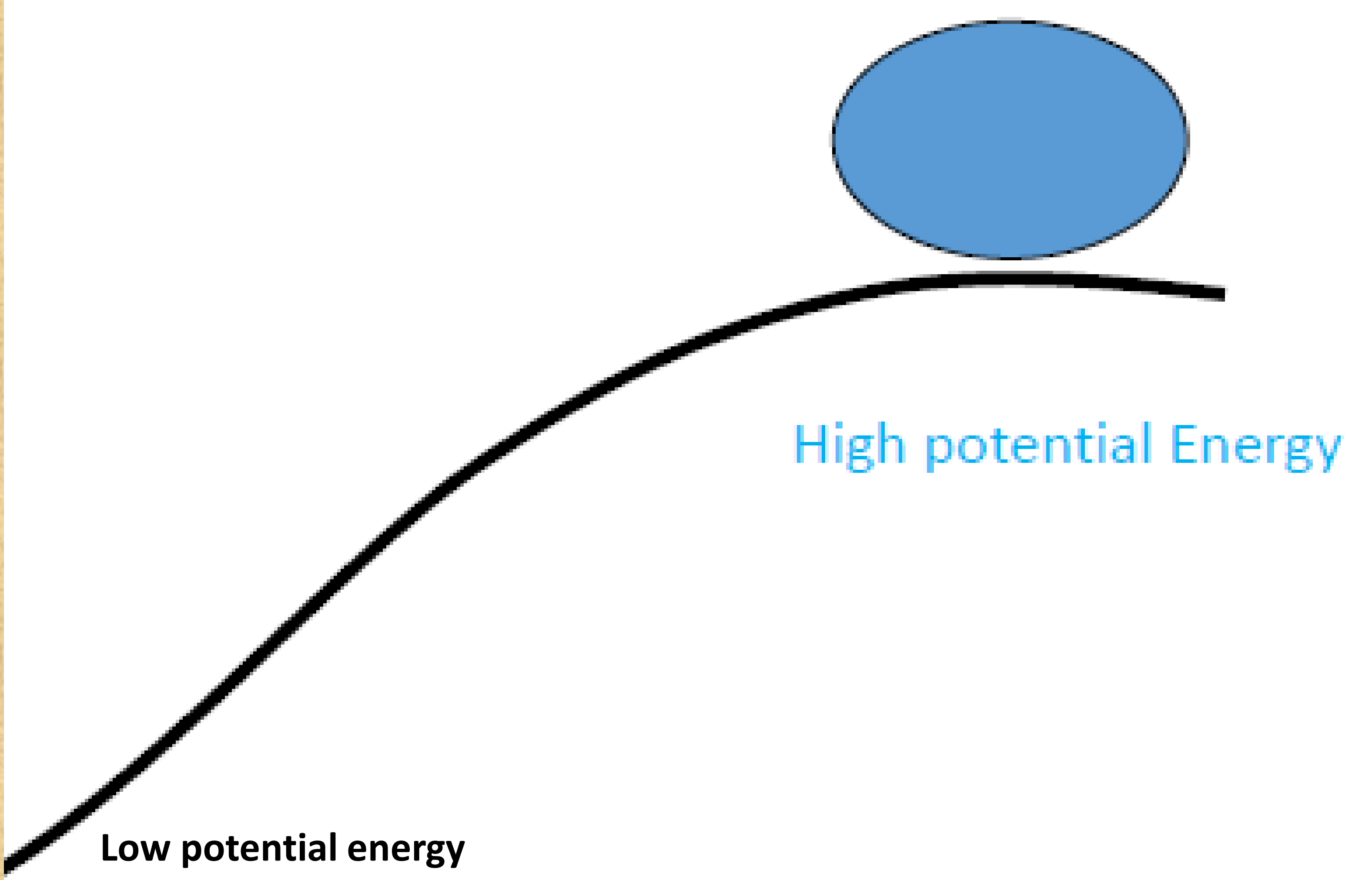
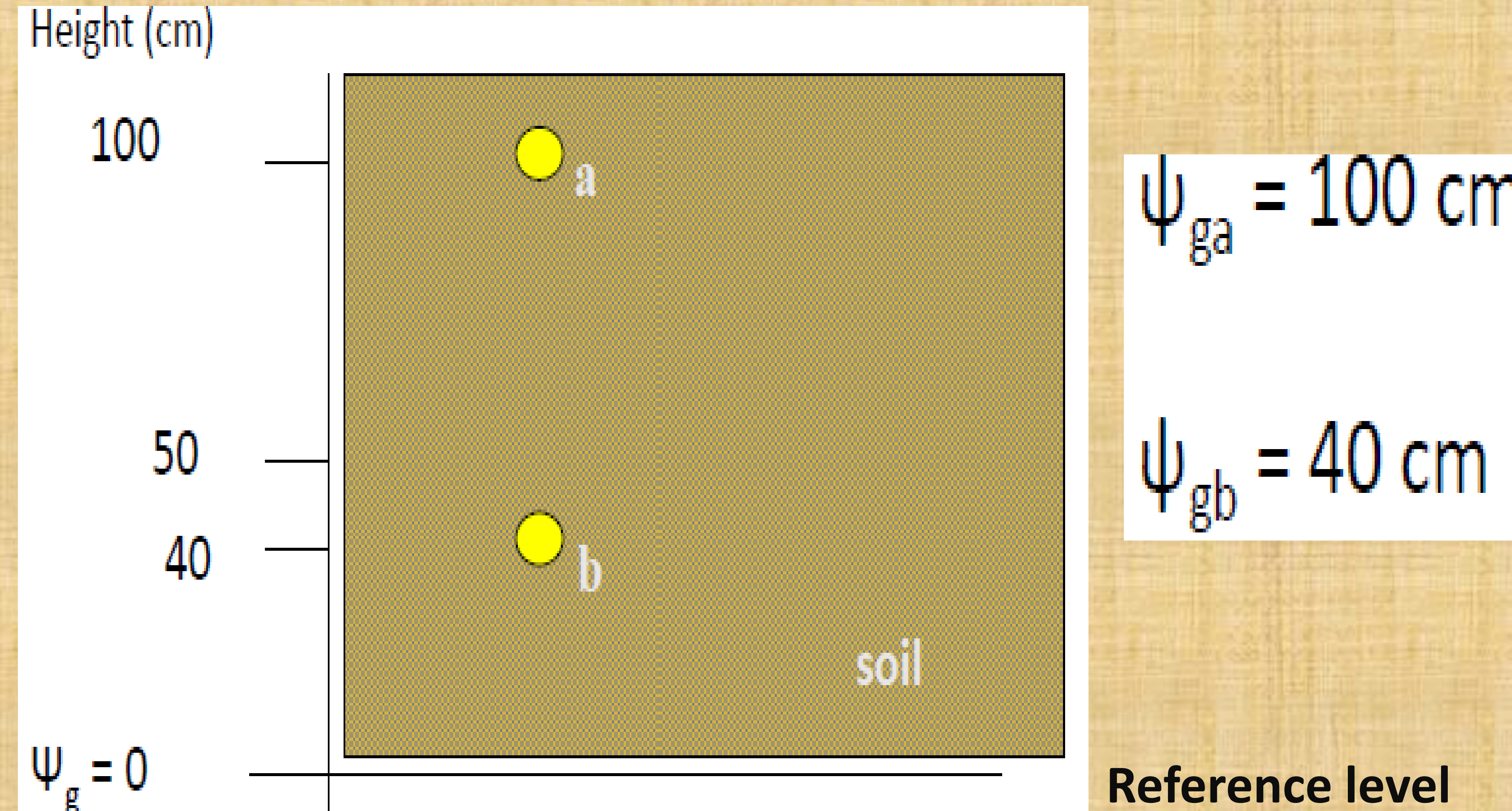
Gravitational potential

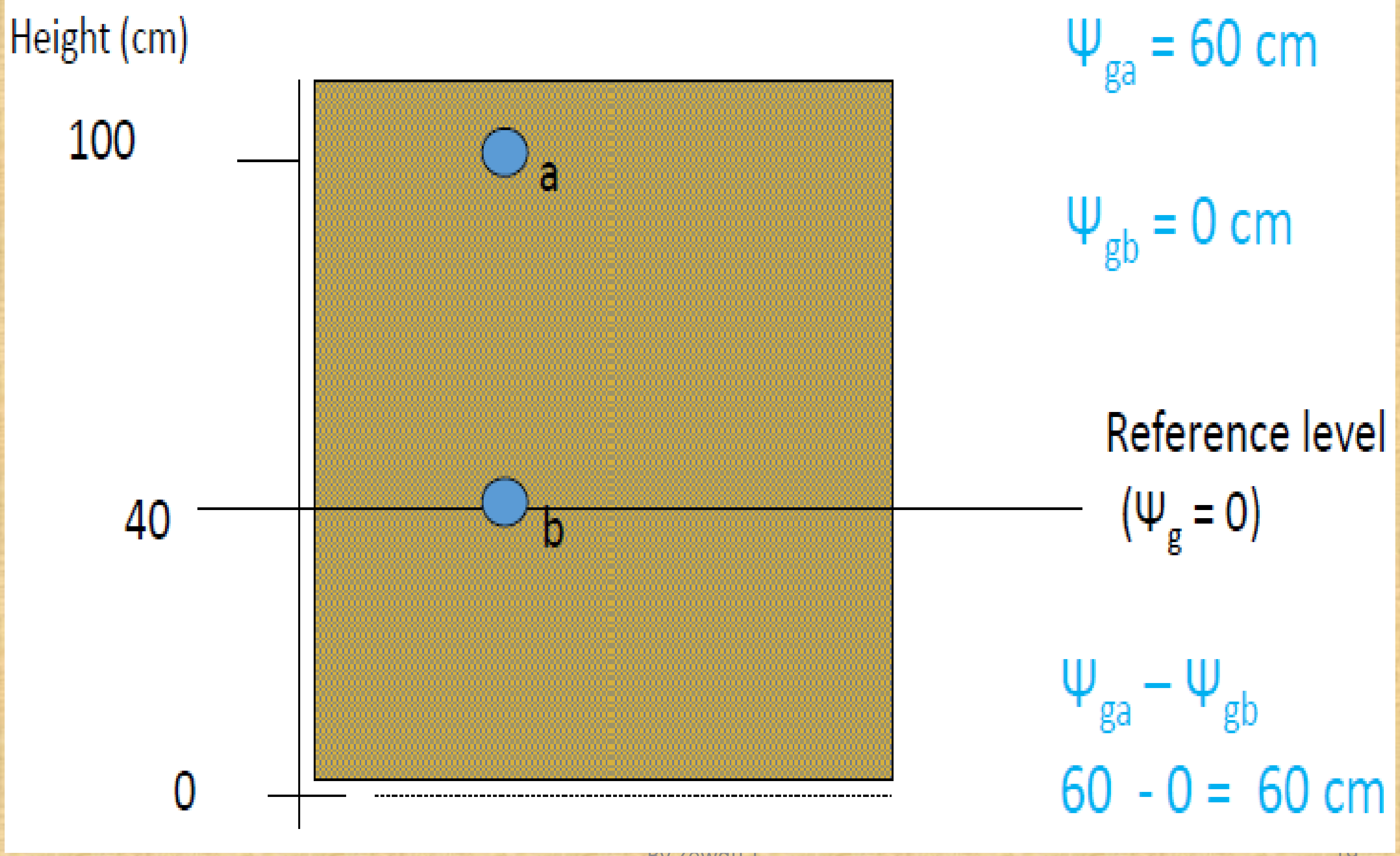


- The greater the height from a reference level, the greater the potential energy.

- The gravitational potential energy is <u>independent of soil physical properties</u>. But <u>dependent on **height**</u> from a reference level

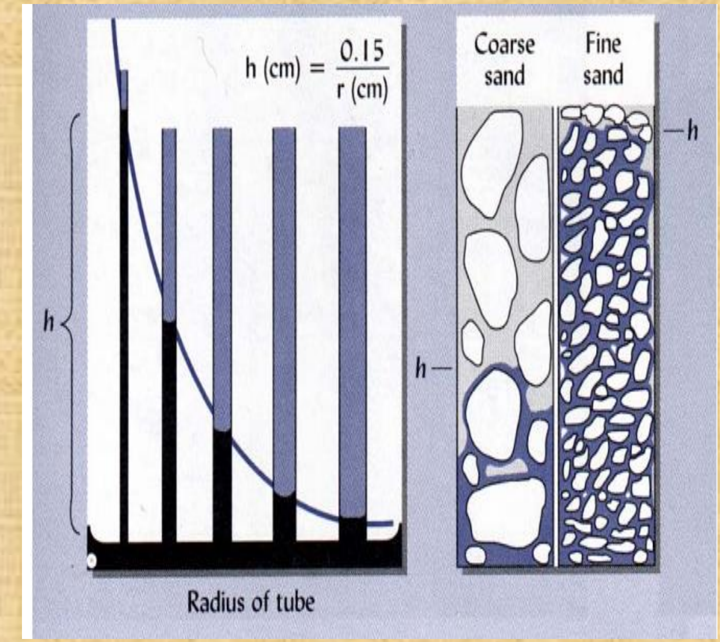


- Gravitational potential energy is due to the height of an object (water) above some reference point



Matric Potential

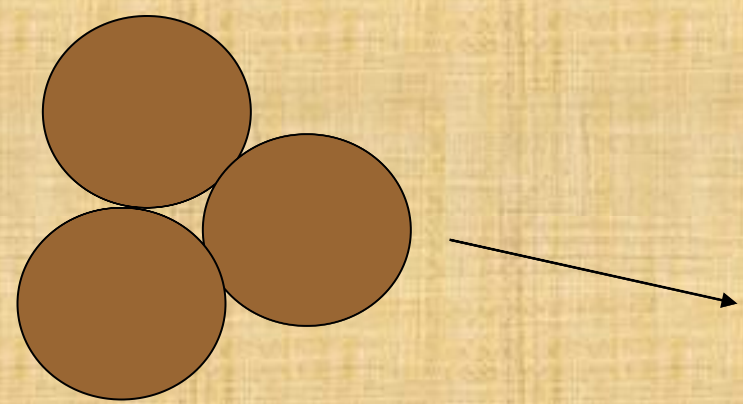
- It is “suction” potential /capillarity
- It is high in narrow capillary tubes (small particles, small pore sizes) than in wide capillary tubes



- Dependent on soil physical properties (texture, density, aggregation)
- Applied in unsaturated soils

Capillarity and Soil Texture

Small pores
Strong suction
Strong capillarity



Large pores
Weak suction
Weak capillarity

Soil moisture characteristics

Soil moisture retention

- Soil's moisture content is defined as the water that may be evaporated from soil by heating at 105°C to a constant weight
- The relationship b/n soil's moisture content (θ) and soil-matric potential (ψ_m) or pressure head is called "soil moisture characteristics," "soil moisture characteristic curve," or "pF curve."
- wetness increases with decrease in soil matric potential from a **high negative value (**for dry condition) to a **near zero** suction (for saturated state)

Soil moisture characteristics

- Adsorptive (cohesion and adhesion) and capillary forces hold water in the voids b/n soil particles
- Matric forces must be overcome to remove water from a soil
- The min. force required to remove water from a soil varies with the amount of water in the soil
- As the soil approaches saturation, the matric forces approach to zero
- As the water content of the soil approaches zero, the matric forces approach negative infinity

Soil moisture characteristics

- The pressure head (h) vary from 0 cm (for saturation) to 10^7cm (for oven-dry conditions)
- pF is the logarithm of the tension or suction in cm of water. It is given by: $pF = \log|h|$
- **Heaver soils** retain greater quantity of water at any particular tension in comparison to a coarser soil (because of large number of small pores)
- Greater amount of **silt and clay** in soil encourages retention of more water at any particular suction

Soil water(moisture) measurement

- ✓ Soil water content is measured using gravimetric, neutron scattering, gamma ray, capacitance method, and time domain reflectrometer
- ✓ expressed on mass basis or volume basis.
- ✓ Gravimetric is most common method but for rough estimation feel & appearance can be used

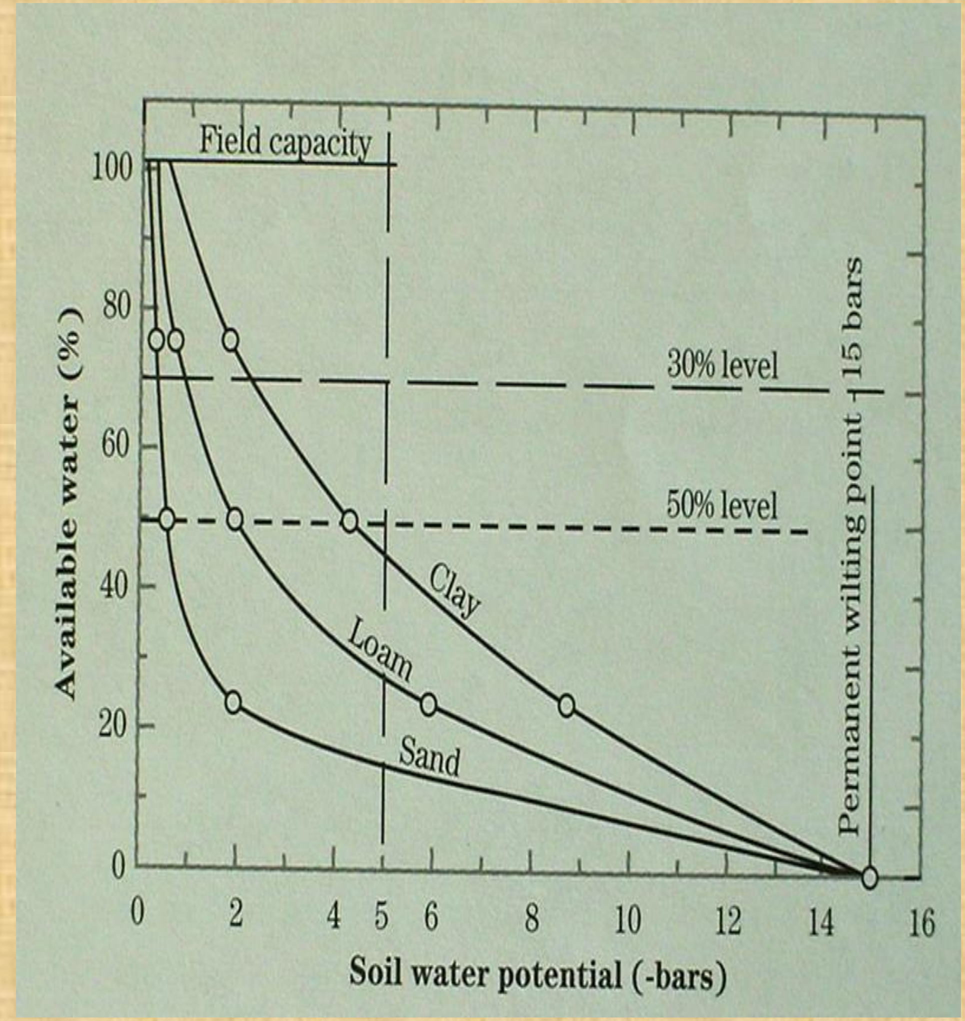
a) Gravimetric

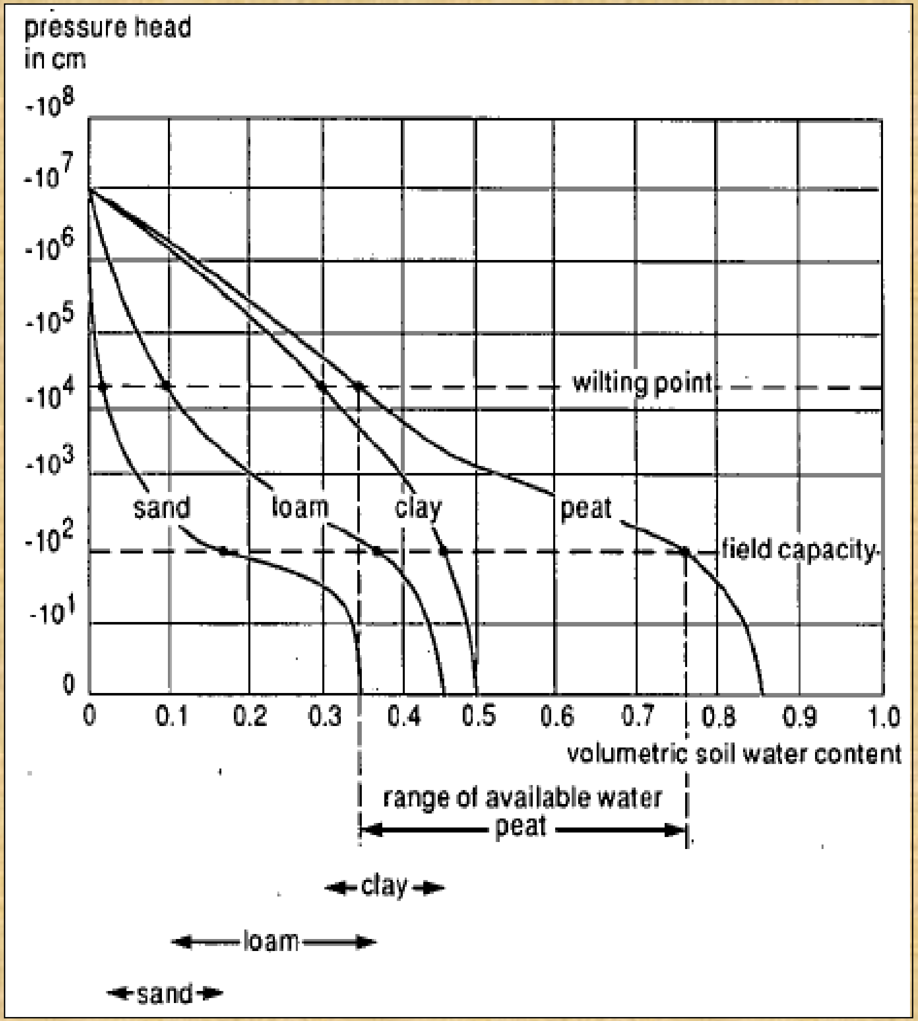
- Measures mass water content (w)
- Take field samples → weigh → oven dry → reweigh
- Advantages: accurate; takes sample from multiple locations
- Disadvantages: laborious; Time delay-lose of moisture before measurement

b) Feel and appearance

- Take field samples and feel them by hand
- Advantages: low cost; samples from multiple locations
- Disadvantages: experience is required; Not highly accurate

Soil moisture characteristics





Soil-water retention curves for different soil types

Movement of water in the soil

Infiltration:

- The entry of water into the soil matrix through air-soil interface
- Important property of soil which affects surface irrigation
- The infiltrated water first meets the soil moisture deficiency, if any, & the excess moves vertically downwards or goes off as surface runoff
- Vertical movement of water is largely due gravity & horizontal movement is due capillarity

Infiltration rate:

- The entry of water into the soil with time
- In dry soils, infiltration rate is high at the beginning of rain/irrigation (due to suction gradients) but rapidly decreases with time until a fairly steady state is reached

Movement of water in the soil

- ***Infiltration capacity***: the maximum rate at which a soil in given condition is capable of absorbing water & given by

Horton's equation:

$$f = f_c + (f_0 - f_c)\, e^{-Kt}$$

where f = Infiltration capacity at any time t.

f_c = The value of infiltration rate after it reaches a constant value.

f_0 = Infiltration capacity at the start

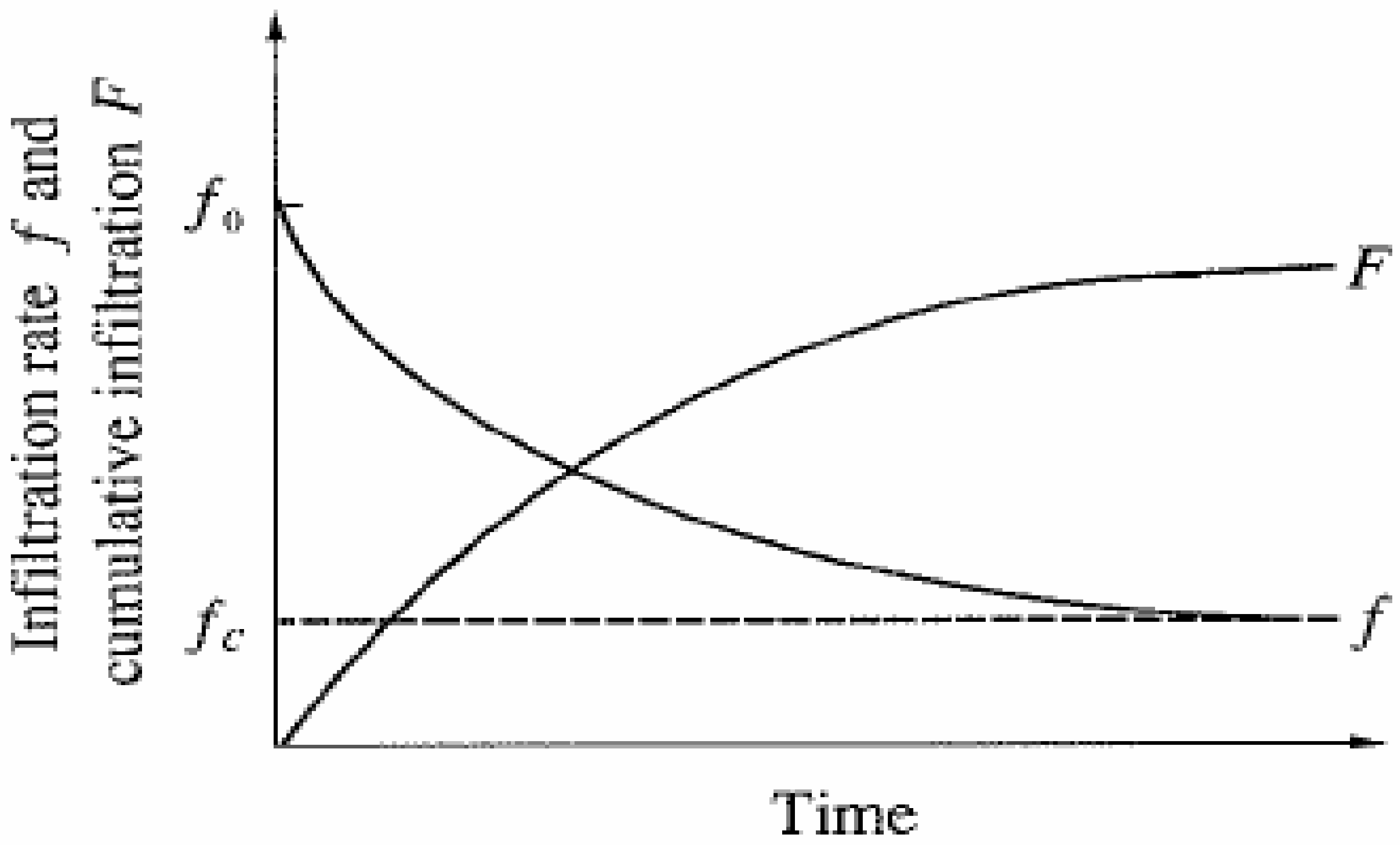
K = a constant.

t = Time from the beginning of rainfall.

- **Cumulative infiltration:** Accumulated depth of water infiltrating during given time

Movement of water in the soil

- Sc



Infiltration rate and cumulative infiltration.

Movement of water in the soil

- Infiltration rate & cumulative infiltration is measured by **infiltrometers**

Single ring

double ring

Movement of water in the soil

Infiltration Rate vs. Time

For Different Soil Textures

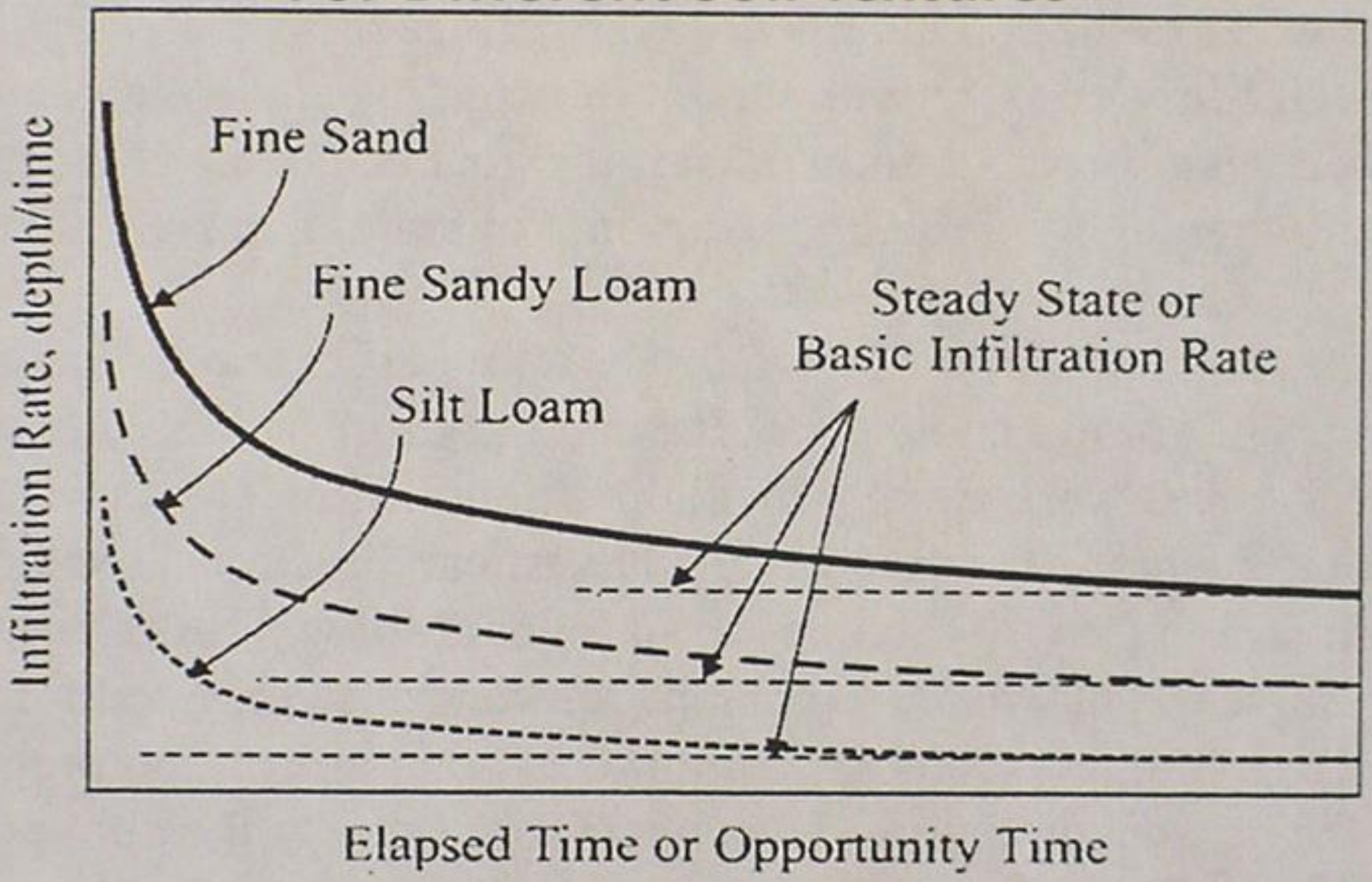
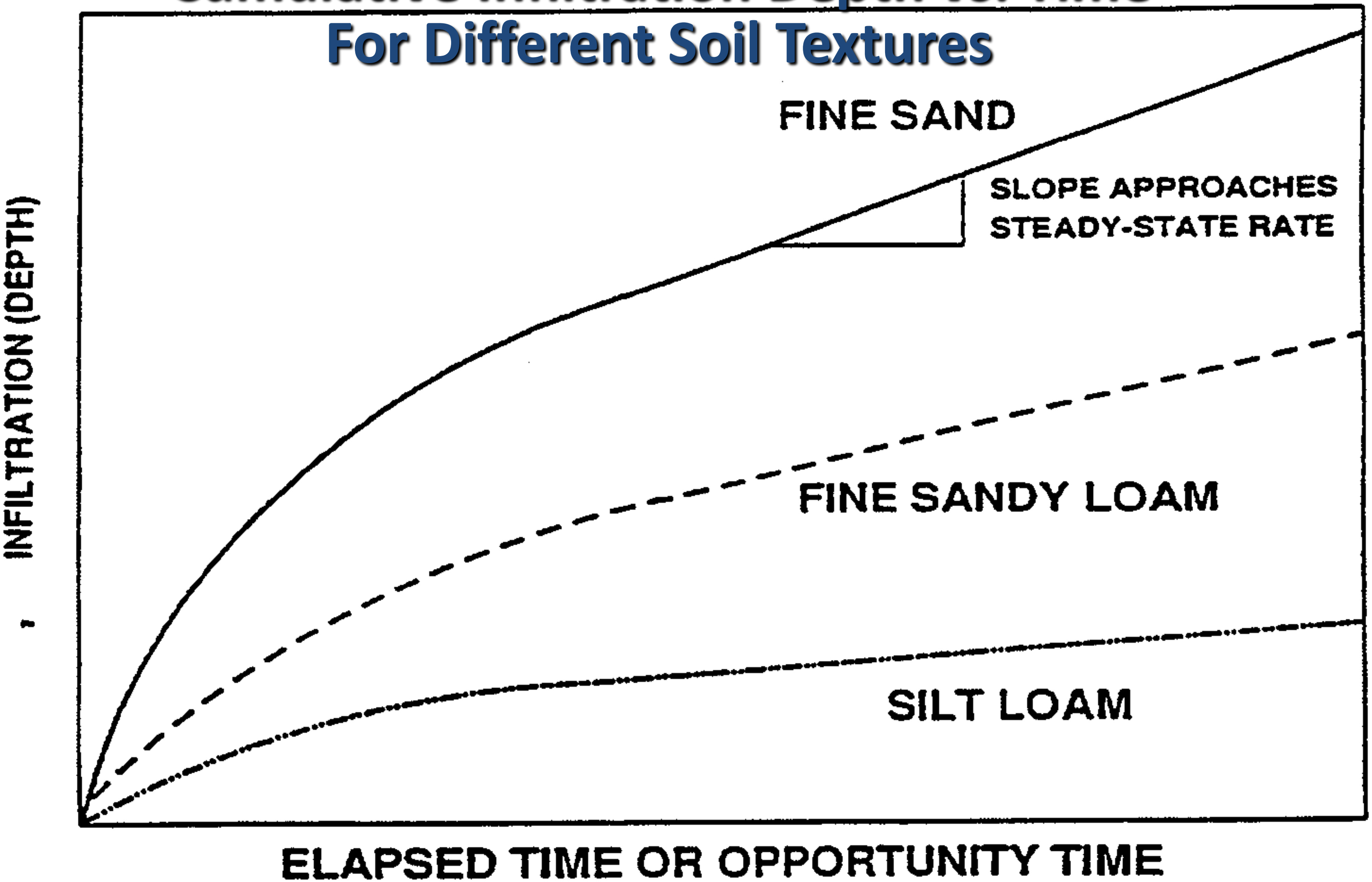


Figure 2.9. Infiltration rate vs. opportunity time.

Movement of water in the soil

Cumulative Infiltration Depth vs. Time For Different Soil Textures



Movement of water in the soil

Factors affecting infiltration

- Soil texture
- Initial soil water content of the given soil
- Surface sealing (structure, etc.)
- Soil cracking
- Tillage practices
- Method of application (e.g., Basin vs. Furrow)
- Water temperature
- Soil compaction

Movement of water in the soil

Water flow in the soil:

- Soil water is dynamic and moves constantly in the soil medium
- Downward and lateral movement of water occurs during irrigation or rainfall
- Upward movement takes place when upper soil layers start drying up

Flow in saturated soil

- Water is not under tension
- Water flow follows Darcy's law which states that the velocity of water flow is directly proportional to the difference of hydraulic heads and inversely proportional to the flow length

Movement of water in the soil

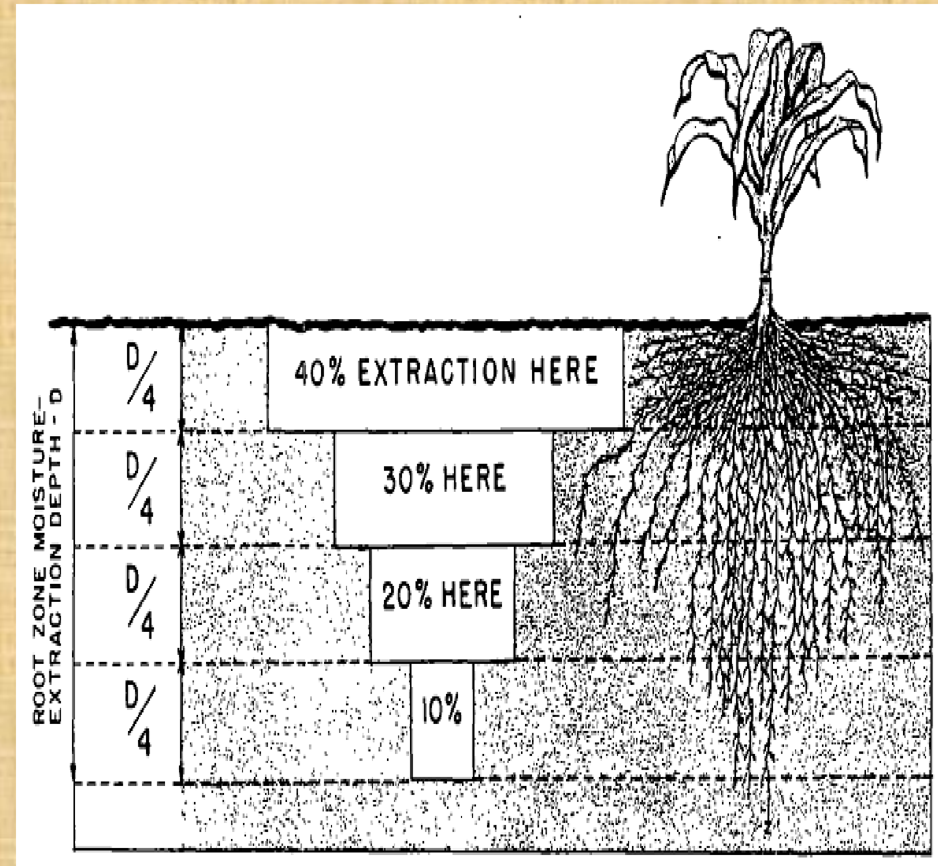
Flow in unsaturated soil

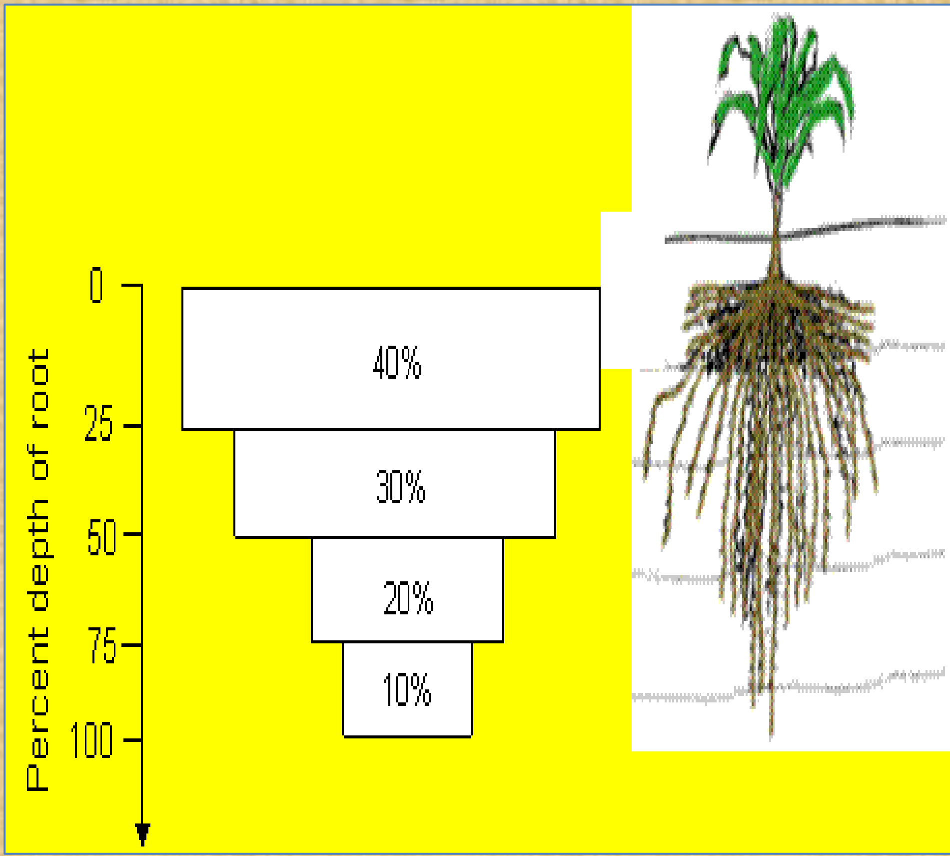
- Only the pores which contain water can contribute to the flow of water →the hydraulic conductivity of unsaturated soils is smaller than that of saturated soils

Water extraction & moisture stress of plants

- Plants have normally a higher concentration of roots in the upper part of the root zone
- About 40% of the water need is met from the first 25% of the root zone
- As the available water from upper layers decreases, plants extract more water from lower depths

- A greater portion of roots of most plants remains within 45 to 60 cm surface soil layers





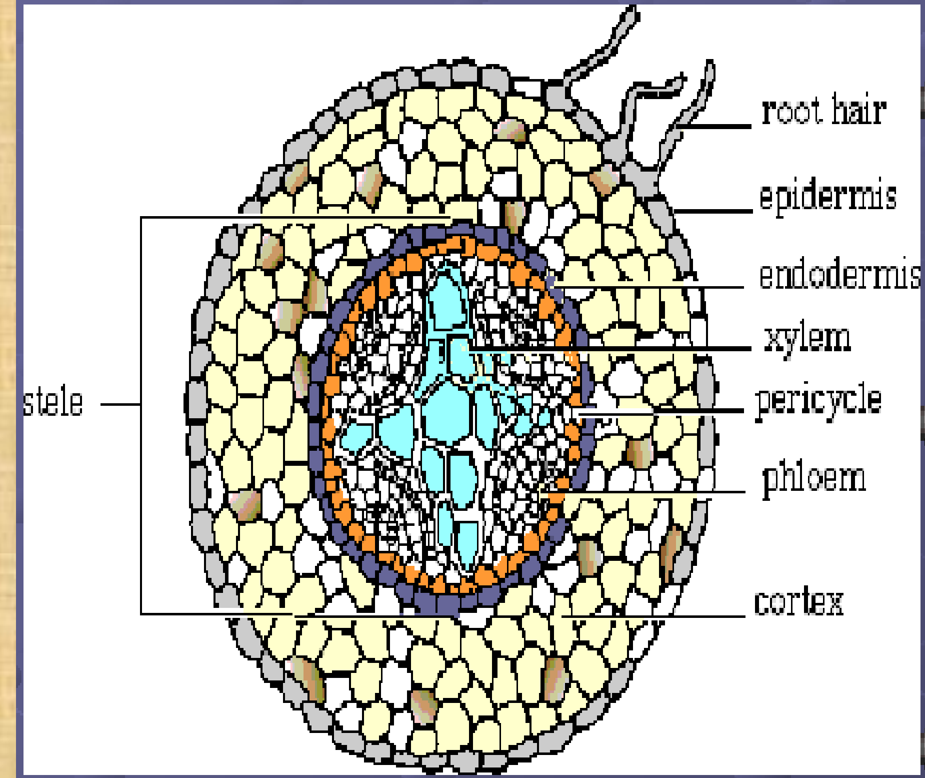
Moisture extraction

A Pathway of water in soil-plant-atmosphere system

- Soil →root (epidermal cell) → conductive system of xylem →leaf cells (intercellular space in the leaf)→ stomata cavities → air layer in the immediate vicinity of the leaf

Moisture stress of plants

- When there is moisture stress in the root zone, the plant will reduce the amount of water lost through transpiration by partial or total stomata closure.
- Closure of stomata decreased photosynthesis since the CO_2 required for this process enters the plant through the stomata.
- Decreased photosynthesis reduces biomass production and results in decreased yields.



- Epidermis, when young they develop root hairs
- Water and nutrients absorbed by root pass through this layer
- In the absorption process, water travels from the soil medium into epidermal cells.
- It then moves from cell to cell through cell walls and through intercellular spaces to xylem.
- the xylem system constitutes the conducting system of water from roots to leaves