3. Soil Physical Properties

ENVS 334: Applied Soil Science & Land Management

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Soil Texture

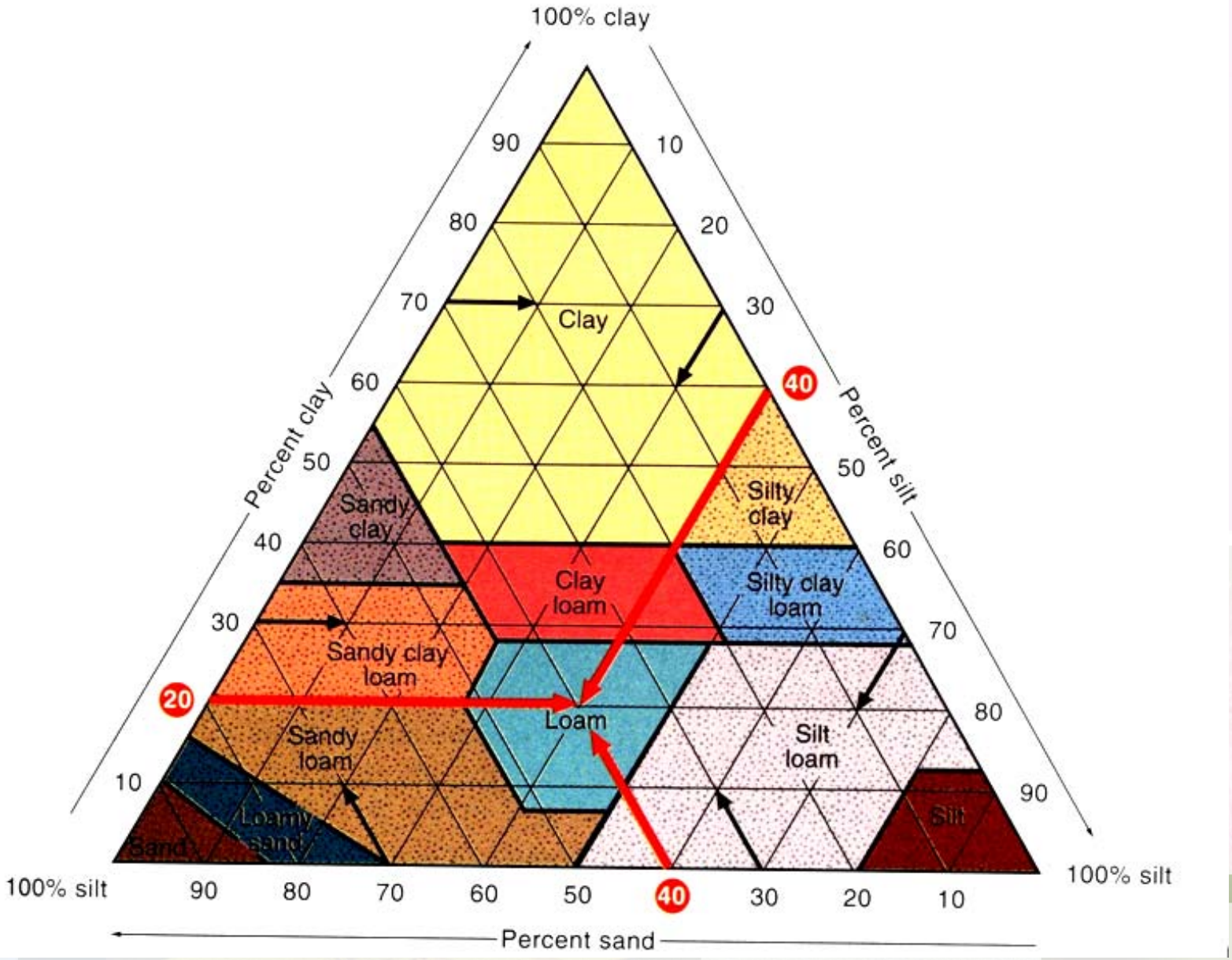
- **Texture is the distribution of different size-fractions of particles.**
- **Particle size distribution: determined by mechanical analysis (ie. Dispersion and settling in water)**
- **Three textural separates are distinguished based on size range: sand, silt and clay**
- **Clays are very small particles (<2 microns) and are colloidal in nature, ie., remain suspended in solution**
  - **Due to size and shape (generally flat, irregular) they have high surface areas, charged surfaces, and are highly reactive**
  - **Unique mineralogy and organisation leading to unique properties, such as, shrink/swell potential, cation exchange capacity, ion fixing ability, and complexation with organic molecules**

Textural Classification (USDA & ISSS)

System	Clay	Silt	Sand					Gravel
			VF	Fine	Med.	Coarse	VCo.	
USDA	<0.002	0.002 - 0.05	0.05	0.10	0.25	0.05	1.00	2.00	>2.0
				Fine Sand			Coarse Sand	
ISSS	<0.002	0.002--0.02	0.02 ---------- 0.20 ---------- 2.0					>2.0

Common name	Texture	Textural classes
Sandy soils	Coarse	Sand; Loamy sands
Loamy soils	Moderately coarse	Sandy loam; Fine SL
	Medium	VFSL; Loam; Silt loam; Silt
	Moderately fine	Clay loam; Sandy clay loam; Silty clay loam (SiCL)
Clayey soils	Fine	Sandy clay; Silty clay; Clay

The USDA Textural Triangle



Soil Density

- **Soil particle density – density of the solid particles of the soil (sand, silt, clay & OM)**
  - **Excluding density of the water or air-filled pores**
  - **Soils tend to be predominated by quartz (sand/silt)**
  - **Quartz and other minerals have a density in the range of 2.7 to 3 g/cc, hence most soils have particle densities in the range of 2.5 to 2.7 g/cc**
  - **Can be determined by water displacement method**
- **Soil Bulk density – soil weight (mass of dry soil) divided by the total volume**
  - **Bulk density includes the volume of pore spaces**
  - **generally range from 1 to 2 g/cc for mineral soils**
  - **depends on structure, porosity, OM content, degree of compaction, etc.**
  - **May be determined by core or clod methods**

Soil Structure and Aggregation

- **Soil structure refers to the arrangement or organisation of the primary particles**
  - **it is a descriptive field term indicating shape and distinctness of aggregates**
  - **Plate-like or flat; prism-like; block-like; spherical/round**
  - **Soil structure greatly influences porosity, water movement and aeration.**
- **Aggregates are groups or clusters of individual soil particles (sand, silt and clay) in intimate association forming a cohesive unit into which the soil readily breaks down when gently crushed in the hands**
  - **forces arising from wetting/drying, freezing/thawing, physical activity of roots/animals, root/micro-org. exudates, adsorbed cations, and tillage all influence aggregate formation**
  - **soil OM and clays play a prominent role in imparting stability to aggregates.**

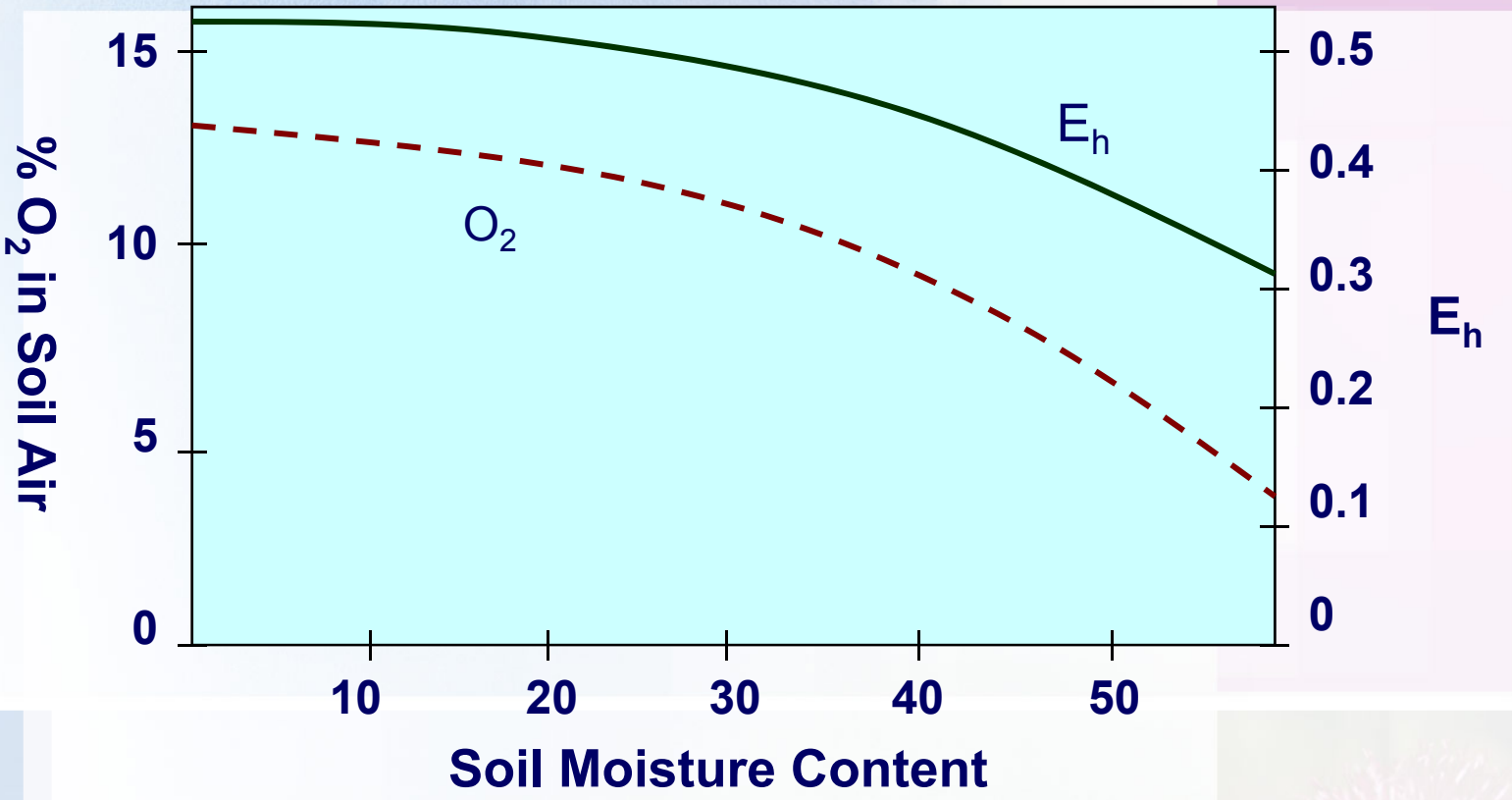
Soil Porosity

- **Pore-spaces in the soil – created by:**
  - Incomplete inter-locking of soil particles
  - Spaces between aggregates & structural units
  - Roots and soil animal channels (worms, insects)
- **Macropores – allow water to flow freely**
  - Dominant in coarse textured soils (sandy)
  - Also occurs in soil with good structure/aggregation
- **Micropores – retain water against gravity**
  - Dominant in fine textured soil (clayey)
  - Also increases with destruction of structure
- **Good soils have a balance of both**
  - Mix of pore sizes assures retention of adequate water for plant growth, while allowing free drainage of excess water
- **Porosity is reduced (or shifted to micropores) by compaction, excessive tillage and puddling (paddy).**

Soil Aeration

- Soil air typically contains less O_2 and more CO_2 than the atmosphere; generally saturated with water vapour.
- Most soil organisms consume O_2 and evolve CO_2
- Air enters the soil by 2 main mechanisms:
  - Diffusion through soil surface (highly dependent on surface physical conditions)
  - Mass flow due to physical disturbances (water flow; tillage, etc.)
- O_2 concentrations & diffusion rate (ODR) affect plant root and shoot growth
  - Both O_2 conc. & ODR decrease with depth
- Oxid.-Reduction Potential (E_h) influenced by soil air
  - Direction of redox reactions (high E_h favours oxidation)
  - Microbial action responsible for much of soil redox act.

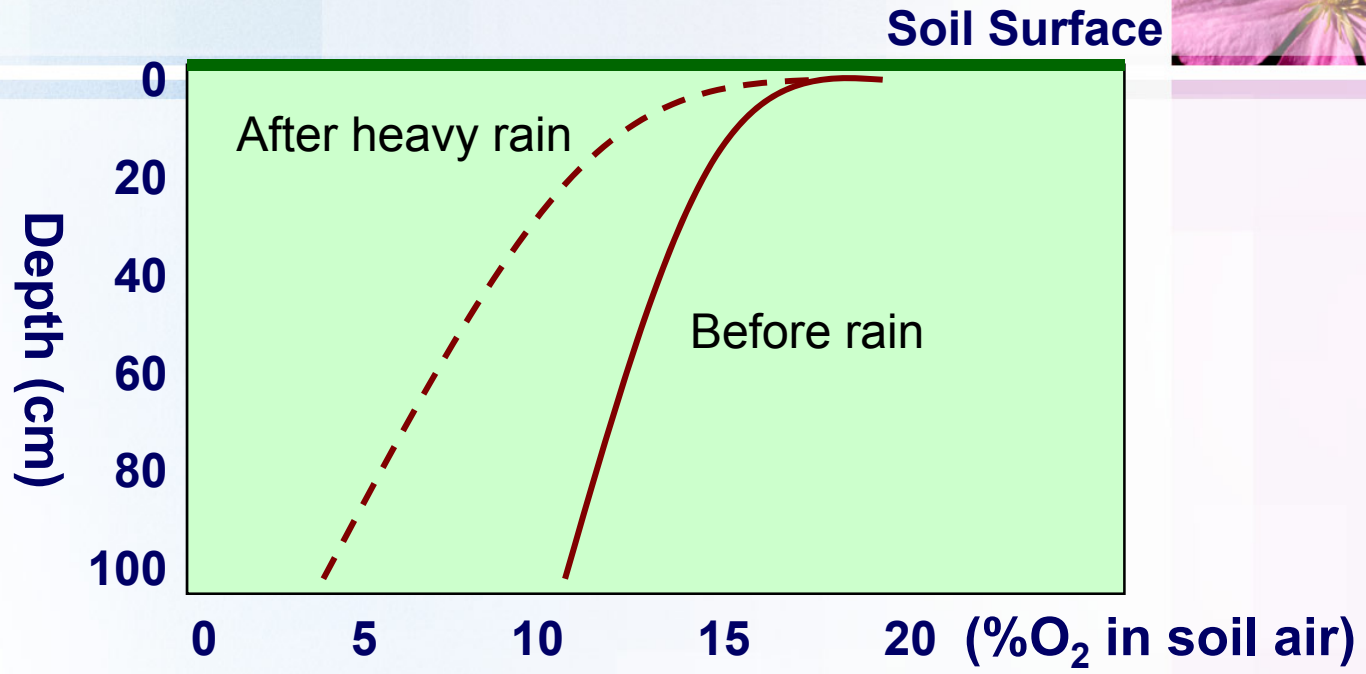
Soil air & moisture relationship

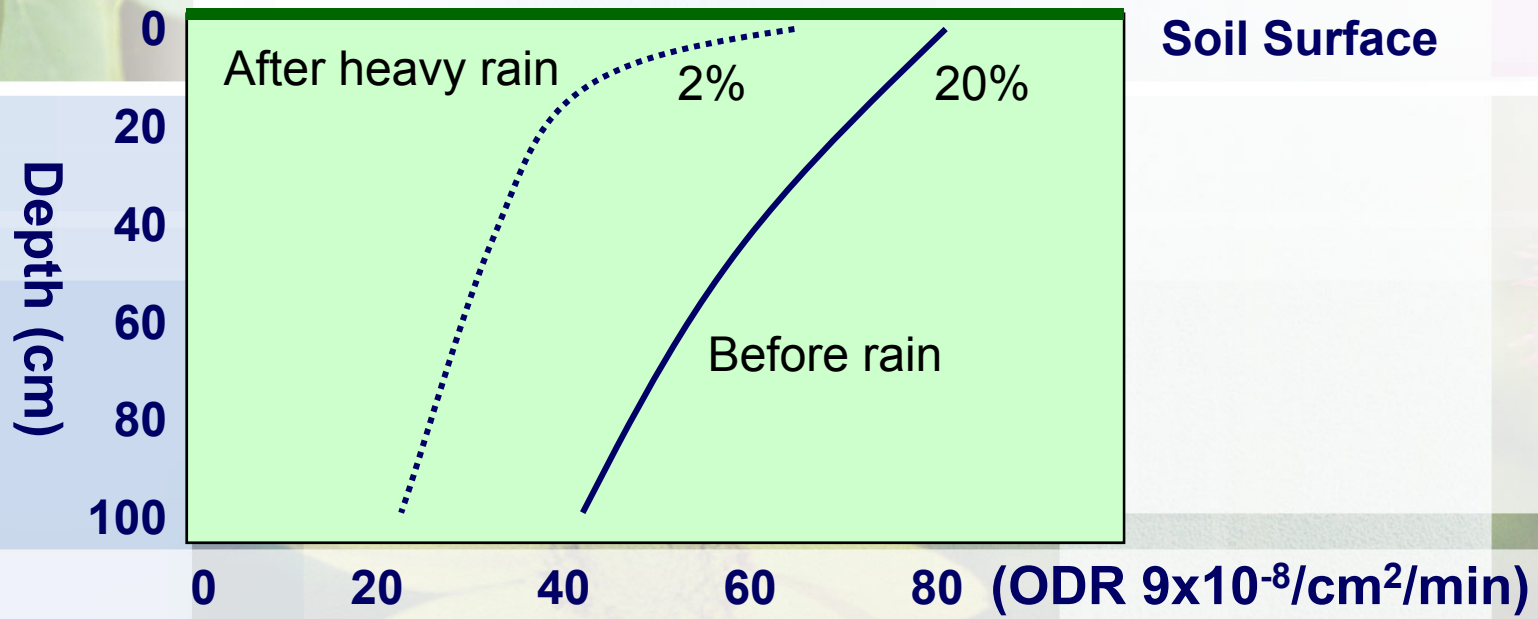


AEROBIC: $C_6H_{12}O_6 + 6O_2$ ---- $6H_2O + 6CO_2$ (g)

ANEROBIC: $C_6H_{12}O_6 + 6O_2$ ---- $6CO_2 + 3CH_4$ (g)

Oxygen concentration & diffusion rate

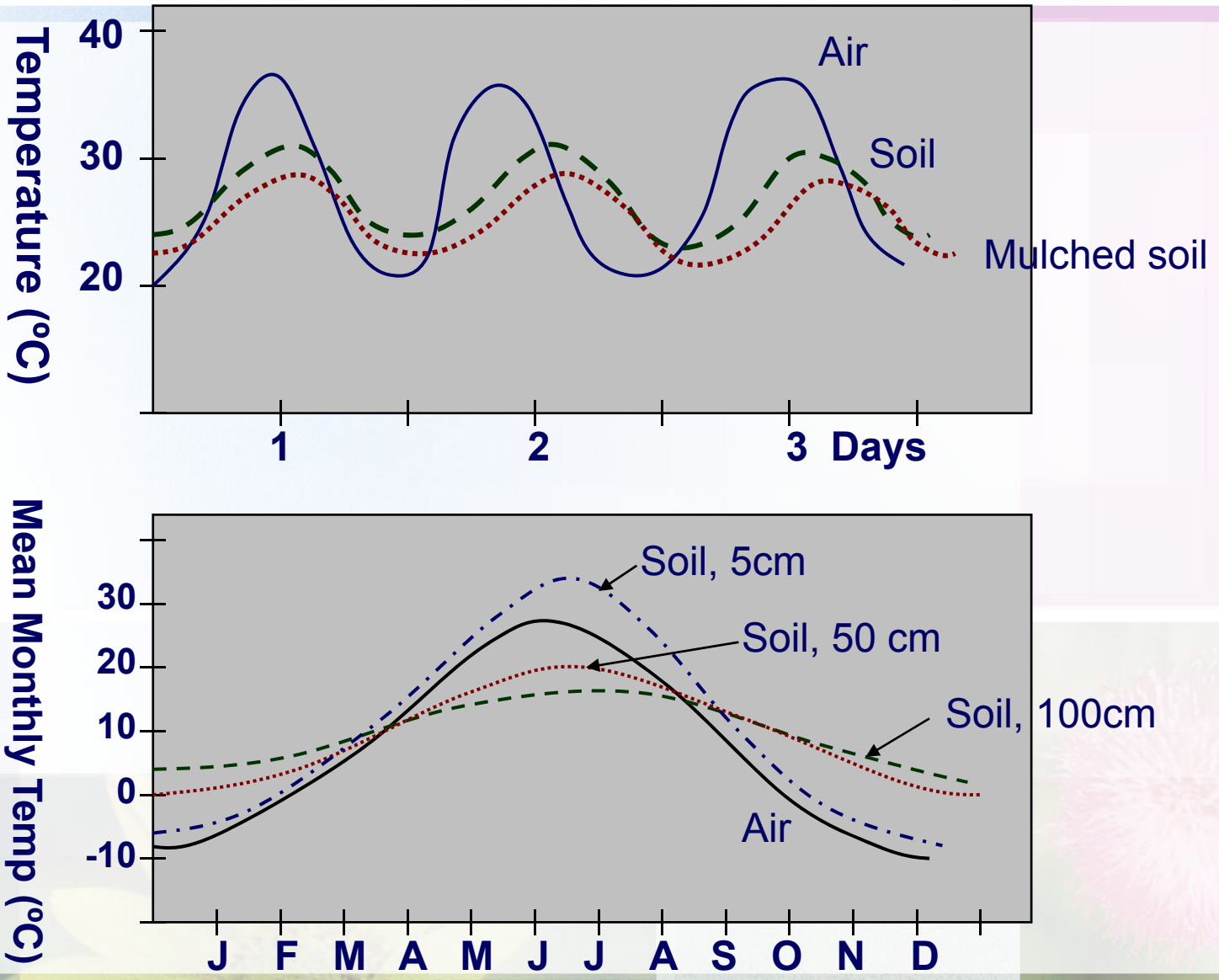




Soil Temperature

- Main source of heat in soil – solar radiation
- Also can be heated or cooled by rain
- Rate of absorption of SR depends on soil colour, wetness, slope aspect and cover.
- Rate of cooling depends on sky (clouds), air temp., cover and soil wetness.
- Soil temp. follows diurnal & seasonal cycles:
  - Warms during day; cools at night
  - Warms in spring/summer; cools in winter/autumn
  - Soil heats/cools from the top down; hence time lags in temperature occurs across the profile
- Soil temp. may be modified by:
  - Drainage and mulching (type, colour)

Diurnal & Seasonal Soil Temp. Variation



4. Soil water and hydraulic characteristics

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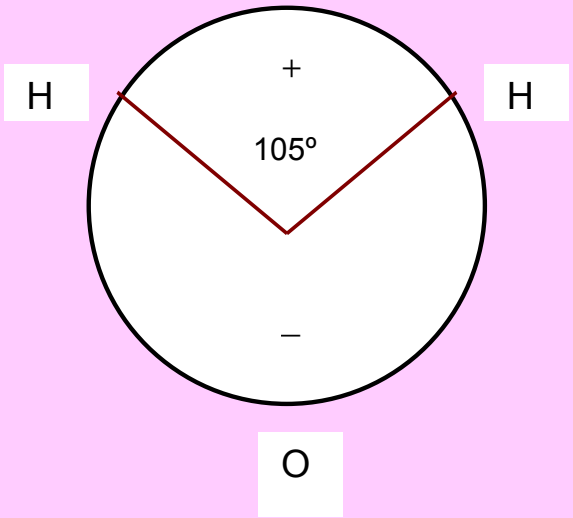
Importance of Soil Water

- **Water in soil is important from the point of view of:**
  - **Water requirements and availability for plant growth**
  - **Essential component of living cells**
  - **Provides support and cooling for plants**
  - **Soil solution, ie., water together with dissolved nutrients**
  - **Processes and reactions, both within and on the surface, of soils which depend or are moderated by water (plant uptake, evapo-transpiration, erosion, etc.), directly or indirectly**
- **Water expands when it freezes**
- **Water exhibits H-bonding, surface tension, capillarity, etc.**

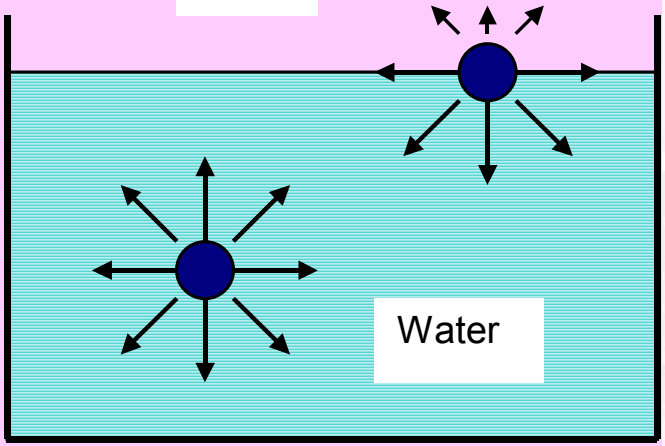
Water – a polar molecule

- **The structure of the water molecule [asymmetrical arrangement of H atoms about the O; 105° angle] leads to** polarity **(oppositely charged ends), which in turn accounts for many other properties of water:**
  - **Behaviour of water molecules (attraction of opposite ends) leads to polymer-like grouping; disintegrates as temperature increases (vapour)**
  - **Hydration of cations due to attraction to the –ve end (O); or clays (attraction to the +ve end, ie., H); lower** free energy **state when water molecules are electrostatically attracted to charged ions or surfaces; therefore, energy is released: *heat of solution, heat of wetting***
  - ***H-bonding*: attraction of H atoms causing linkage of molecules; accounts for lattice structure, high boiling pt., specific heat and viscosity**
  - **Capillarity: water rises above normal surface of repose in very small tubes**

- **Cohesion/Adhesion arising from H-bonding:**
  - **Cohesion: attraction of water molecules for each other**
  - **Adhesion: attraction of water molecules for solid surfaces**
- **Surface tension: due to greater attraction of water molecules to each other than to the air at air—liquid interface; causes capillarity**
- **These characteristics of water influence the retention, movement and plant-uptake of water in soils**



Water molecule structure

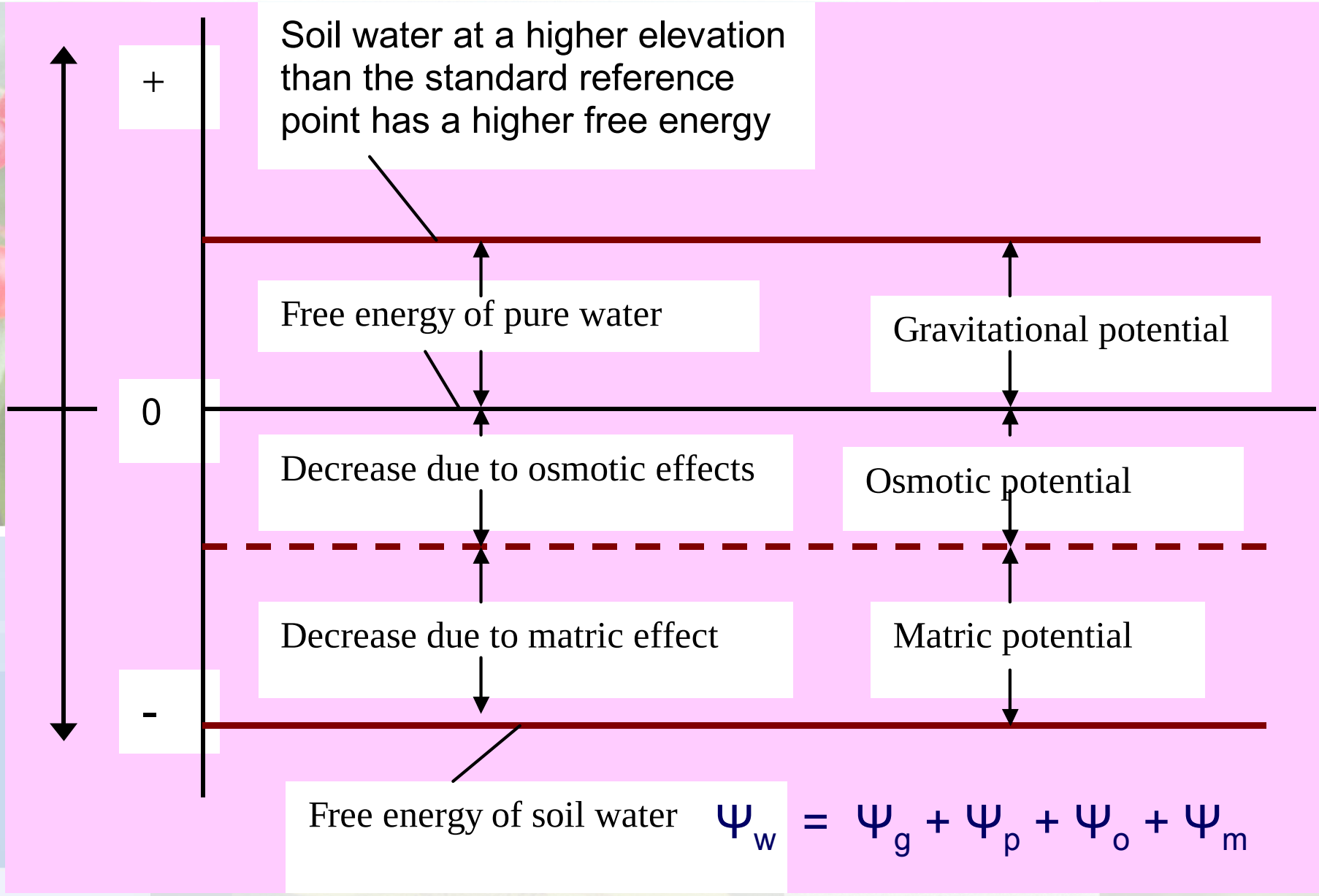


Surface tension

Concept of Free Energy - Thermodynamics

- **"Free energy" – expresses quantity of energy available to do work**
  - **Measured relative to some other energy state**
  - **Indicates spontaneity of processes: i.e., spontaneous processes lead to reduced free energy**
  - **Leads to work done or heat evolved**
- **Soil water tends to change state to that of lower free energy.**
- **Four sources of soil water potential:**
  - **Gravitational: height of water above ref. (+ve)**
  - **Matric: attraction of water to soil solids (-ve)**
  - **Osmotic: due to conc. of dissolved solutes (-ve)**
  - **Pressure: application of external pressure (+ve)**
- **Soil water potential expressed in bars or MPa**
  - **1 MPa = 10 bar (1 bar = 760 mm Hg)**
  - **Soil water potential usually <0 due to impurities**

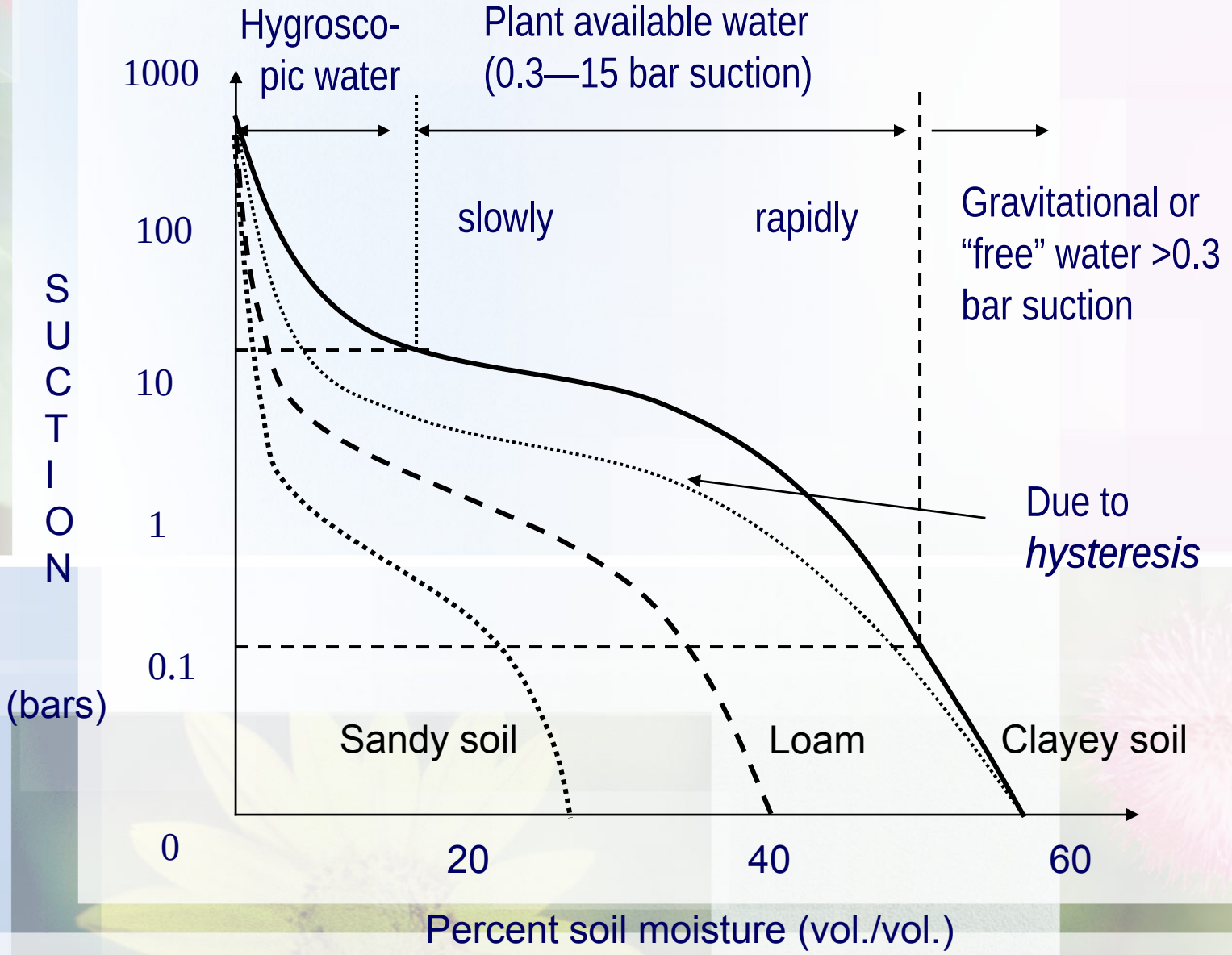
Soil water energy/potential



Soil Moisture Content

- **The water content of soils may be expressed:**
  - **On a weight basis (gravimetric): mass of water per unit mass of soil (g/kg) – θ_g**
  - **On a volume basis (volumetric): volume of water per unit volume of soil (cm^3/cm^3) – θ_v**
  - **Soil moisture tension: suction with which water is held in the soil; approximates soil water potential; indicates energy required to remove water from soil**
- **Classification of soil water:**
  - **Gravitational: drains by gravity, saturated to near sat. conditions; held at 0 to -0.03 MPa in soil**
  - **Capillary: important for water availability to plants; does not drain under influence of gravity; move by matric & osmotic forces (-0.03 to -1.5 MPa)**
  - **Hygroscopic: bound to solid surfaces; exist at tensions greater than -3.1 MPa**

Soil moisture characteristic curve & available water



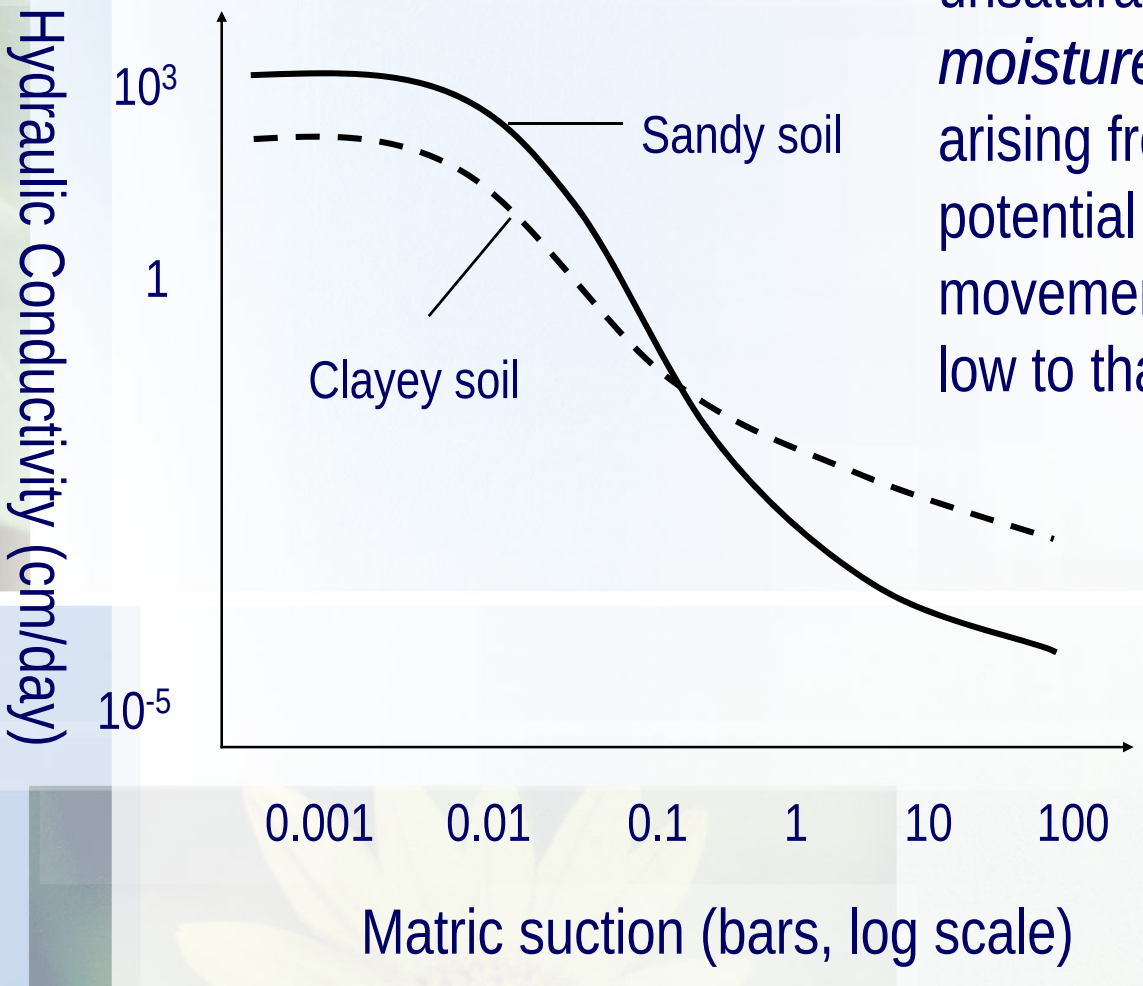
Water movement in soils

- **Water movement in soils may be of three kinds:**
  - **Saturated flow (pores completely filled with water)**
  - **Unsaturated flow (pores only partially filled)**
  - **Vapour flow (gaseous form)**
- **Under saturated conditions, volume flow of water, $V \propto kf$ where k is the saturated hydraulic conductivity, and f is the hydraulic gradient; this is Darcy's Law:**
  - **Discarge, $Q = A\ k\ \Delta\Psi / \Delta x$, where**
    - **Q = volume of flow**
    - **A = cross-sectional area of flow**
    - **K = hydraulic conductivity**
    - **$\Delta\Psi / \Delta x$ = potential difference (gradient)**
- **In vertical flow, the driving force (hydraulic gradient) is the difference in height of water, which acts due to the force of gravity.**

Soil water movement, continued . . .

- **Water always moves from zones of higher to lower potential; potential difference is the (gradient) driving force for water movement.**
- **The water rate of flow depends on both the driving force and the hydraulic conductivity of the soil which depends upon:**
  - **Size and configuration of pores: flow in pores is proportional to th 4^{th} power of the radius, ie., flow through a 1mm radius pore = 10,000 X flow through a 0.1 mm radius pore.**
  - **Texture: sandy soils conduct water more rapidly than fine textured soils**
  - **Structure: stable granular structure favours rapid water flow**
  - **OM content: due to increased stablity and greater macropores**

Water flow through unsaturated soils



The driving force for unsaturated flow is the *moisture suction gradient* arising from the matric potential of the soil; movement is from a zone of low to that of high suction.

The forces responsible for matric suction are attraction of soil solids for water and capillarity.

Water Infiltration and plant uptake

- **Infiltration is the movement of water into soil through the surface.**
  - **Affected by surface and subsurface structure/conds.**
  - **It is a saturated flow with strong matric components in case of initially dry soil.**
  - **Well aggregated or sandy/loose soils have high infil.**
  - **Soil surface seal or crust formation reduced infil. rates.**
- **Water absorption by plants depends on:**
  - **Root system type and size**
  - **Hydraulic conductivity of soil (water flow rate)**
  - **Soil moisture content**
  - **Potential difference between root and rhizosphere**
    - **Soil moisture content**
    - **Osmotic potential**
    - **Plant type/species**

Infiltration (double-ring method)