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Soil Water Plant Relationship

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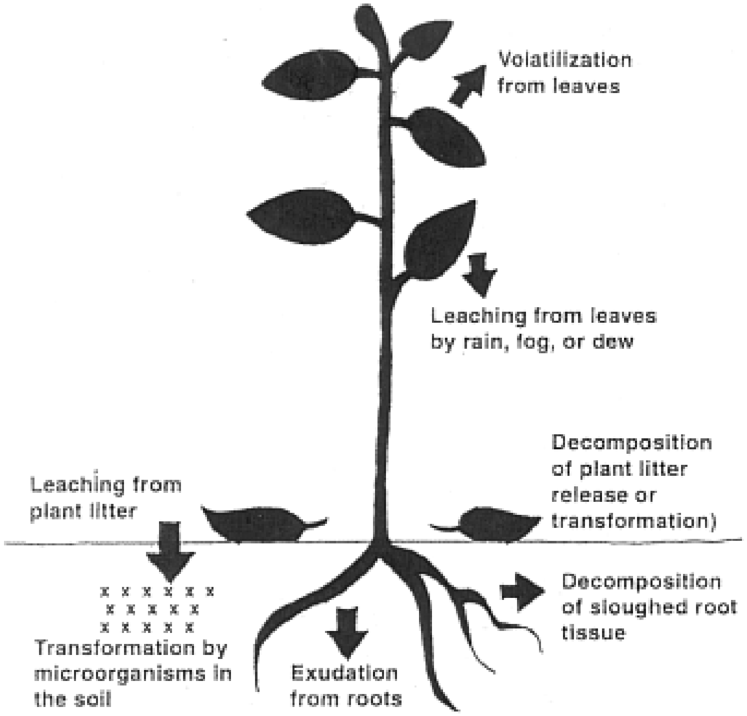
Science for Better Livelihoods in Dry Areas

Soil Water Plant Relationship

The role of soil from the view of a plant…

Source of water
Source of nutrients
Anchorage



Environmental routes of entry [*Chick, Kielbaso*].

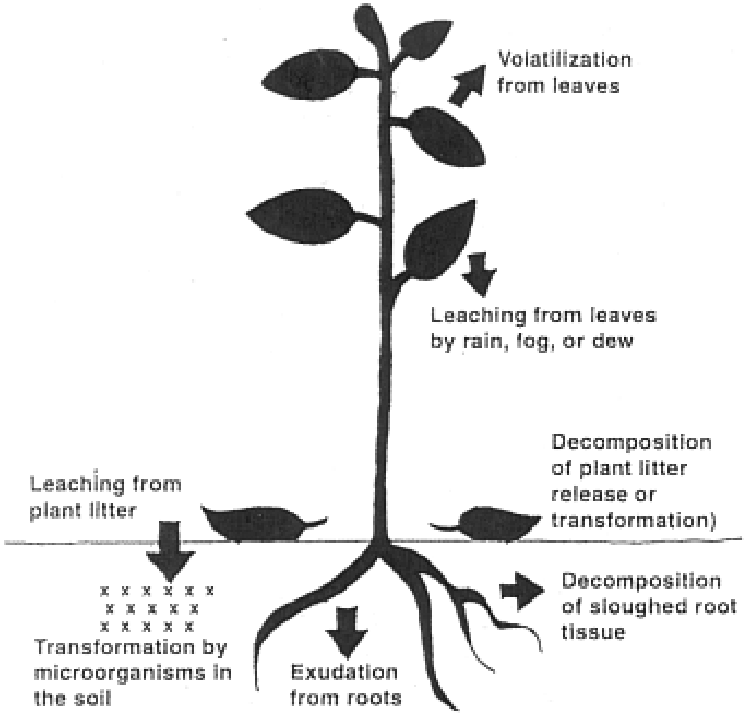
Soil Water Plant Relationship

The role of soil from the view of a plant…

Source of water

Source of nutrients

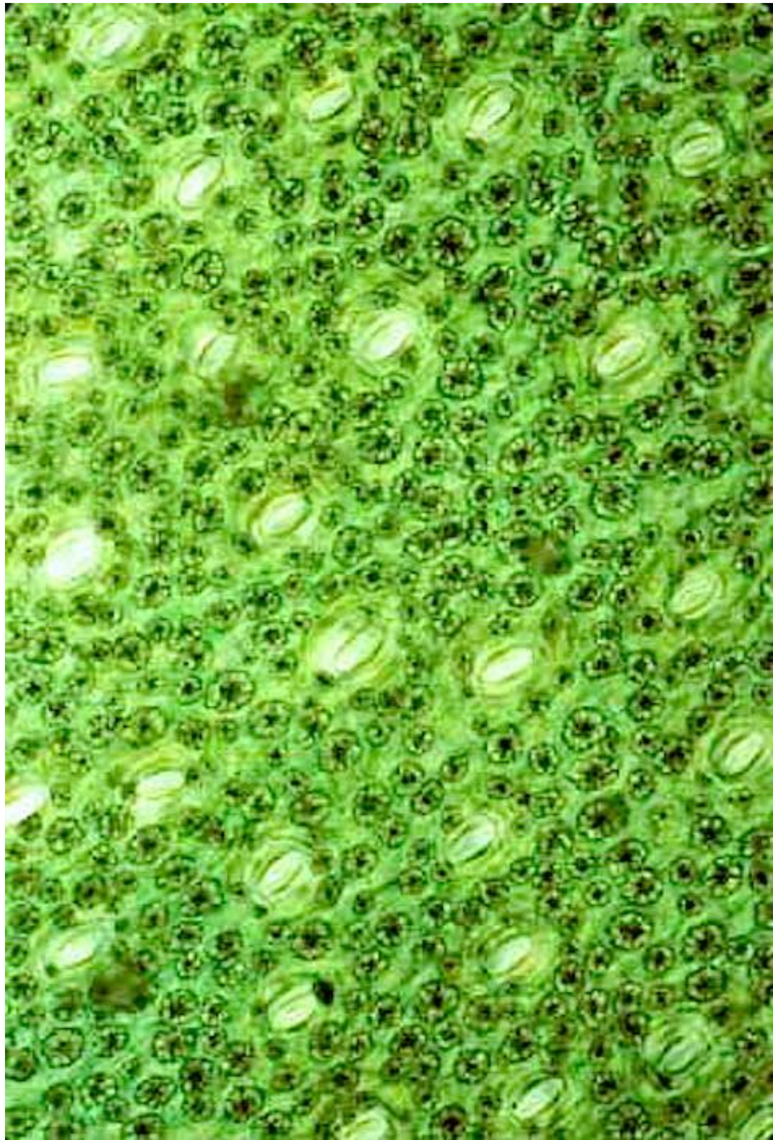
Anchorage



Environmental routes of entry [*Chick, Kielbaso*].

Soil Water Plant Relationship – The Plant Water Dilemma

Plant growth - > photosythesis needs energy, water and carbon….



- Atmospheric environment provides CO_2 and light, but it is dry (atmospheric water potential can reach -100 MPa)

Water potential in gas phase

$$\emptyset = \frac{RT}{\bar{V}} ln \frac{pH2O}{p, sH2O}$$

- Biochemistry requires a highly hydrated environment (> -3 MPa)

Soil Water Plant Relationship – The Plant Water Dilemma

How a plant leaf handles this…?

Soil Water Plant Relationship – The Plant Water Dilemma

How a plant leaf handles this…?

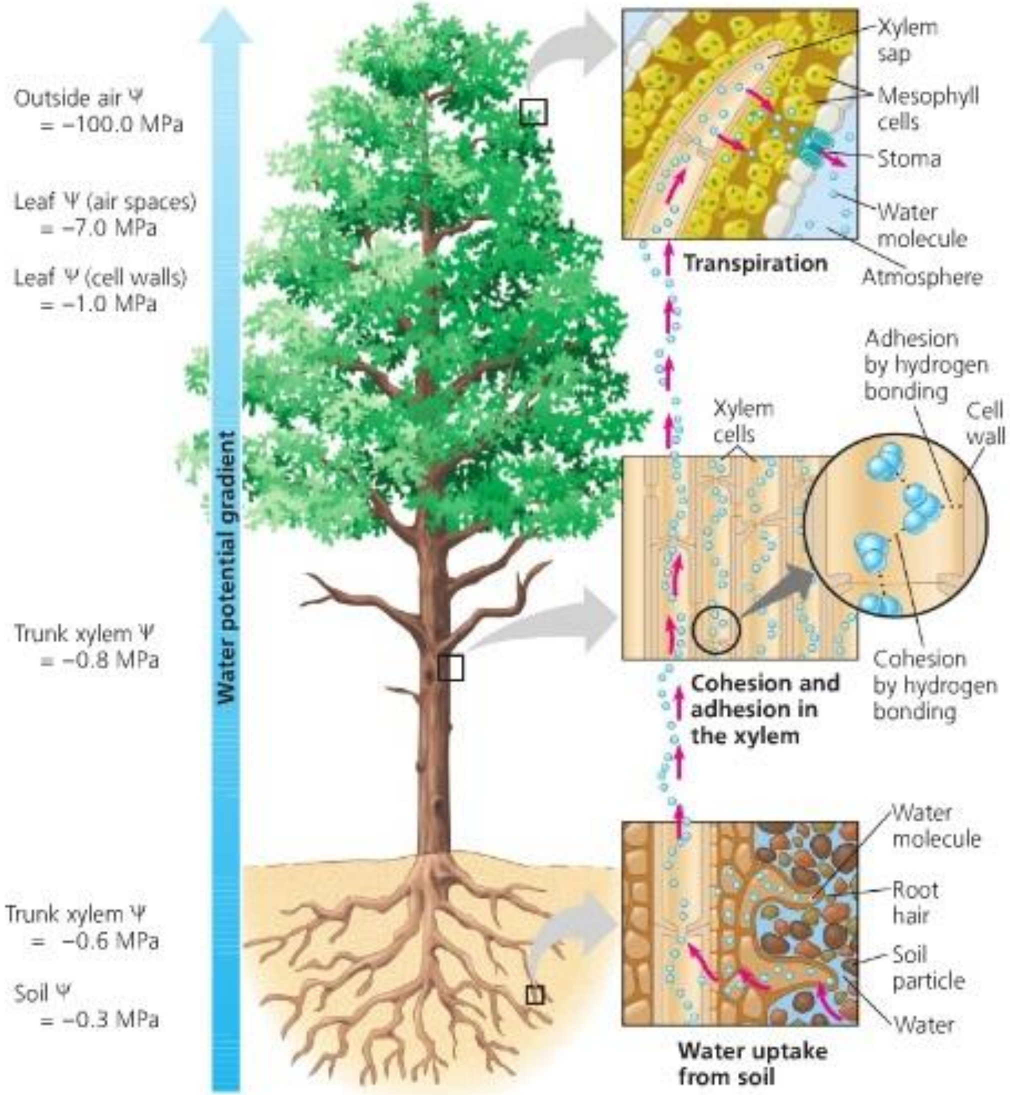
Taking the water from the soil!

Soil Water Plant Relationship – Large Scale

Boundary layer conductance to water vapor flow

Stomatal conductance to water vapor flow

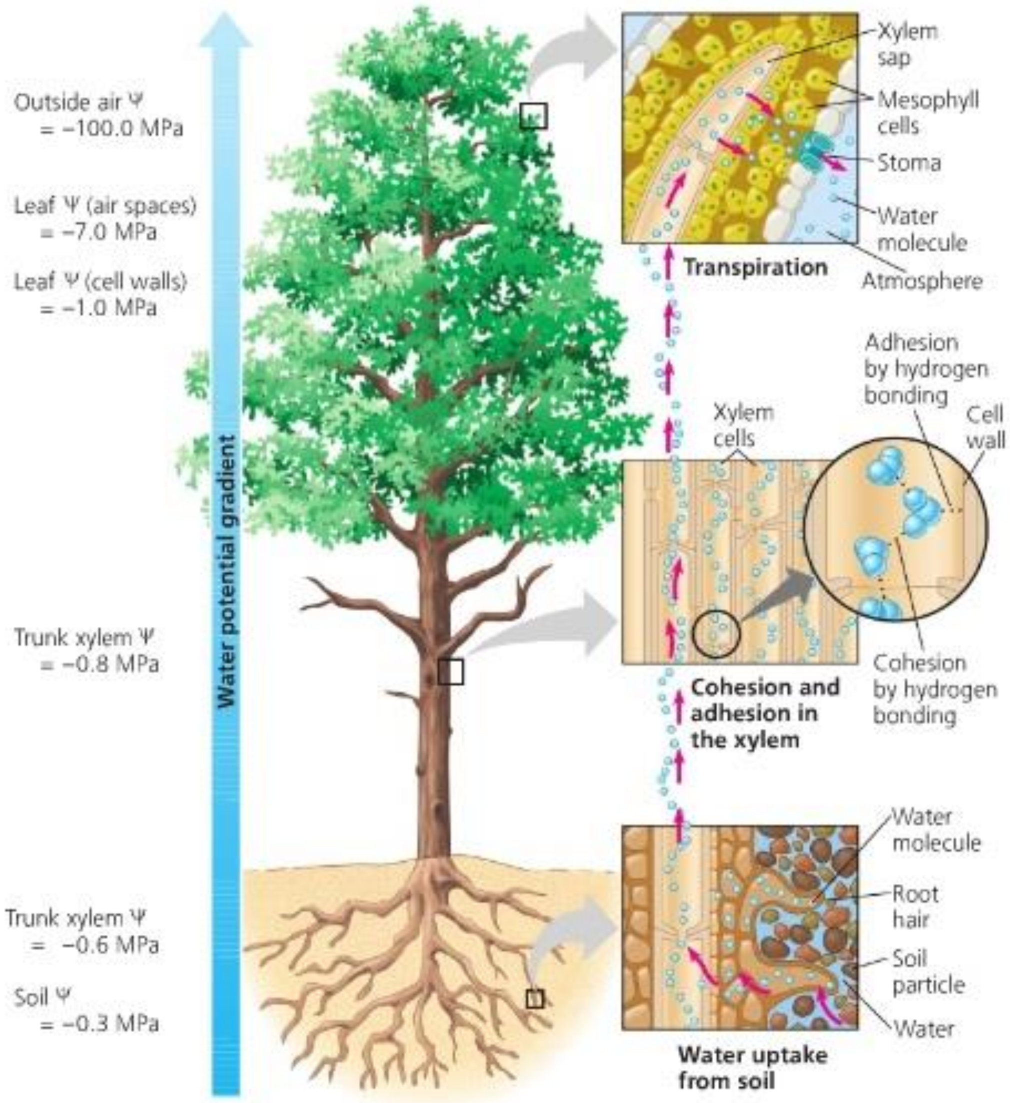
Water availability in the soil



Soil Water Plant Relationship – Large Scale

Low water potential

High water potential

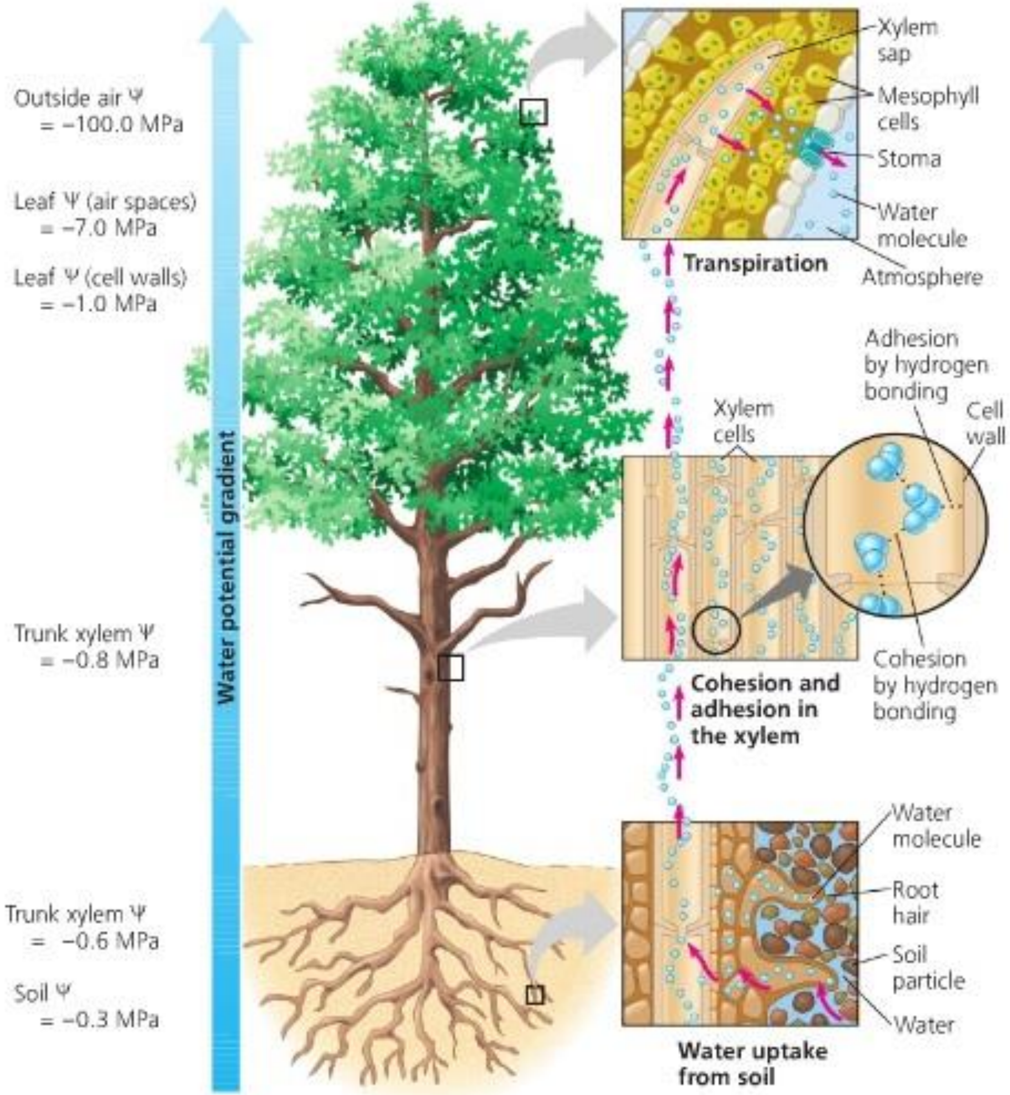


Soil Water Plant Relationship – Large Scale

Low water potential

Potential-gradient allows the water flow to the leafs!

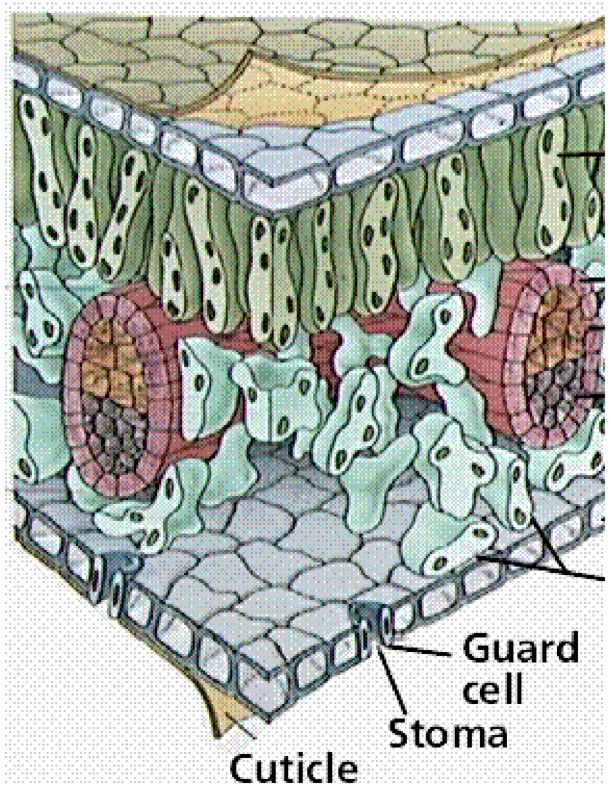
High water potential

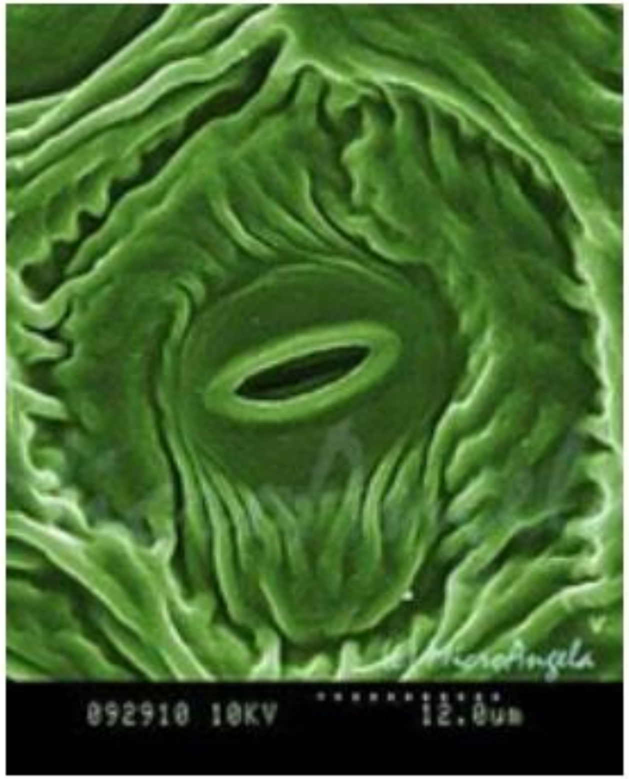


Soil Water Plant Relationship – Leafs

The water matric potential of a leaf Ψ_{leaf} outside of the cells (only matric potential) - is in equilibrium with the water inside the cell:

$$\Psi_{cell} = \Psi_{leaf}$$

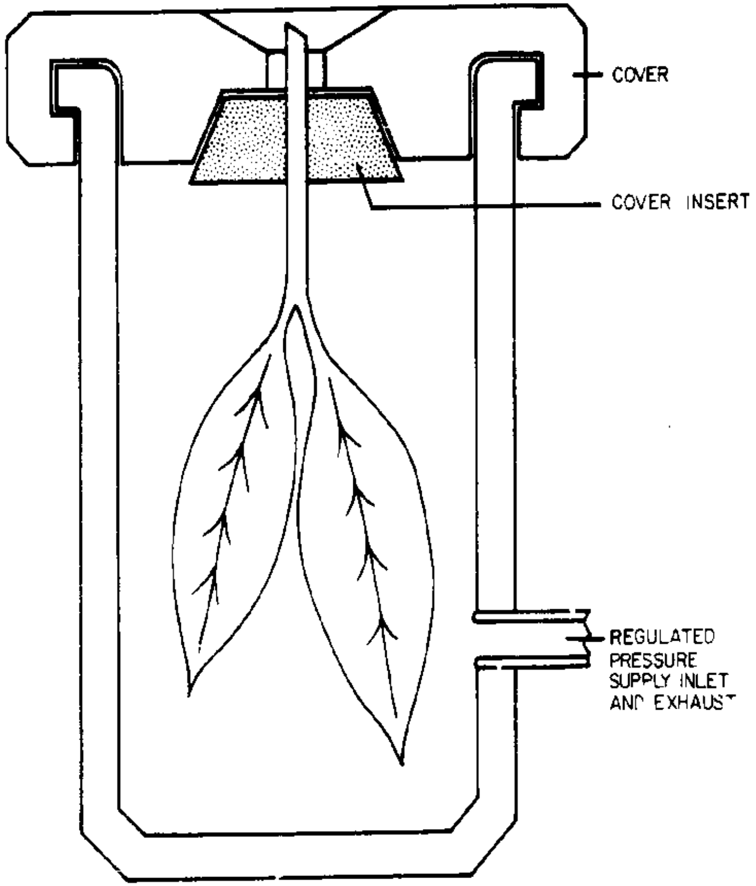




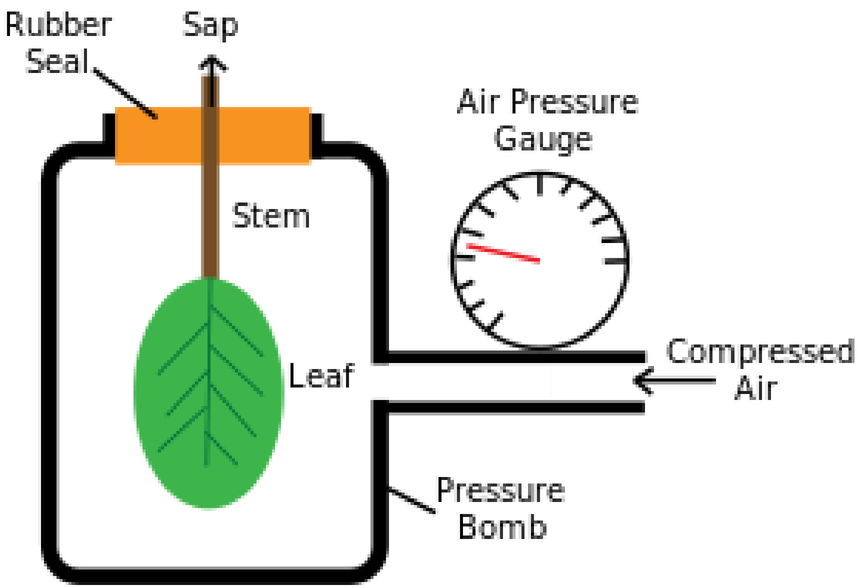
Soil Water Plant Relationship – Leafs

- Measure leaf water potential (ψ_{leaf})
- Equilibrate pressure inside a chamber with suction inside leaf

$$\Psi_{leaf} = \psi_{PressureChamber}$$



Soil Water Plant Relationship – Leafs



Soil Water Plant Relationship – Leafs Water Stress

Can be an indicator of water stress

- Maximize crop production
- Schedule deficit irrigation

Many annual plants will shed leaves rather than allow leaf water potential to change past a lower threshold

Most plants will regulate stomatal conductance before allowing leaf water potential to change below threshold

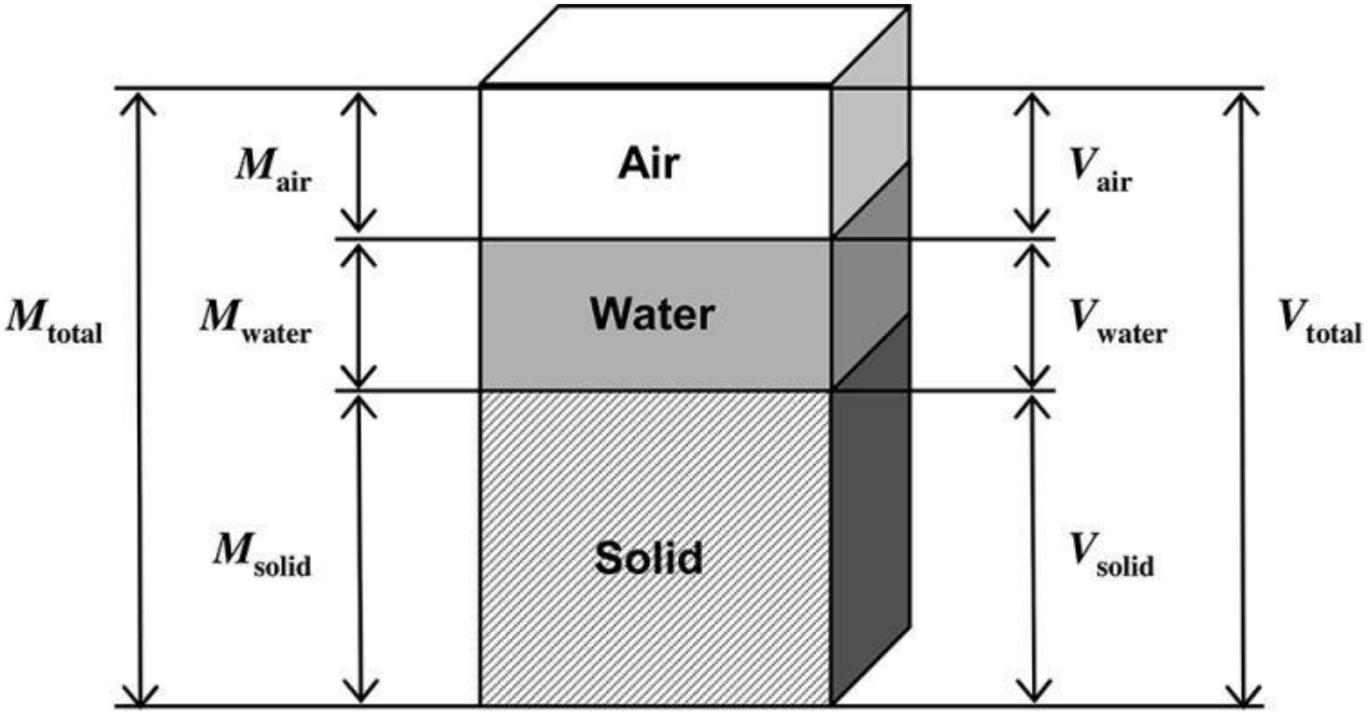
Soil Water Plant Relationship – Leafs Water Stress

Soil Water Relationship

Soil as a water source

Soil Water Plant Relationship
From a Soil Physical View

Soil physics deals with the dynamics of physical soil components and their phases as solid, liquids, and gases. Lal and Shukla (2004)



Soil Water Plant Relationship
From a Soil Physical View

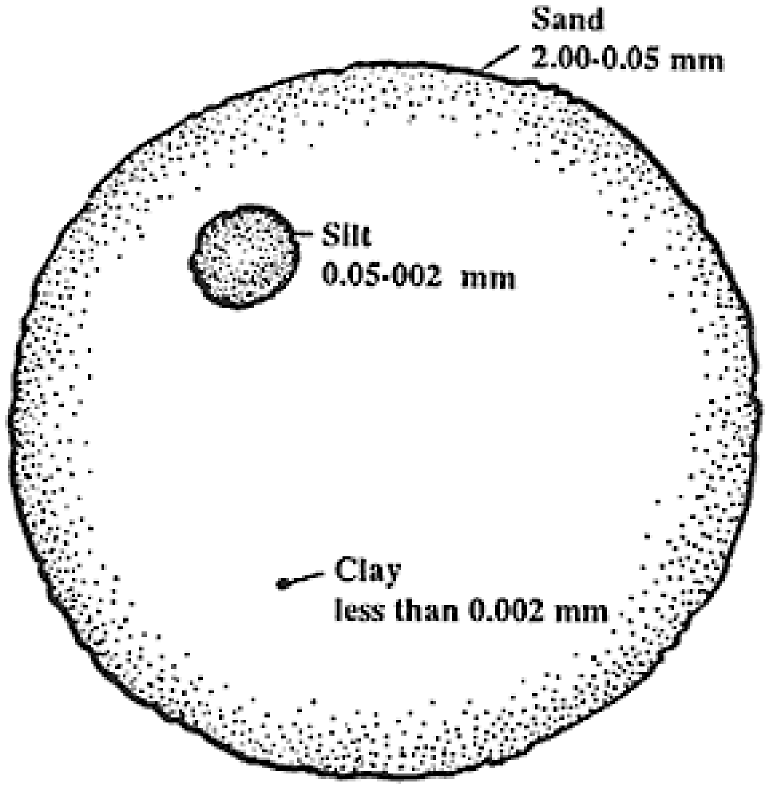
Soil physics deals with the dynamics of physical soil components and their phases as solid, liquids, and gases. Lal and Shukla (2004)

solid	Minerals, organic matter and chemical compounds
liquid	Water, dissolved minerals and soluted organic matter
gas	O_2, CO_2, N_2

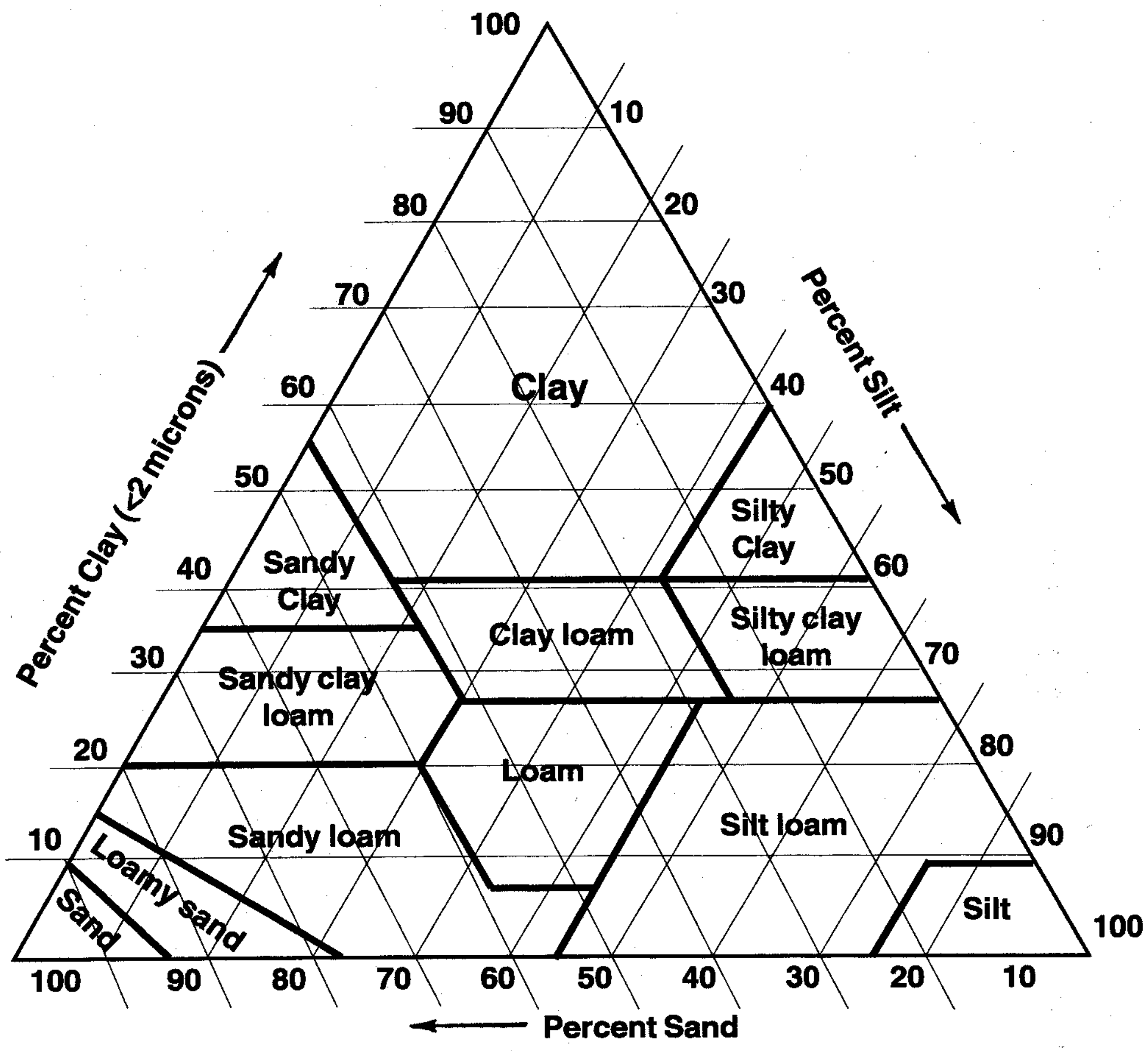
Soil Physical Properties

Texture
Relative proportions of various sizes of individual soil particles

<u>USDA classification</u>
Sand: 0.05 – 2.0 mm
Silt: 0.002 - 0.05 mm
Clay: <0.002 mm

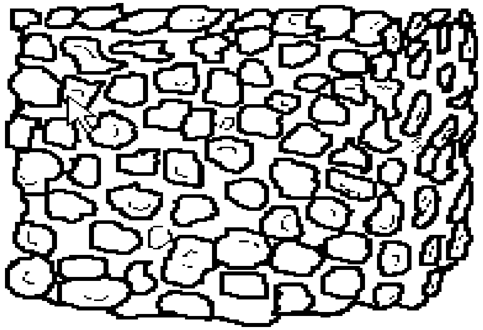
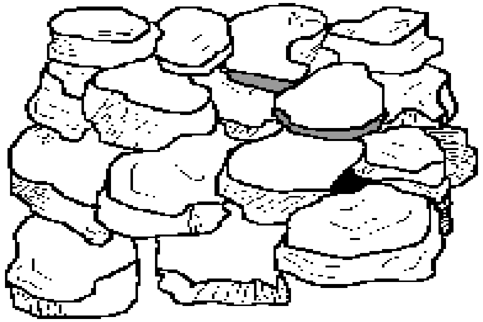
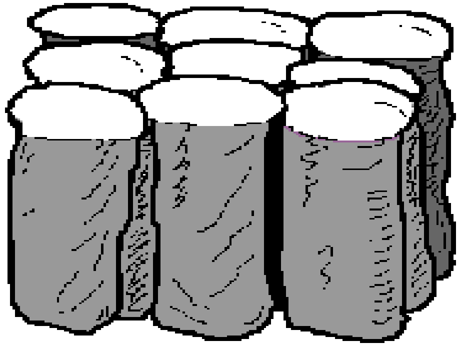
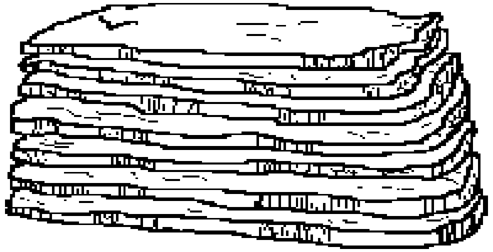
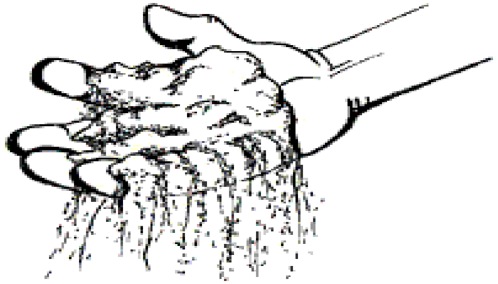


Soil Physical Properties



Soil Physical Properties

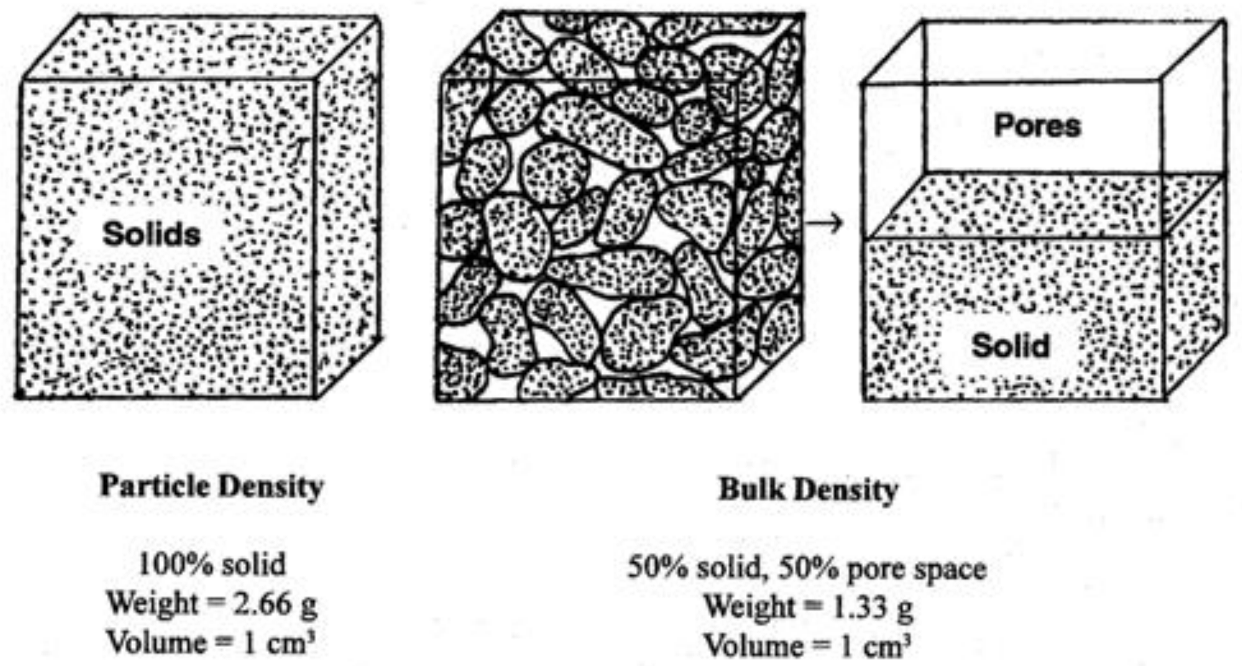
Structure

		
Granular: Resembles cookie crumbs and is usually less than 0.5 cm in diameter. Commonly found in surface horizons where roots have been growing.	**Blocky**: Irregular blocks that are usually 1.5 - 5.0 cm in diameter.	**Prismatic**: Vertical columns of soil that might be a number of cm long. Usually found in lower horizons.
		
Columnar: Vertical columns of soil that have a salt "cap" at the top. Found in soils of arid climates.	**Platy**: Thin, flat plates of soil that lie horizontally. Usually found in compacted soil.	**Single Grained**: Soil is broken into individual particles that do not stick together. Always accompanies a loose consistence. Commonly found in sandy soils.

Soil Physical Properties

Structure

Soil Physical Properties



Soil Physical Properties

Particle density
(g cm³)

$$\rho_b = \frac{M_s}{Vs}$$

Ms = mass of dry soil, g
Vb = volume of soil sample, cm^3
Vs = volume of solids, cm^3

Bulk density
(g cm³)

$$\rho_p = \frac{M_s}{V_b}$$

Porosity
(%)

$$\phi = \frac{\text{volume of pores}}{\text{volume of soil}}$$

$$\phi = \left(1 - \frac{\rho_b}{\rho_p}\right)100\%$$

Soil Physical Properties

Mass water content (%)

$$\theta_m = \frac{M_{sample} - M_s}{M_s}$$

Volumetric water content (%)

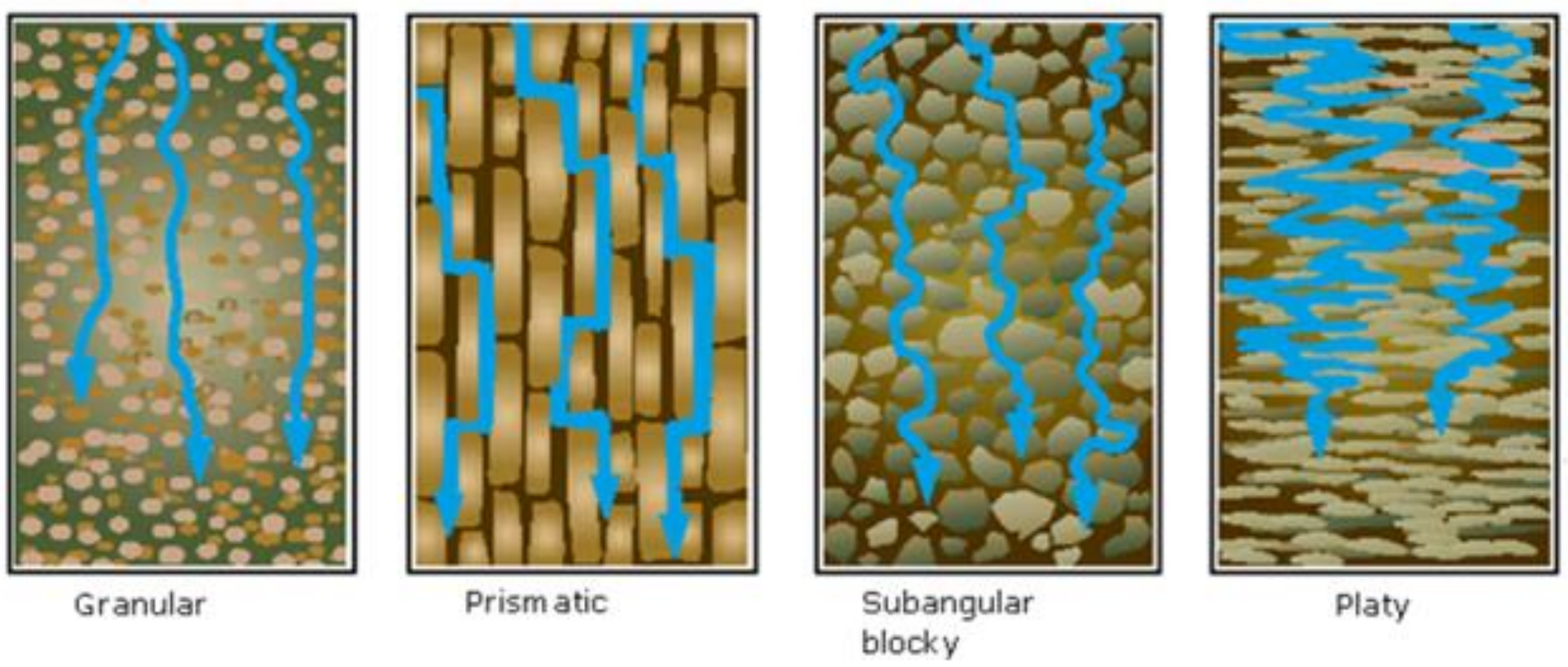
$$\theta_V = \frac{V_w}{V_{sample}}$$

Equivalent depth of water (cm)

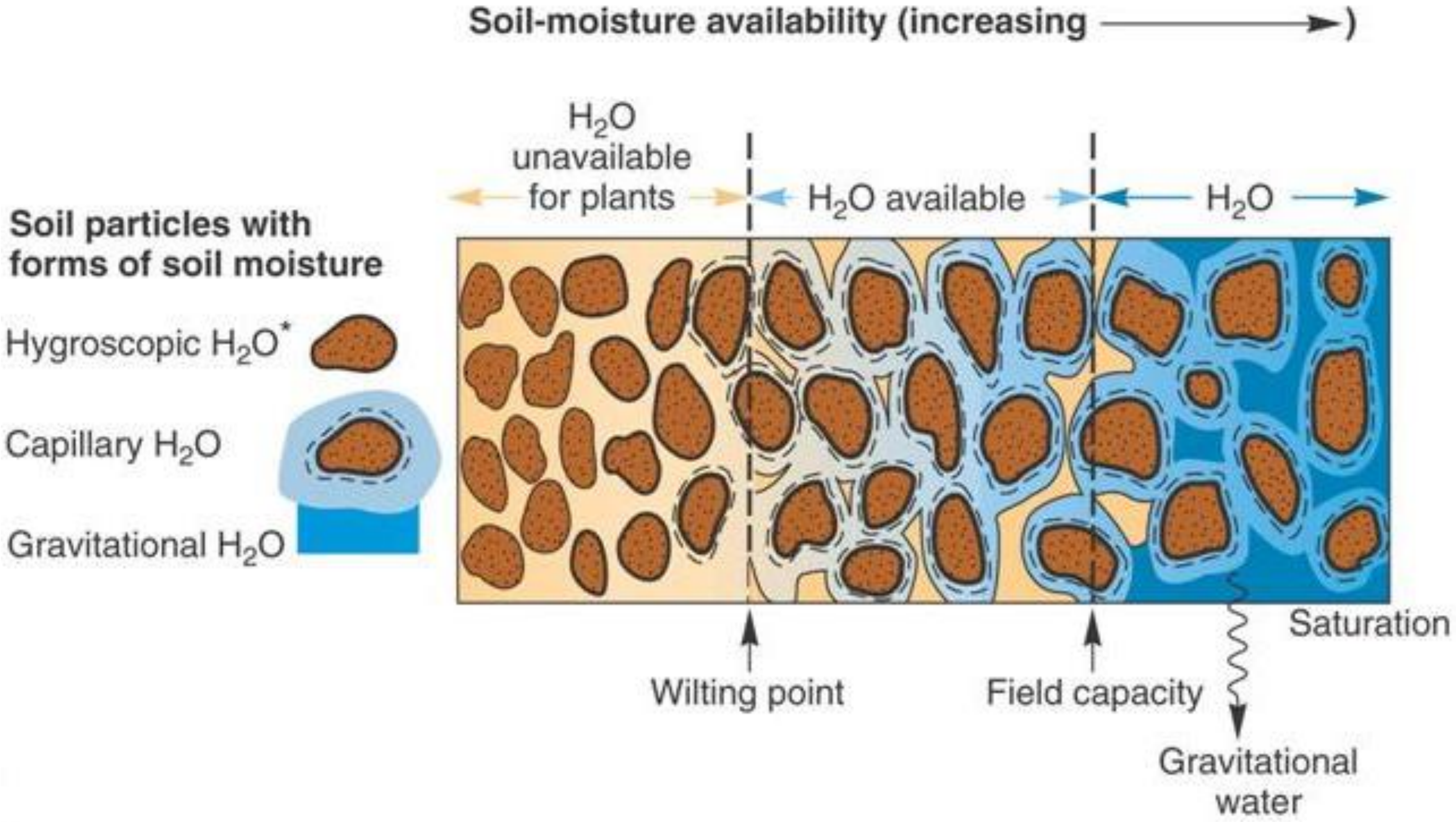
$$d = \frac{\theta_{\mathrm{m}}}{100} * \rho_{sample} * D$$

Msample = Total mass of soil, g
Ms = Mass of dry soil, g (≥24 hours @ 105oC)
Vw = Volume of water, cm^3
Vb = Volume of soil sample, cm^3
D = Depth (thickness) of the soil layer, cm

Water Movement in Soils



Water Movement in Soils



Soil Water Potential Theory

- Driving force for water flow in the soil-plant-atmosphere continuum due to difference in Water Potential
- Reflects the energy status of the soil water
- Reflects the required work-level of a plant to extract water
- Units of measure are normally bars (or cm)
- Soil water potentials are negative pressures (tension or suction)
- Water flows from a higher to a lower potential

Soil Water Potential Theory

$$\psi_t = \psi_m + \psi_p + \psi_g + \psi_o$$

ψ_t = Total soil water potential
ψ_m = Matric potential (capillary)
ψ_p = Pressure potential (elevation)
ψ_g = Gravity potential (elevation)
ψ_o = Osmatic potential

Soil Water Potential Theory

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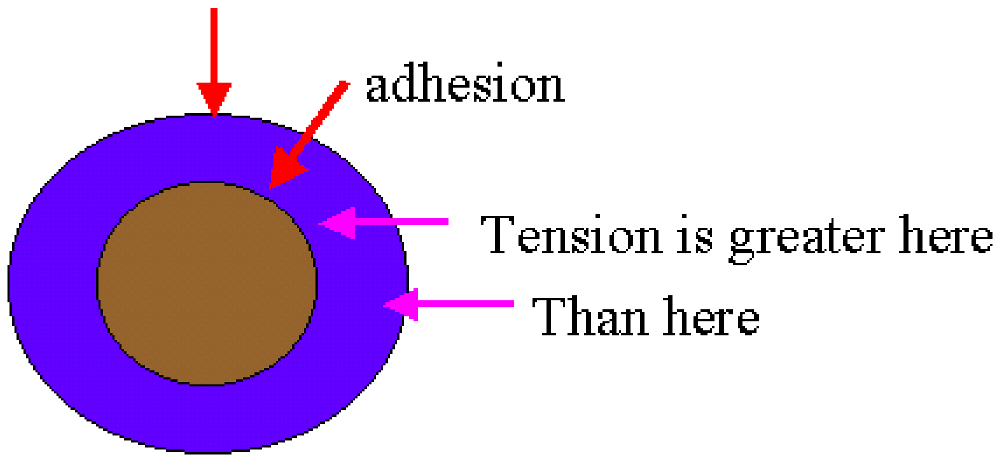
ψ_g = Gravity potential (elevation)
ψ_o = Osmatic potential

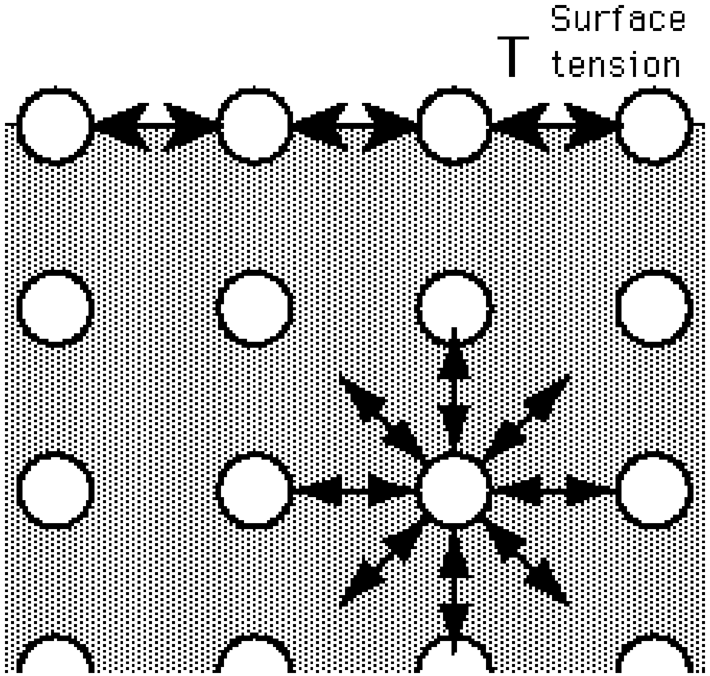
ψ_m commonly, has the greatest effect on release of water from soil to plants

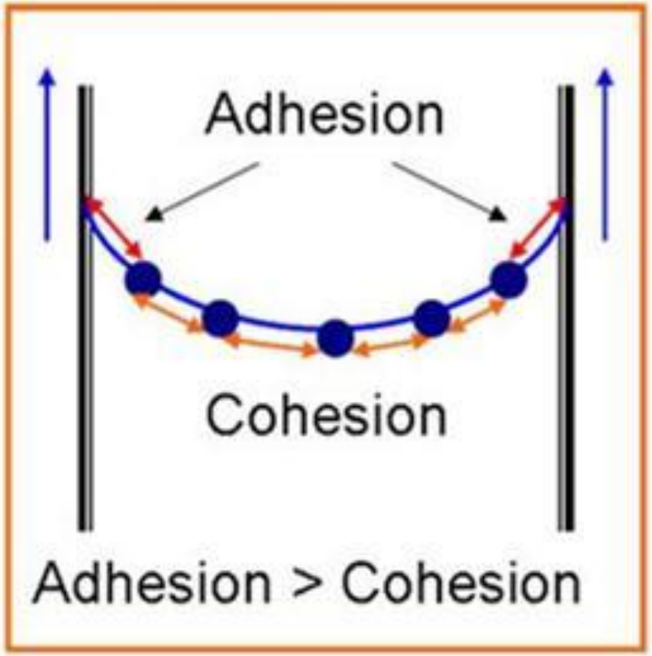
Soil Matric Potential Theory

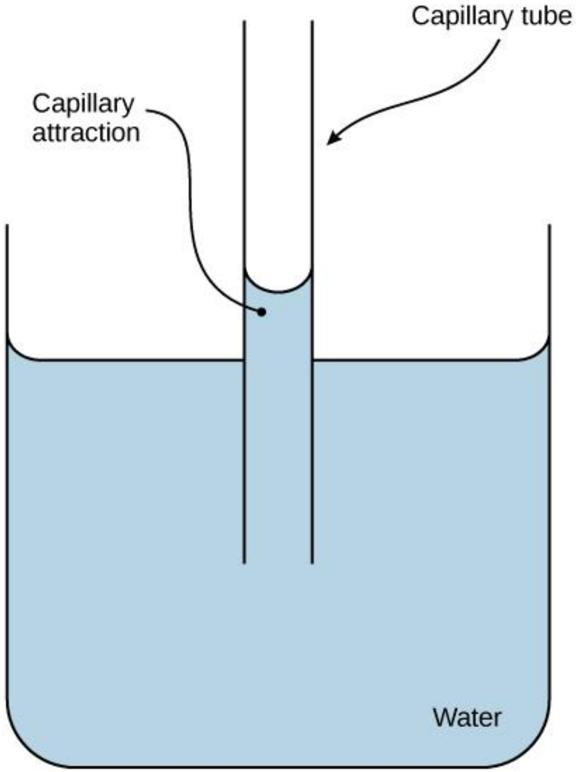
A component of water potential due to the adhesion of water molecules to non-dissolved structures of the system



Soil Matric Potential – Capillary Rise

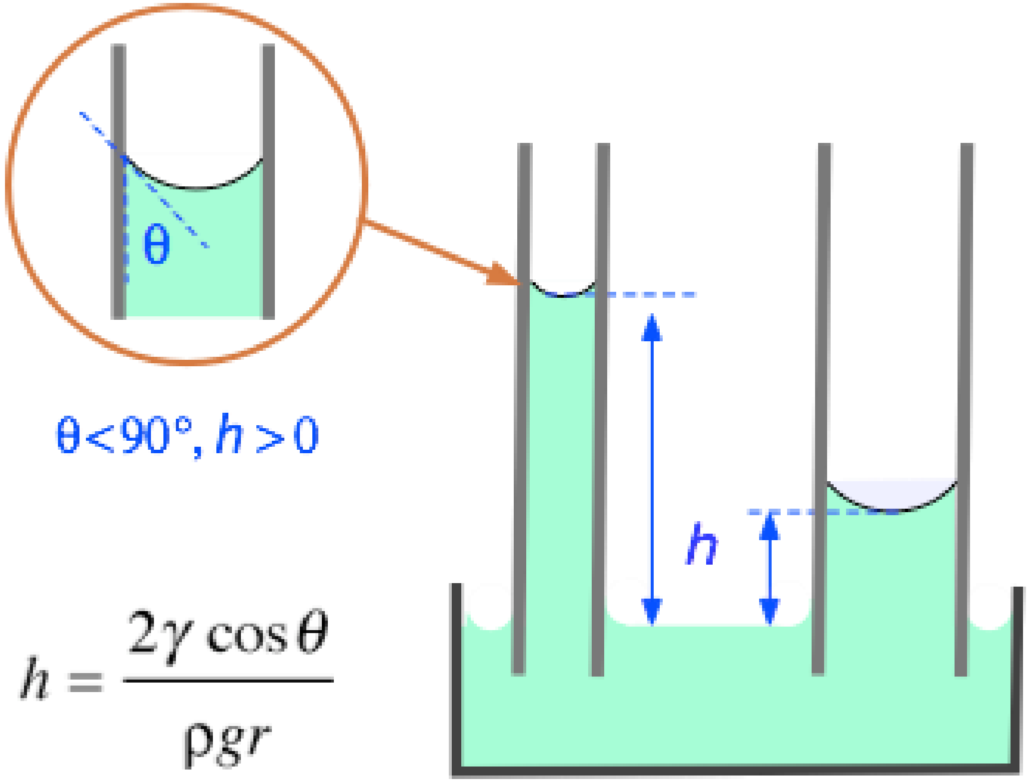






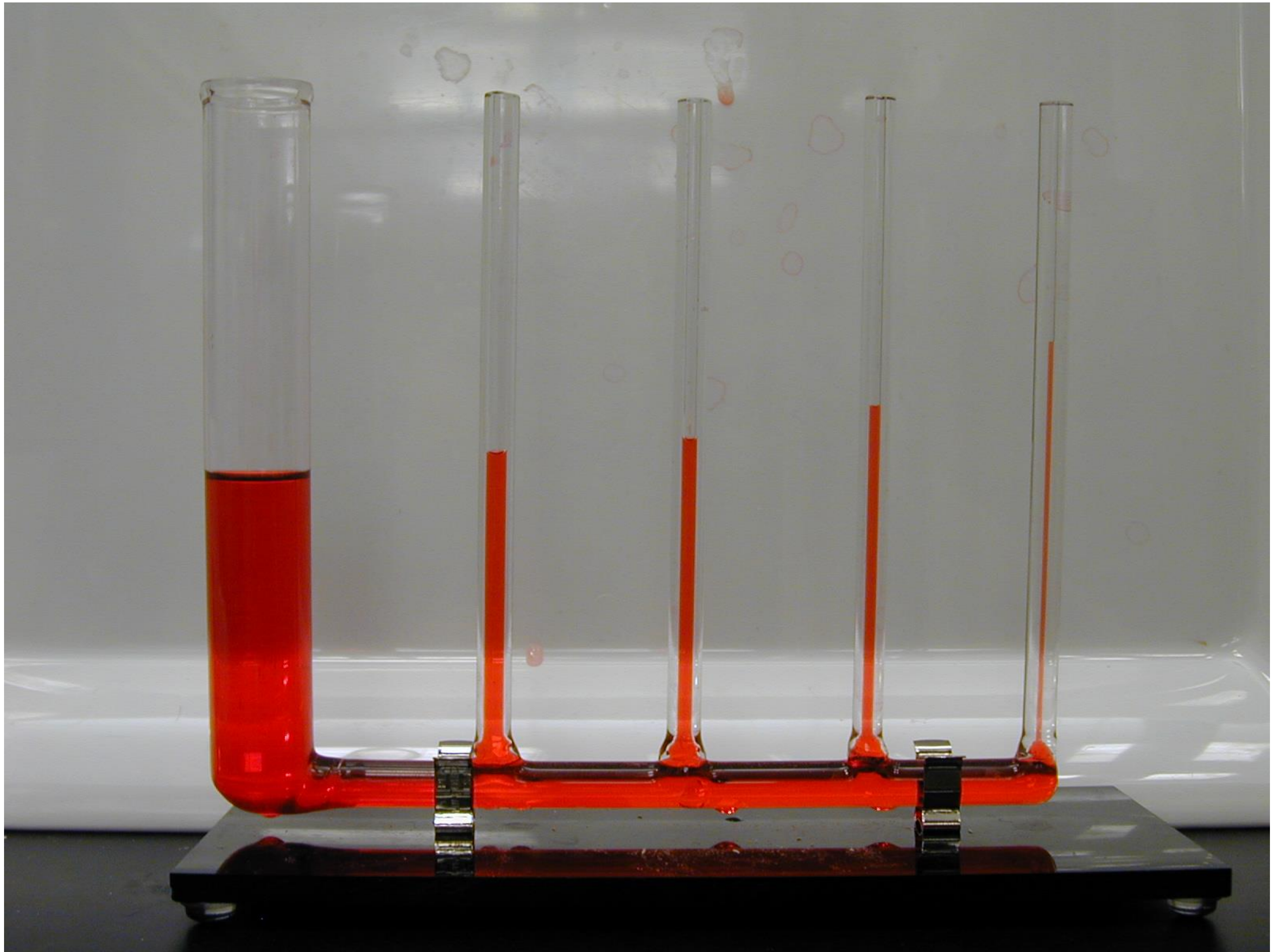
Soil Matric Potential – Capillary Rise

The tension or suction created by small capillary tubes (small soil pores) is greater that that created by large tubes (large soil pores). At any given matric potential coarse soils hold less water than fine-textured soils.

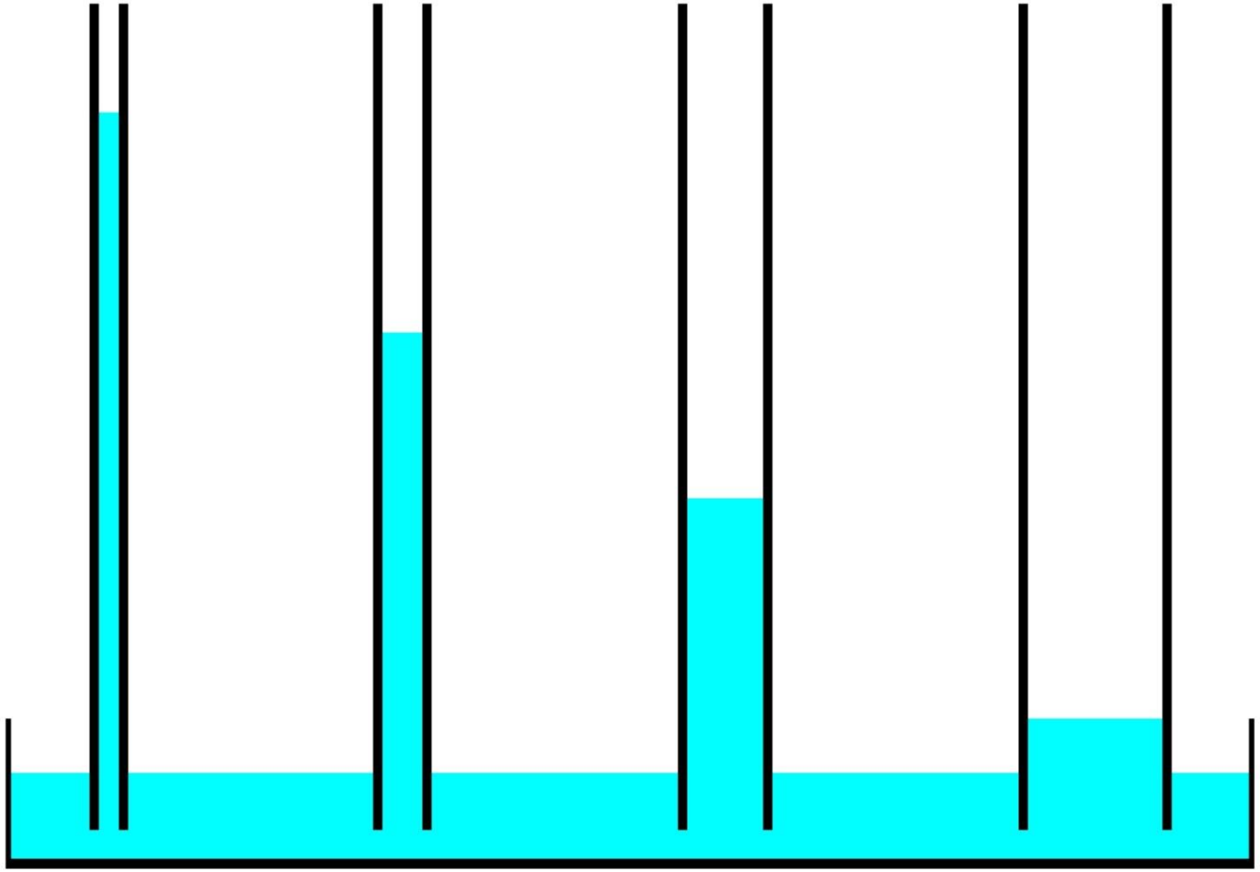


$$h = \frac{2\gamma \cos\theta}{\rho g r}$$

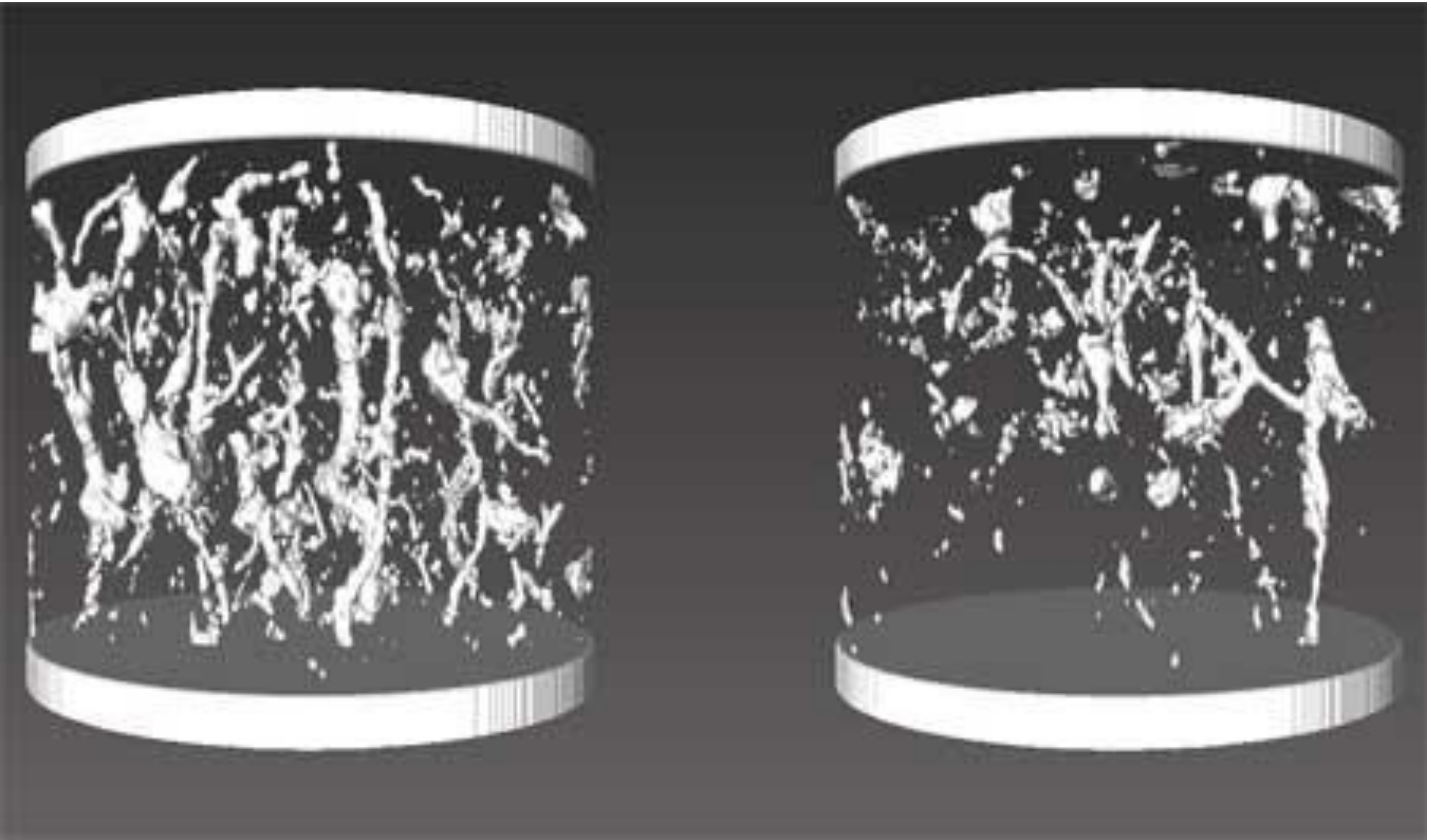
Soil Matric Potential – Capillary Rise

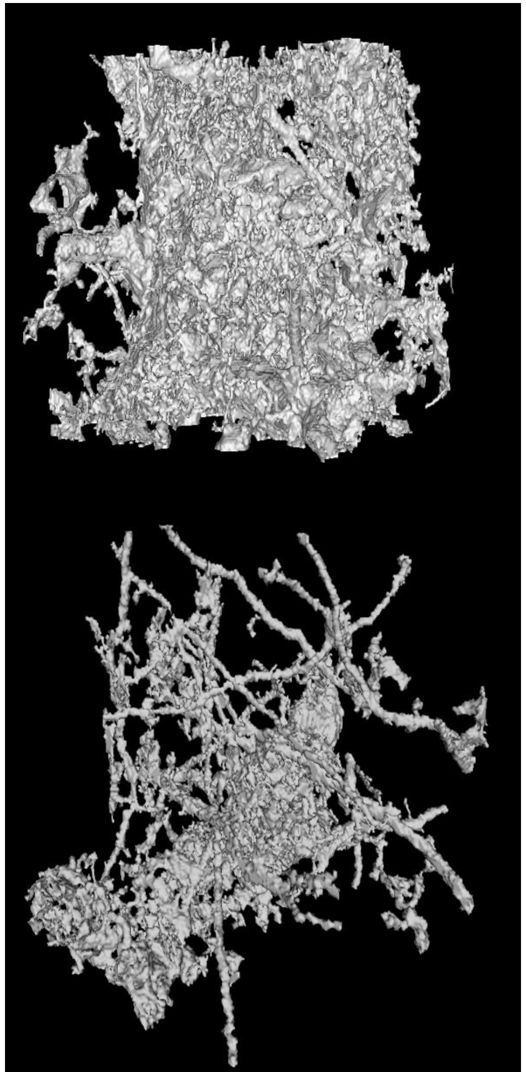


Soil Matric Potential – Capillary Rise

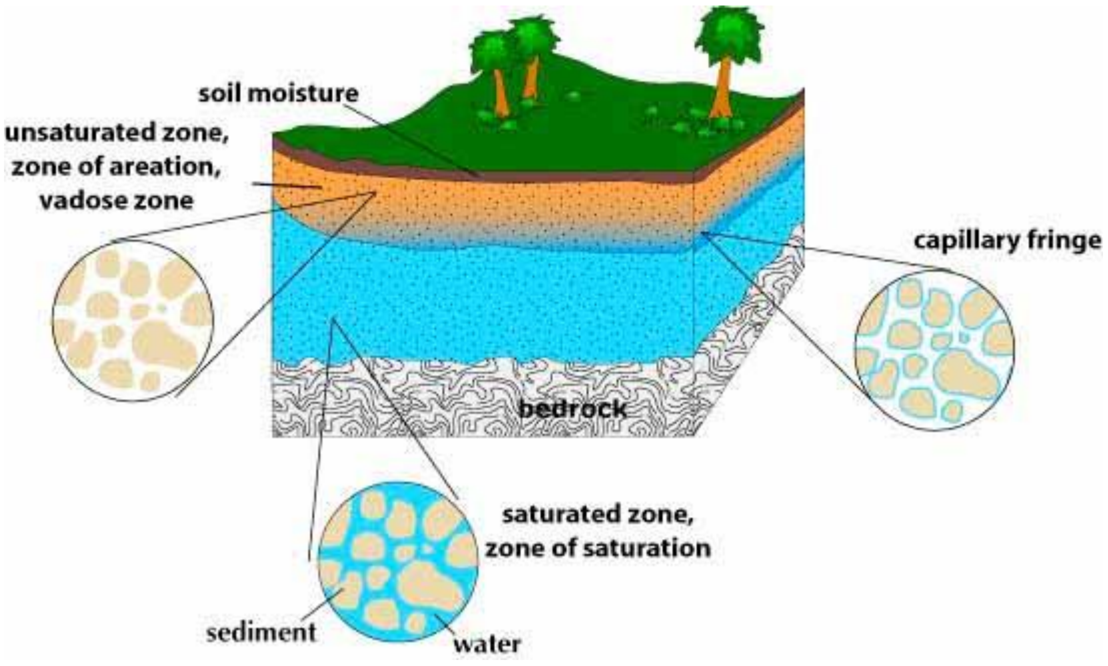


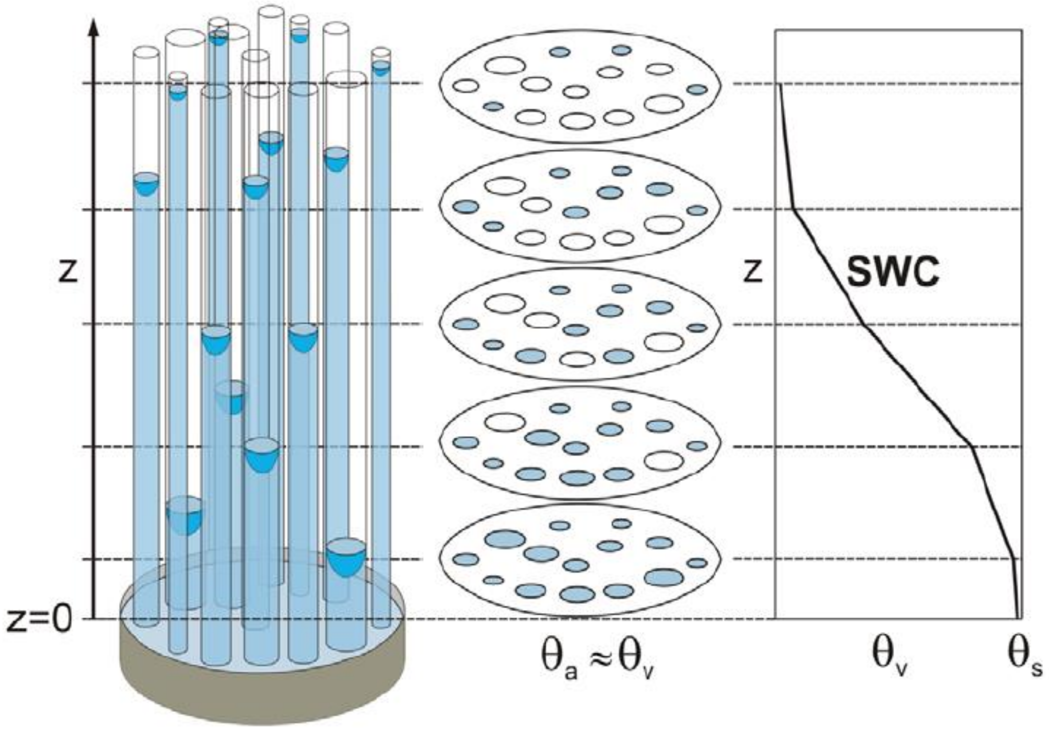
Soil Matric Potential – Soil Water Pores



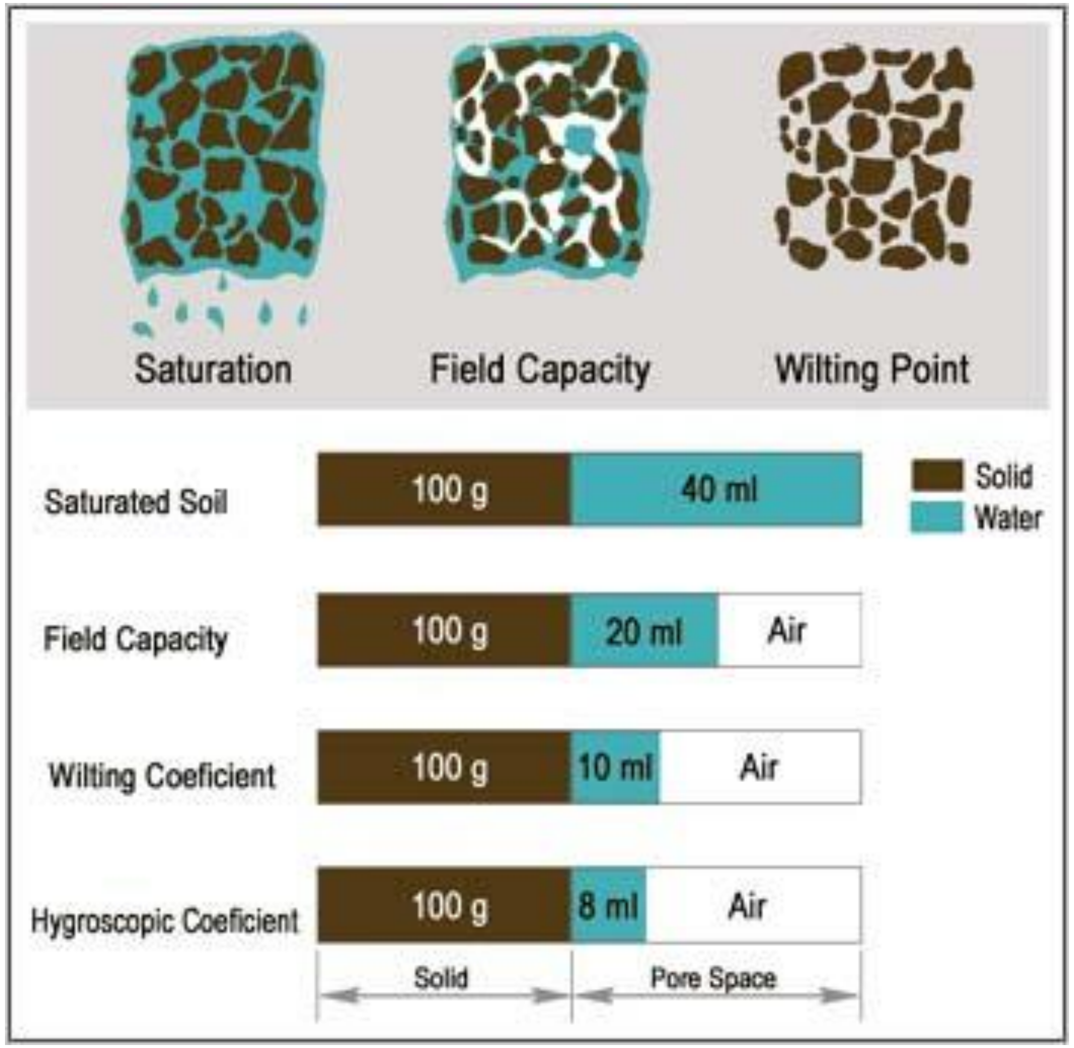


Soil Matric Potential – Soil Water Pores





Soil Matric Potential – Soil Water Status



Soil Matric Potential – Soil Water Status

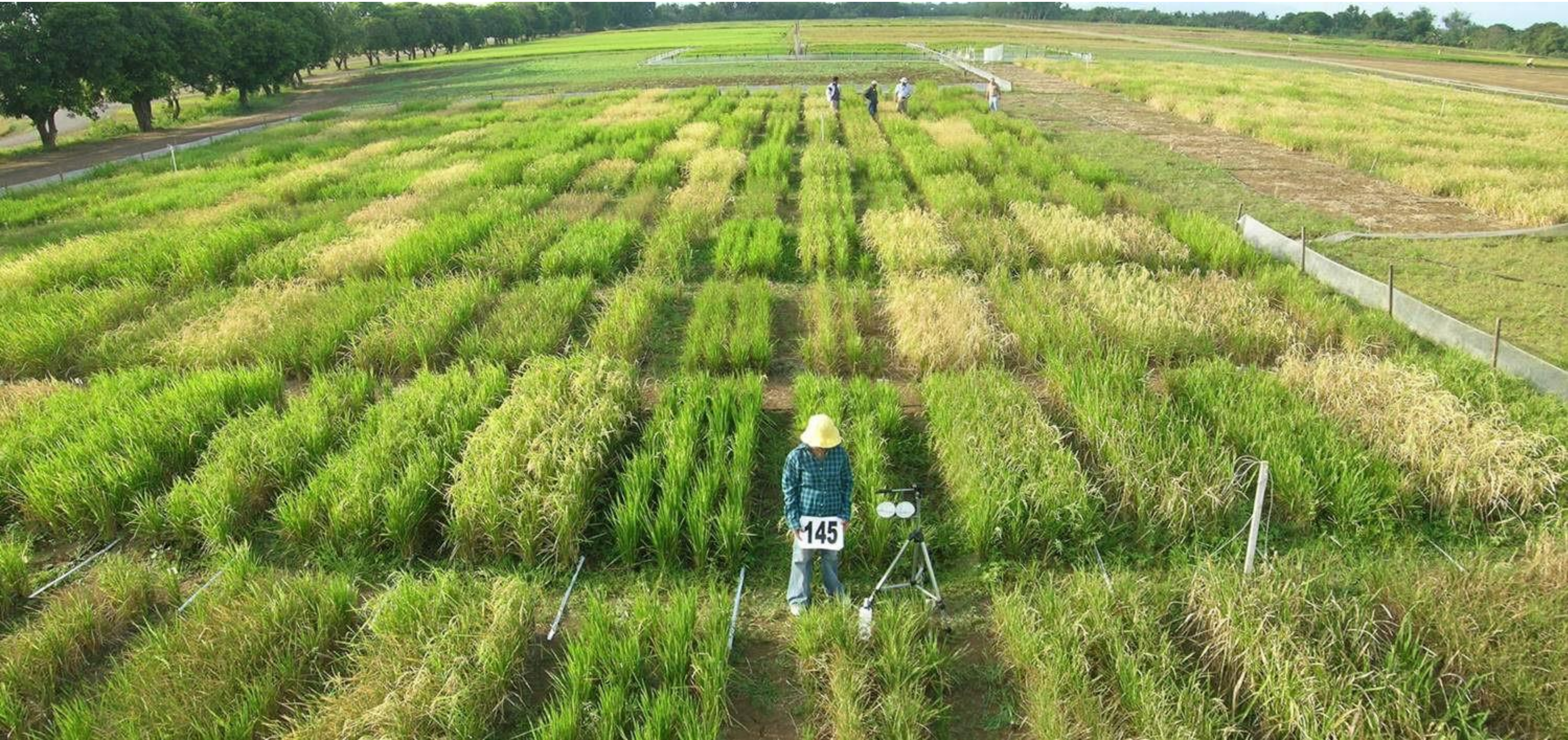
Field Capacity (FC or θfc)

- Soil water content where gravity drainage becomes negligible
- Soil is not saturated but still a very wet condition
- Traditionally defined as the water content corresponding to a soil water potential of -1/10 to -1/3 bar
- As a rule of thumb: evolves in full saturated soil profile after 2-5 days

Permanent Wilting Point (WP or θwp)

- Soil water content beyond which plants cannot recover from water stress (d)
- Still some water in the soil but not enough to be of use to plants
- Traditionally defined as the water content corresponding to -15 bars of SWP

Soil Matric Potential – Soil Water Status



Soil Matric Potential – Soil Water Status

Plant Available Water

- Water held in the soil between field capacity and permanent wilting point
- “Available” for plant use

Available Water Capacity (AWC)

- AWC = $\theta fc - \theta wp$
- Units: depth of available water per unit depth of soil, “unitless” (in/in, or mm/mm)
- Measured using field or laboratory methods (described in text)

Soil Water Availability

Plant Available Water Content

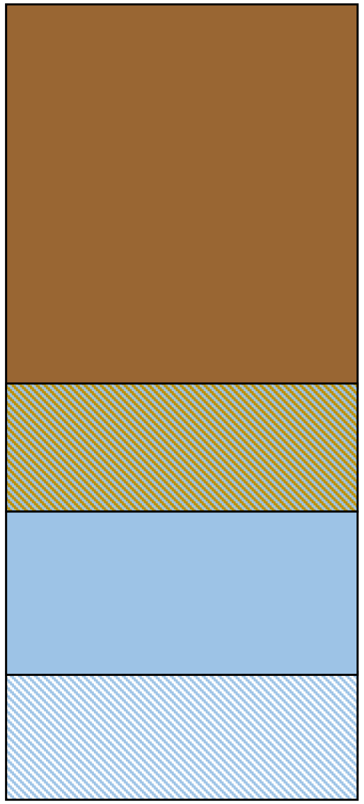
Soil Solids (Particles) ca. 50%

Total Pore Space ca. 50%

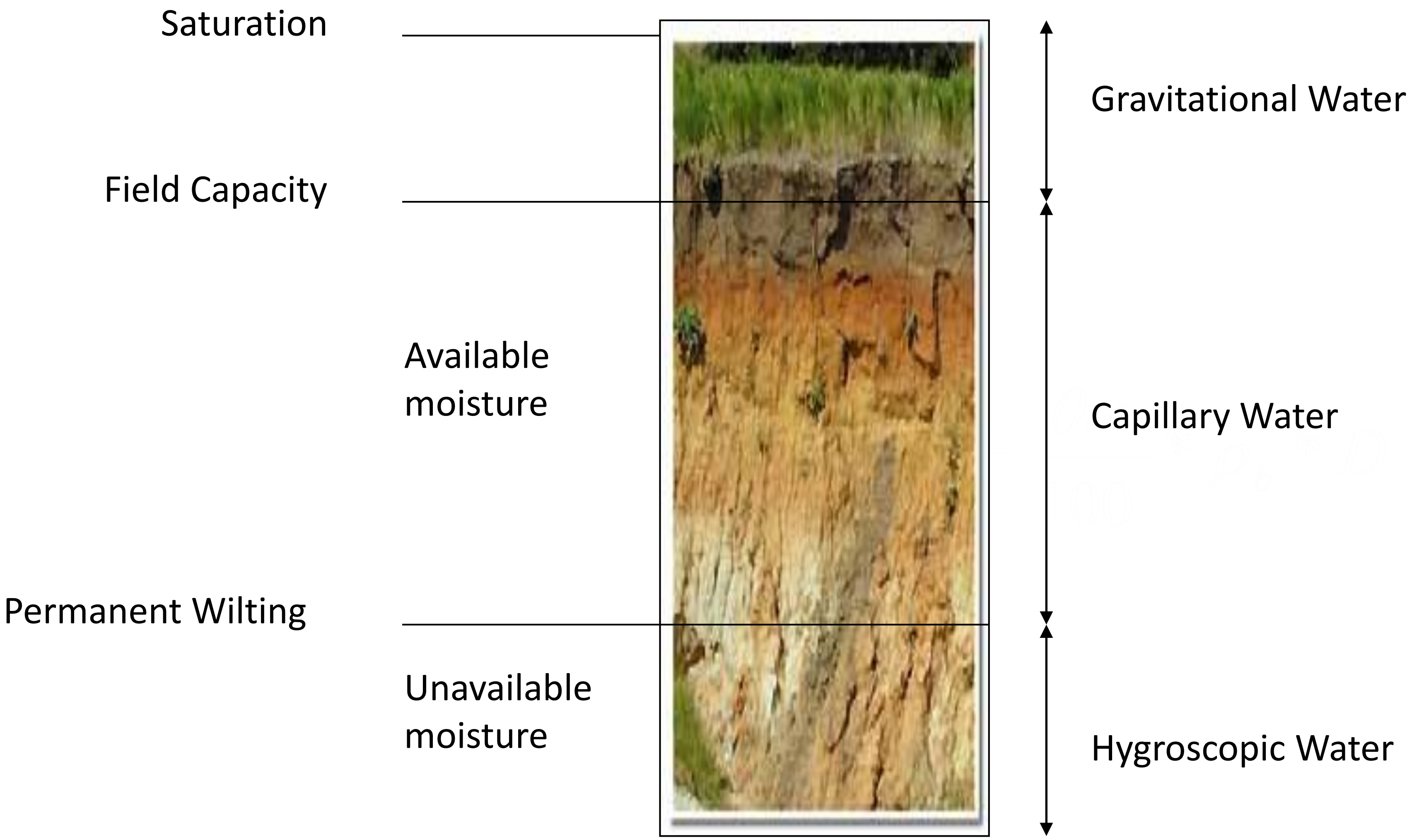
Very Small Pores: 15%
(Fixed/Unavailable Water)

Medium-sized Pores: 20%
(Plant Available Water)

Very Large Pores: 15%
(Gravitational Water Loss)

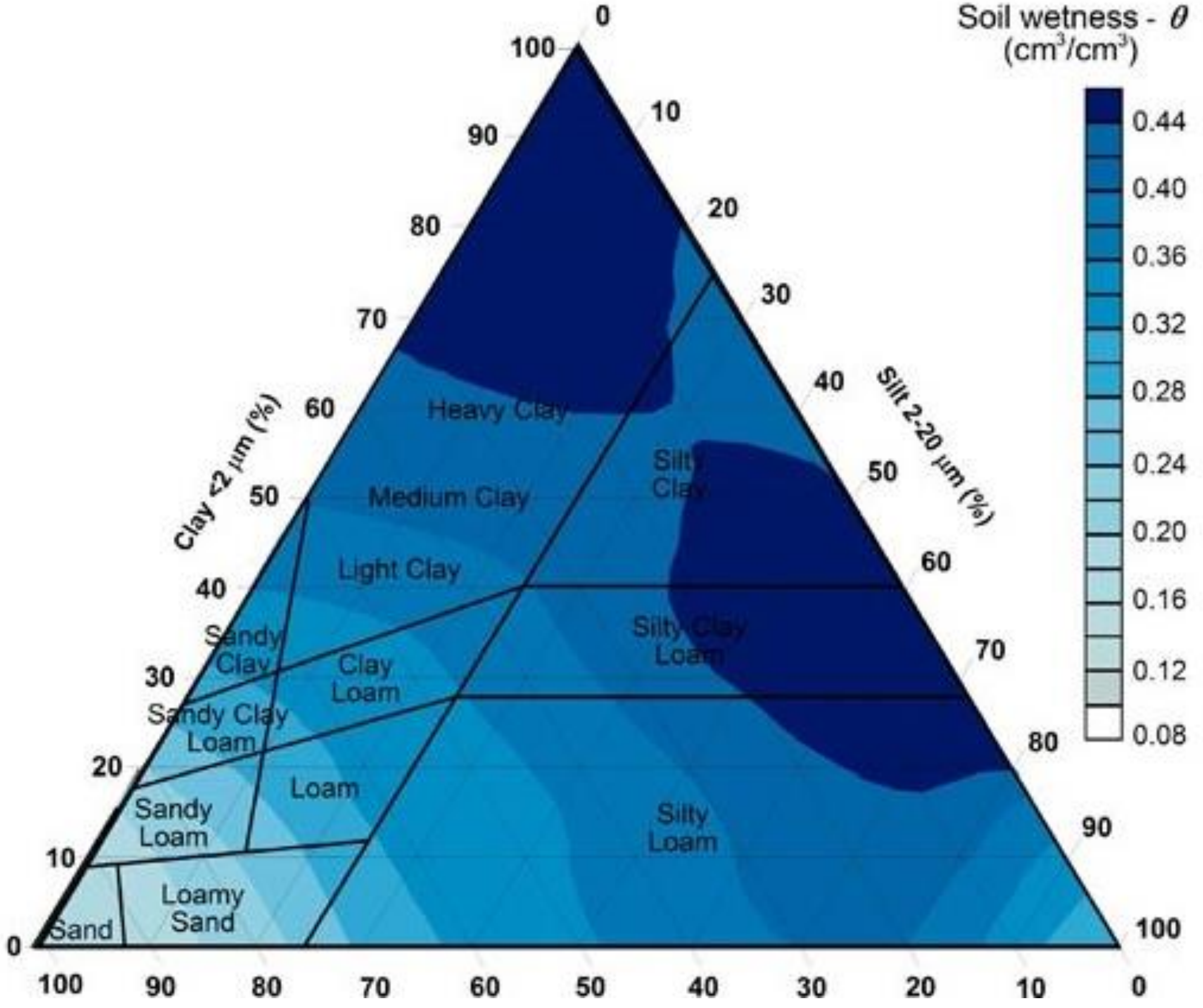


Soil Water Availability



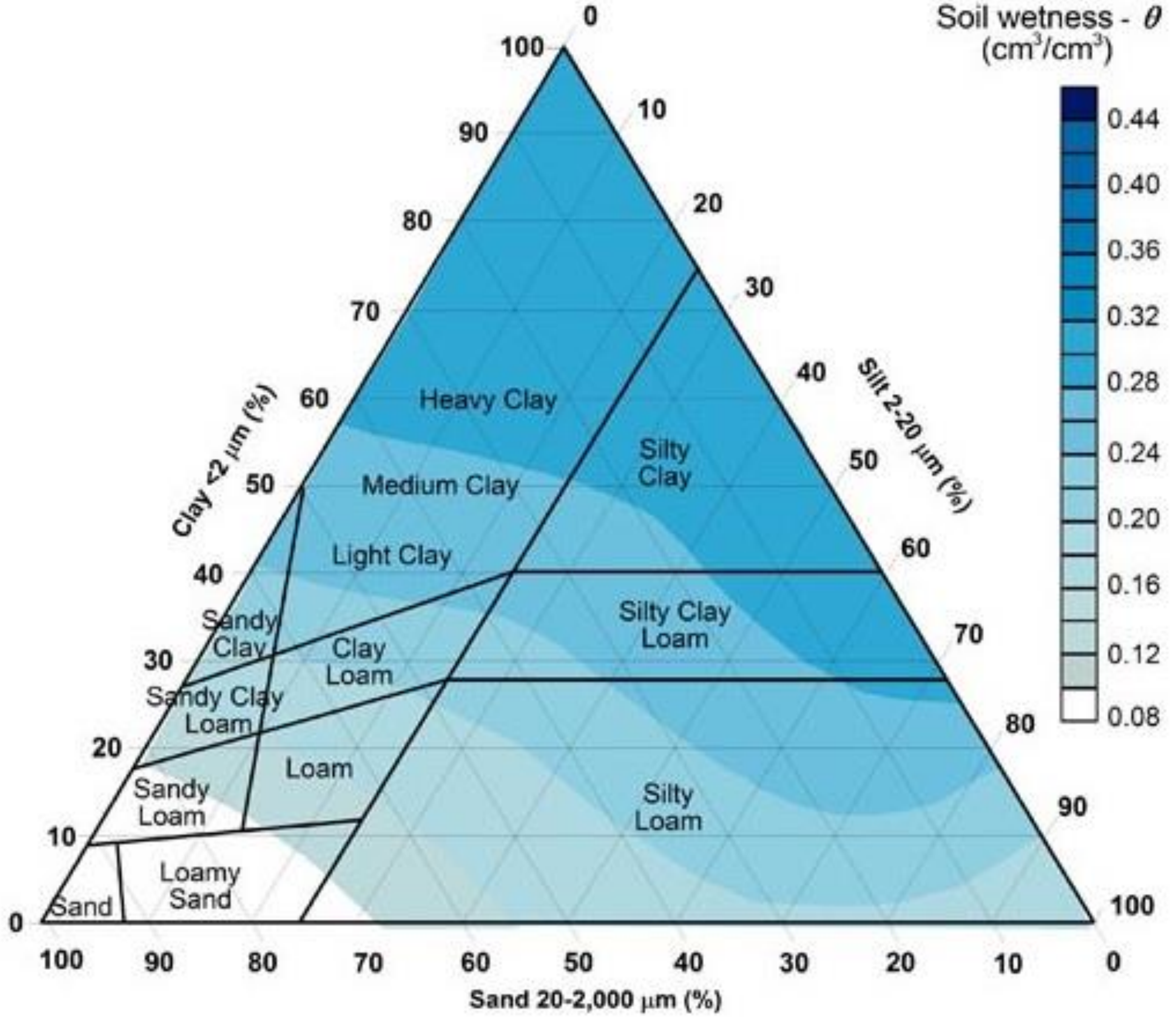
Soil Water Availability – link with Soil Texture

Field Capacity



Soil Water Availability – link with Soil Texture

Permanent Wilting Point



Soil Water Availability – link with Soil Texture

Plant Available Water Content

Soil Texture	θ_{fc}	θ_{wp}	AWC
Coarse Sand	0.10	0.05	0.05
Sand	0.15	0.07	0.08
Loamy Sand	0.18	0.07	0.11
Sandy Loam	0.20	0.08	0.12
Loam	0.25	0.10	0.15
Silt Loam	0.30	0.12	0.18
Silt Clay Loam	0.38	0.22	0.16
Clay Loam	0.40	0.25	0.15
Silt Clay	0.40	0.27	0.13
Clay	0.40	0.28	0.12

Soil Water Availability - Example

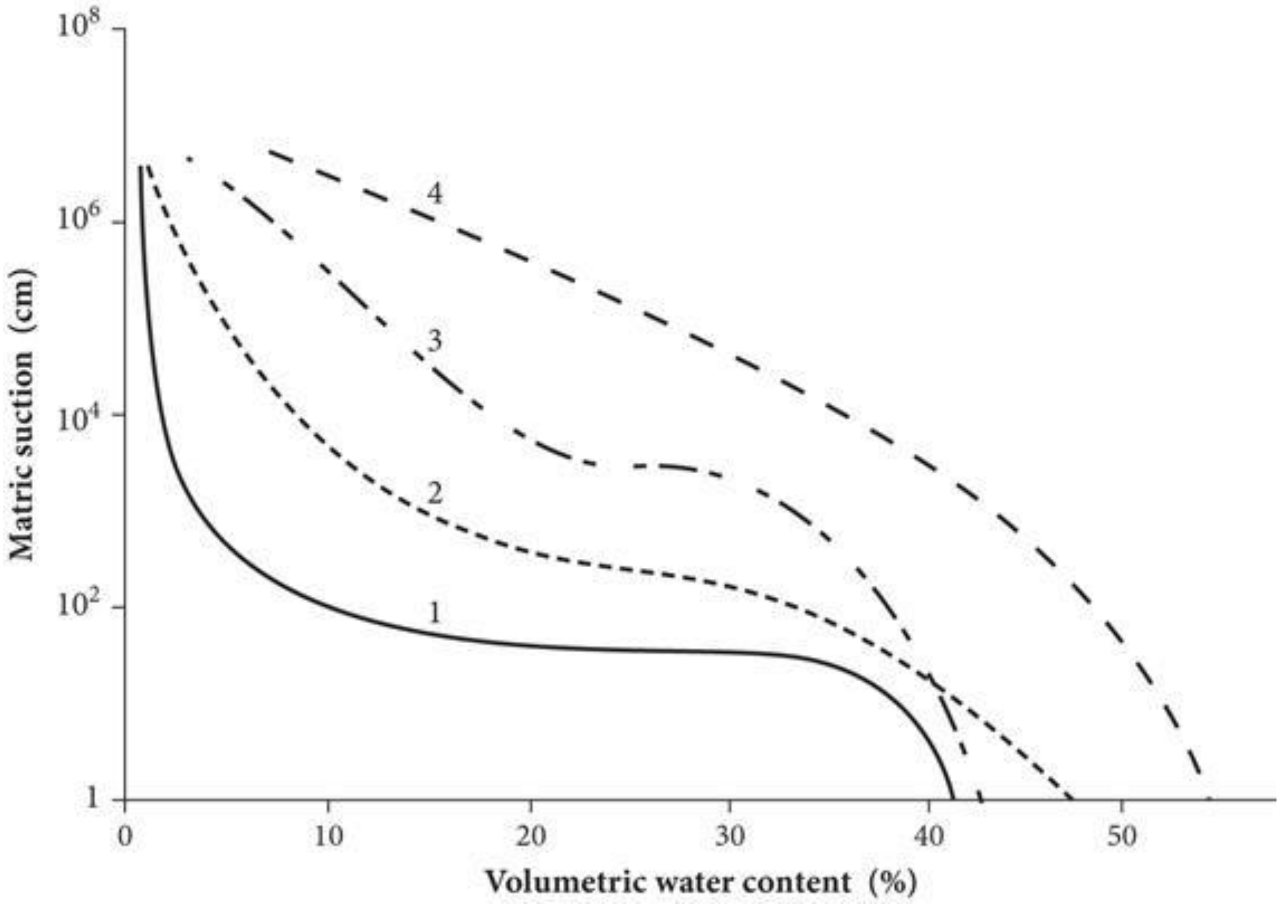
Soil Layer (cm)	Soil Sample		Field Capacity		Wilting Point		Bulk Density (g/cm^3)	FC (%)	WP (%)	TAW (mm)
	Volume (cm^3)	Mass of Dry Soil (g)	Total Mass (g)	Mass of Dry Soil (g)	Total Mass (g)	Mass of Dry Soil (g)				
0-30	100	134.6	38.3	28.9	34.3	28.1	1.35	24.54	18.08	26.16
30-60	100	137.7	38.2	29.5	34.9	28.3	1.38	22.77	18.91	15.98
60-90	100	128.5	36.2	27.7	33.0	26.9	1.29	23.48	18.48	19.35
Total										61.49

Soil Water – Soil Matric Potential: Soil Water Retention

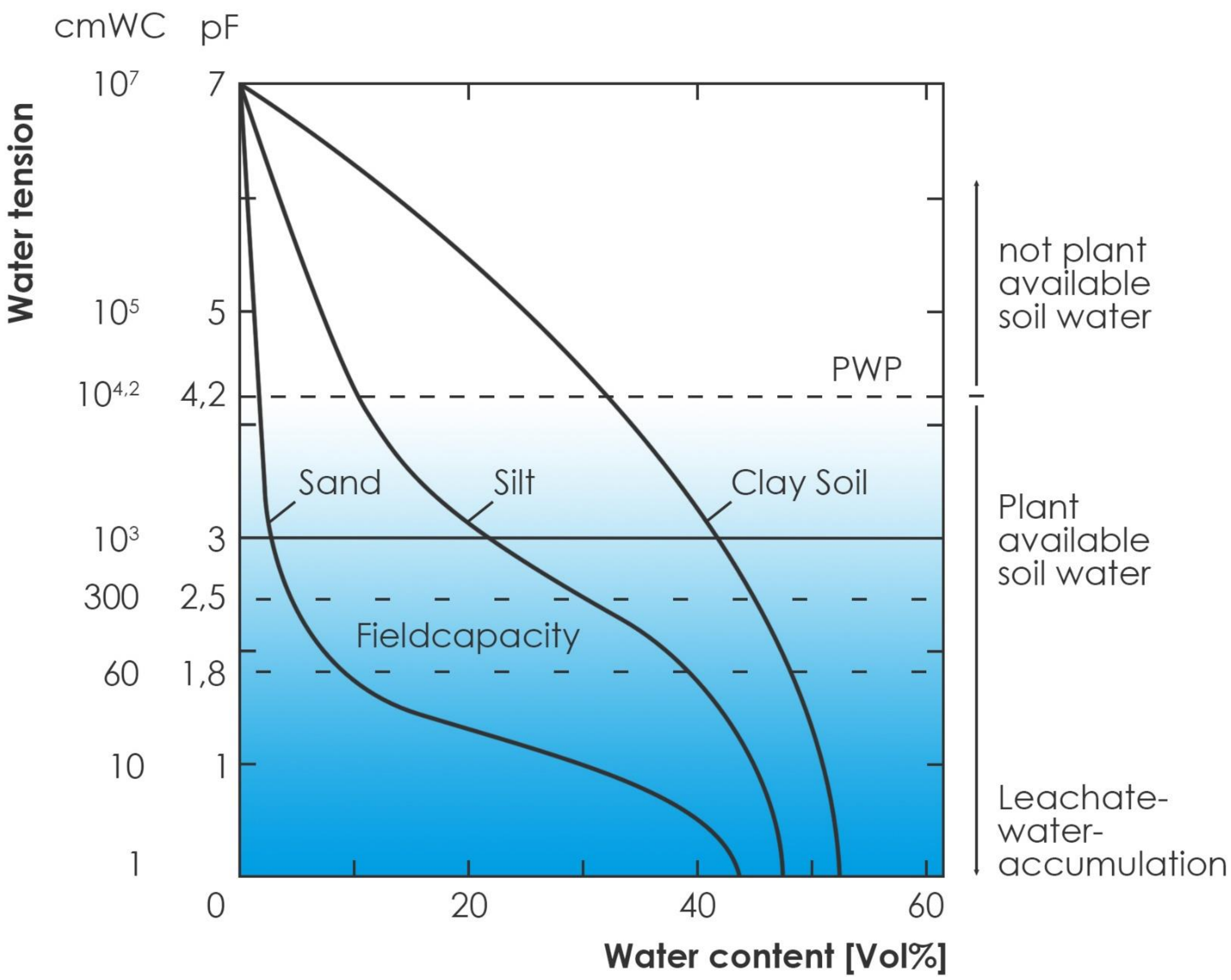
Retention Curve

Water retention curve is the relationship between the water content, ϑ, and the soil water potential, ψ. This curve is characteristic for different types of soil, and is also called the soil moisture characteristic.

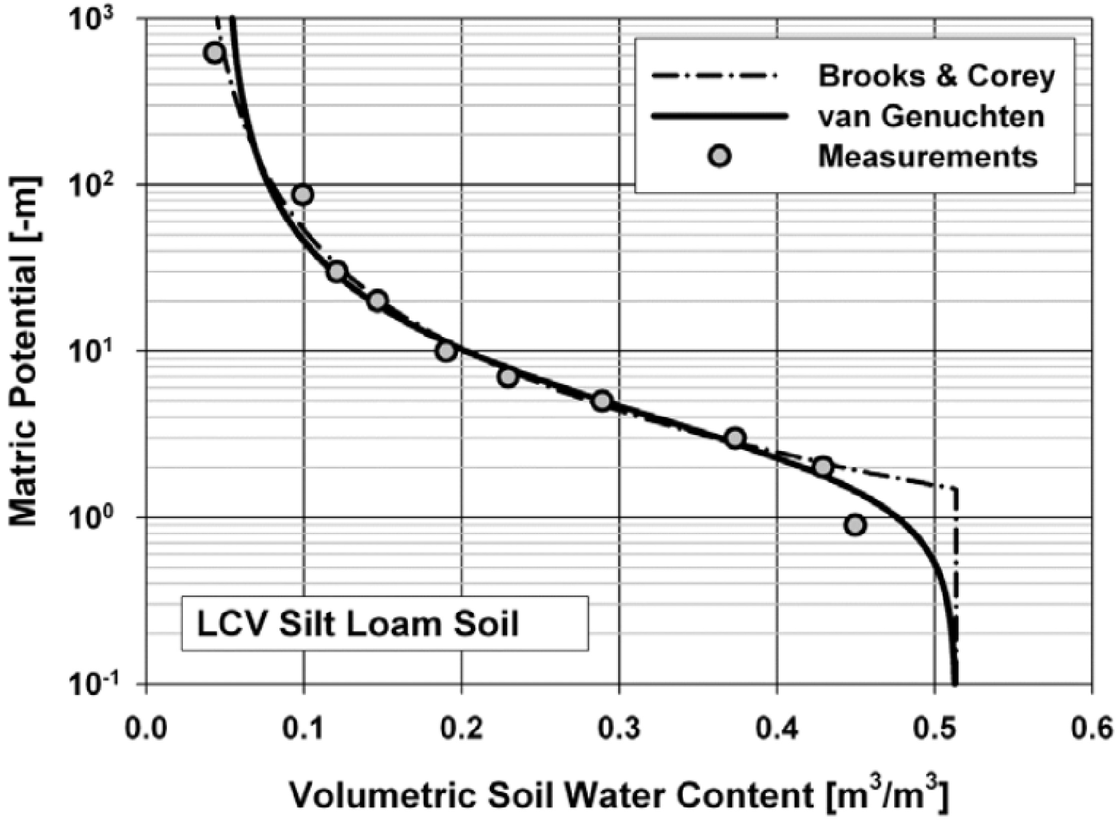
It is used to predict the soil water storage, water supply to the plants (field capacity) and soil aggregate stability. Due to the hysteretic effect of water filling and draining the pores, different wetting and drying curves may be distinguished.



Soil Water Retention



Soil Water Retention



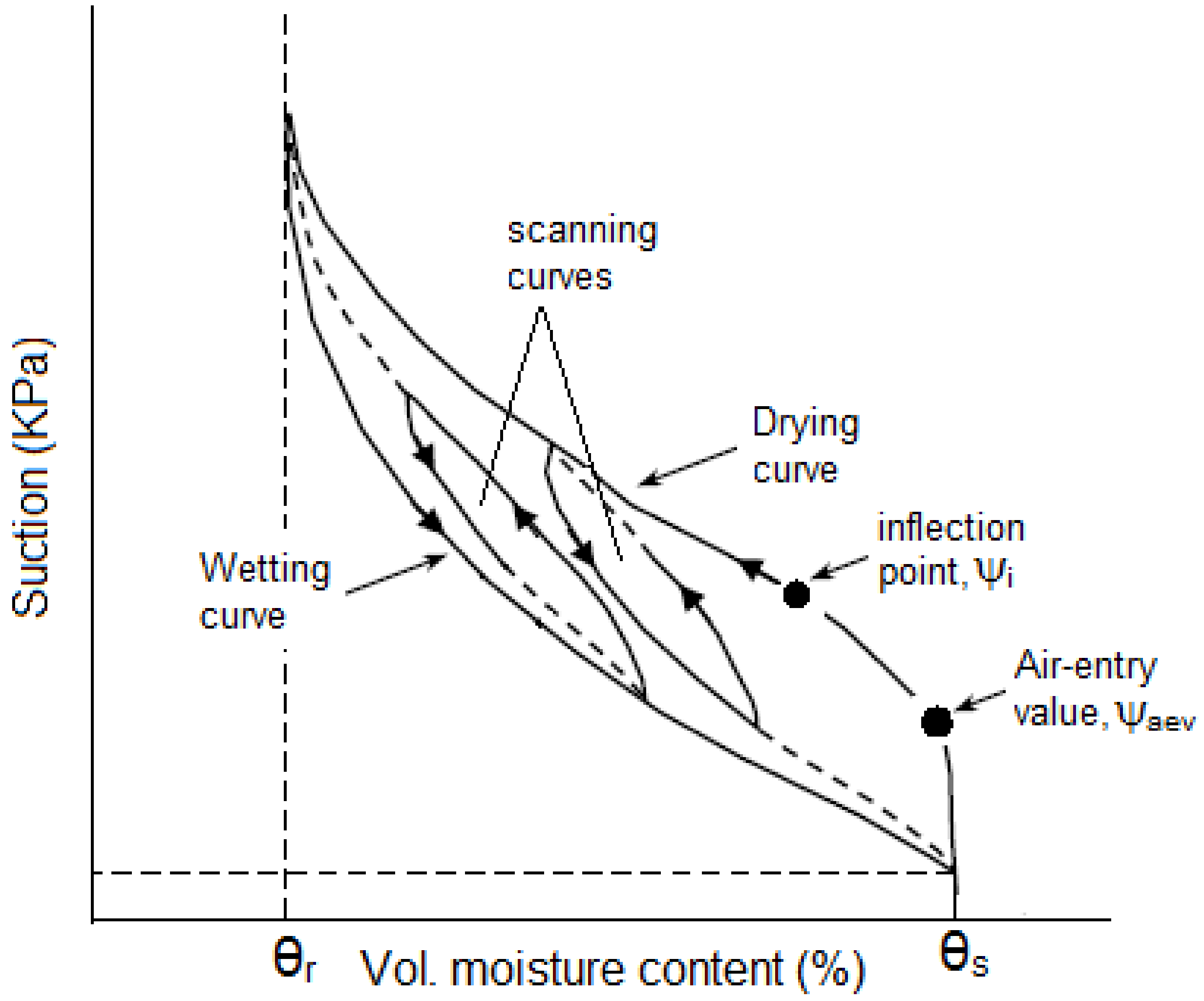
Van Genuchten

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[\frac{1}{1 + (\alpha \ \psi_m)^n} \right]^m$$

Brooks & Corey

$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left(\frac{\psi_b}{\psi_m} \right)^\lambda$$

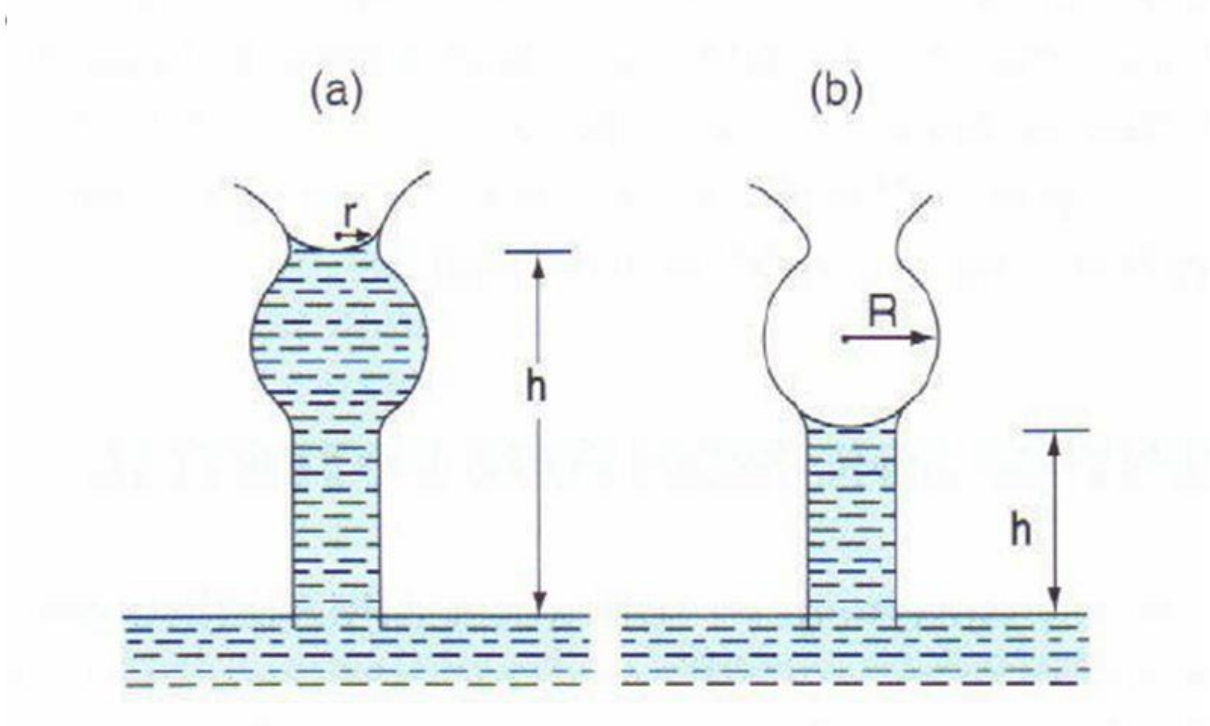
Soil Water Retention



Soil Water Retention

Causes of hysteresis

- Nonuniform shape of individual pores: “ink bottle”



Soil Water Retention

Retention Curve

The retention curve explains the relation between soil moisture status and soil matric potential

Thus, the retention curve explains the plant stress stage (depending on soil moisture)

Knowing the retention curve of a soil (in different depths) water movement can be explained by knowing the soil moisture status

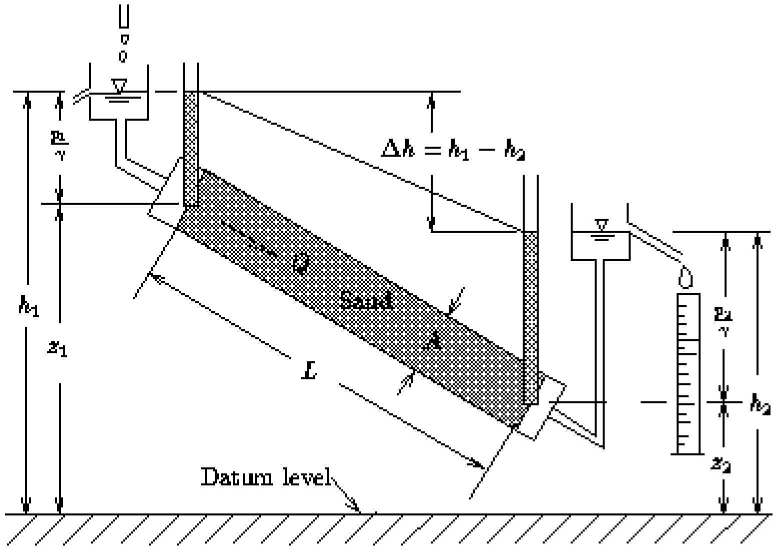
Soil Water Movement

Fully saturated conditions

- All pores are filled with water
- Movement is controlled by friction and gravitational forces

Darcy's law

$$q = K \nabla H$$



Unsaturated conditions

- *Not all pores are filled with water*
- *Movement is controlled by friction, gravitational forces and matric potential*

Richrads's equation

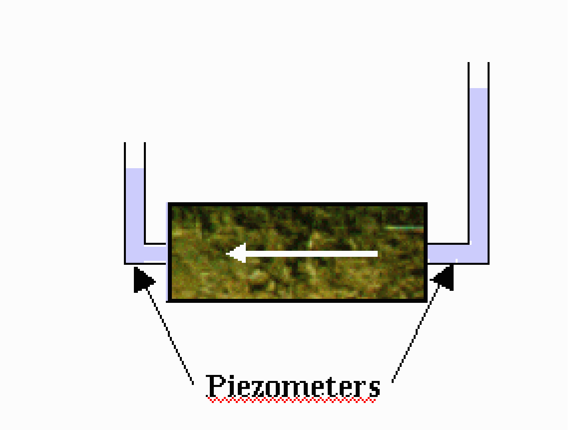
$$q \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}[K(\theta)(\partial \varphi / \partial z + 1)]$$

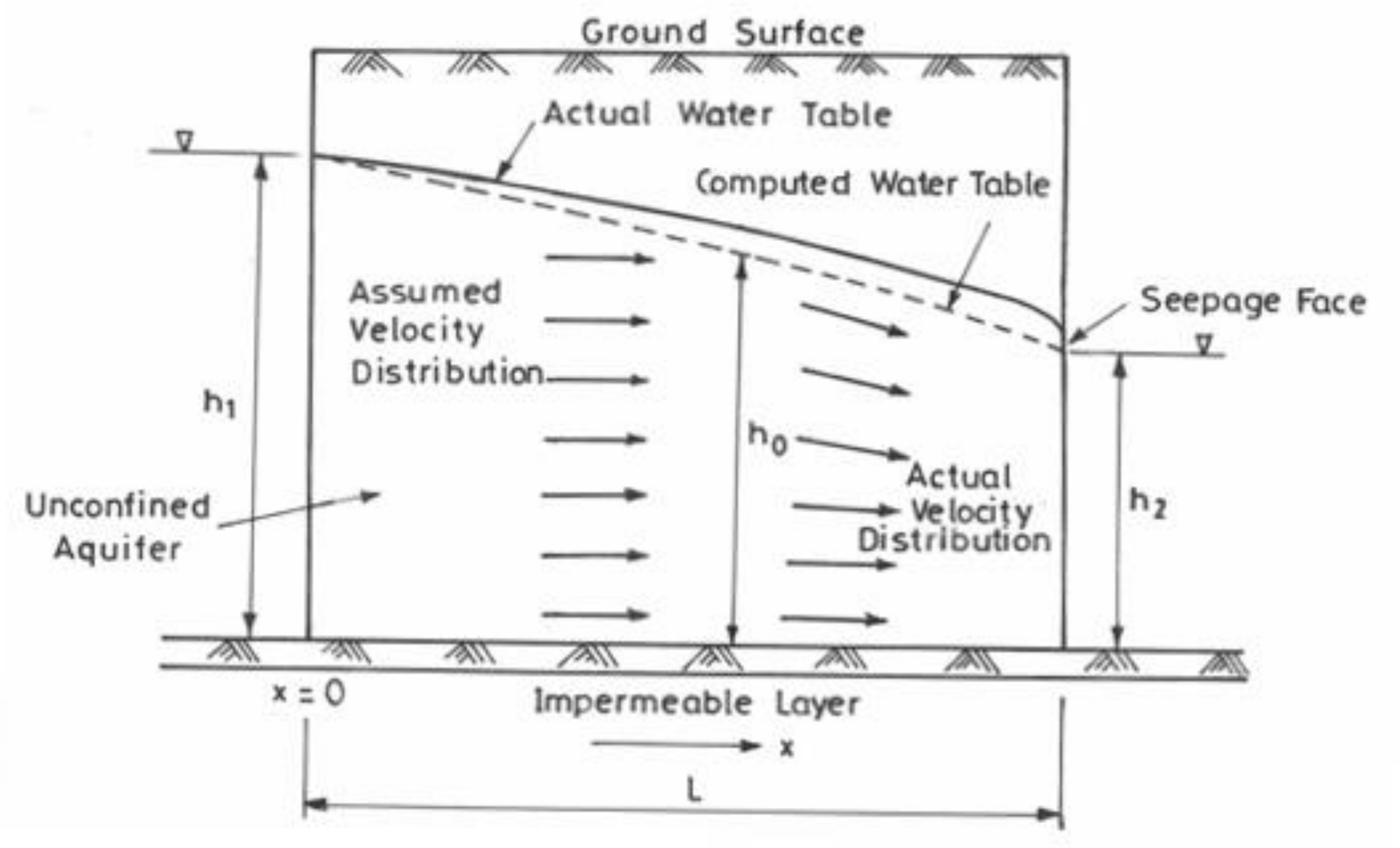
Soil Water Movement

Saturated flow

-> hydraulic gradient

dH/dL



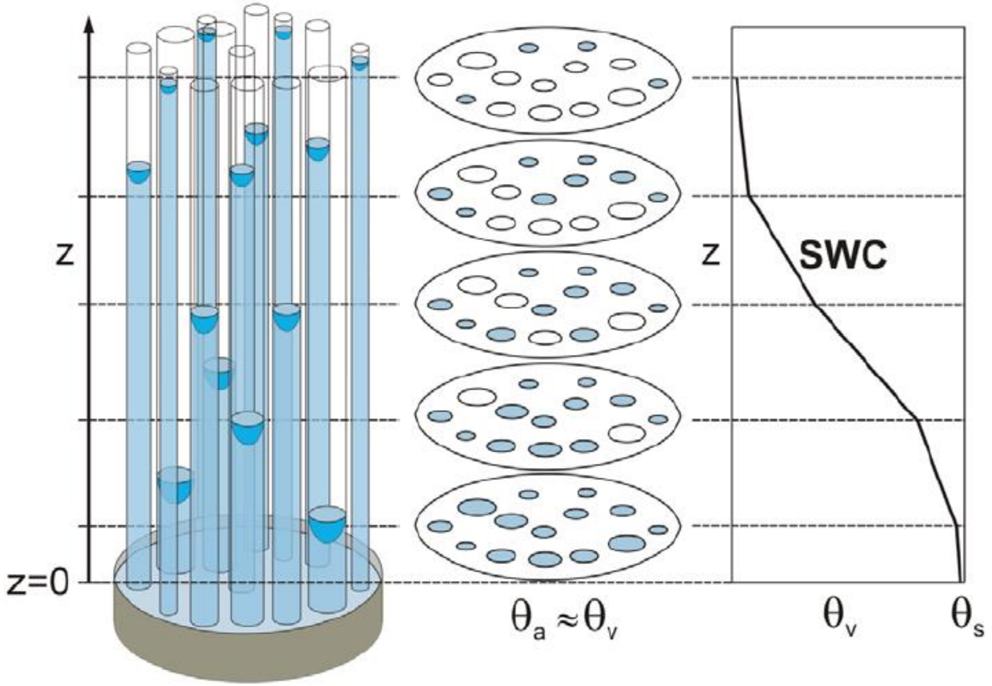


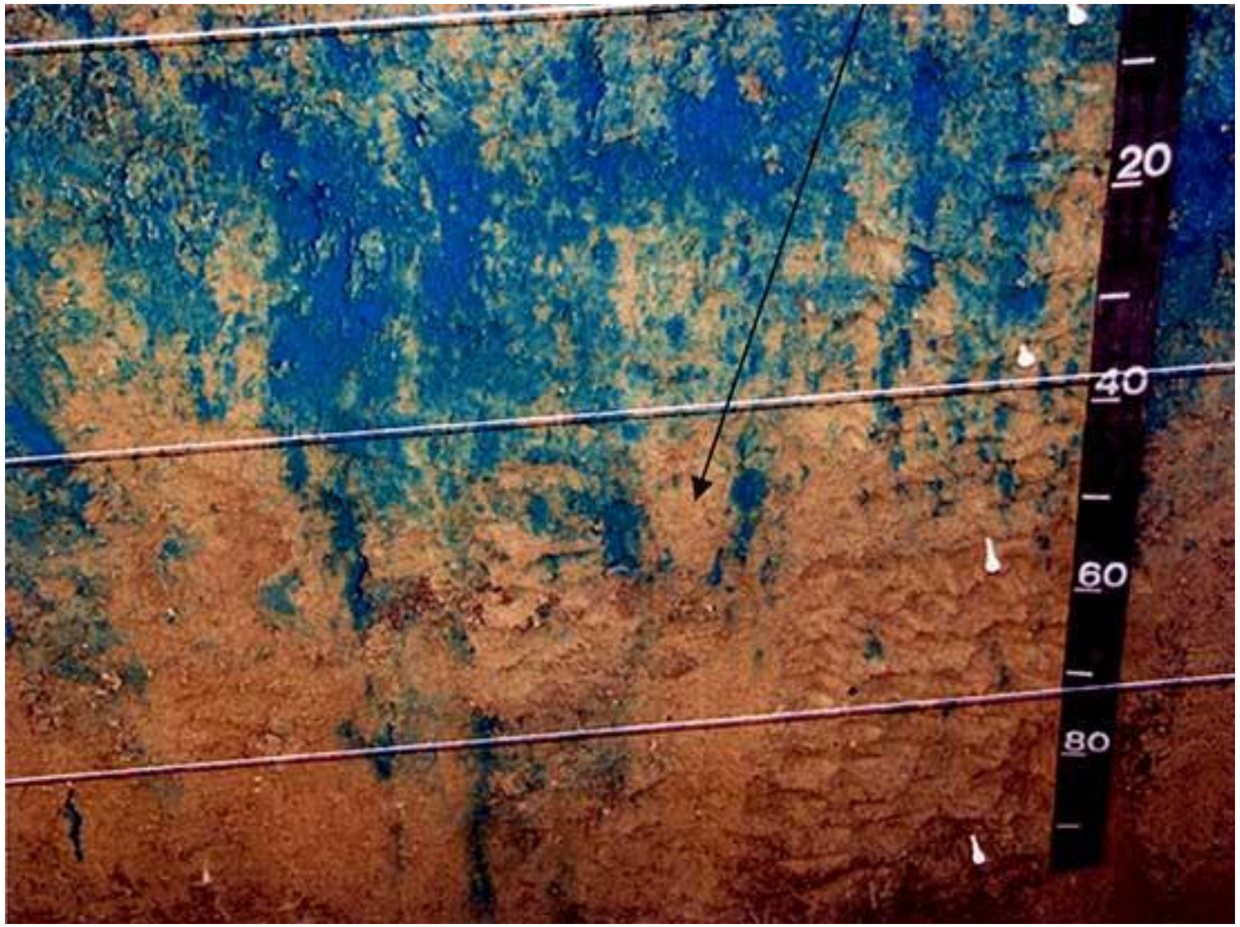
Soil Water Movement

Unsaturated flow

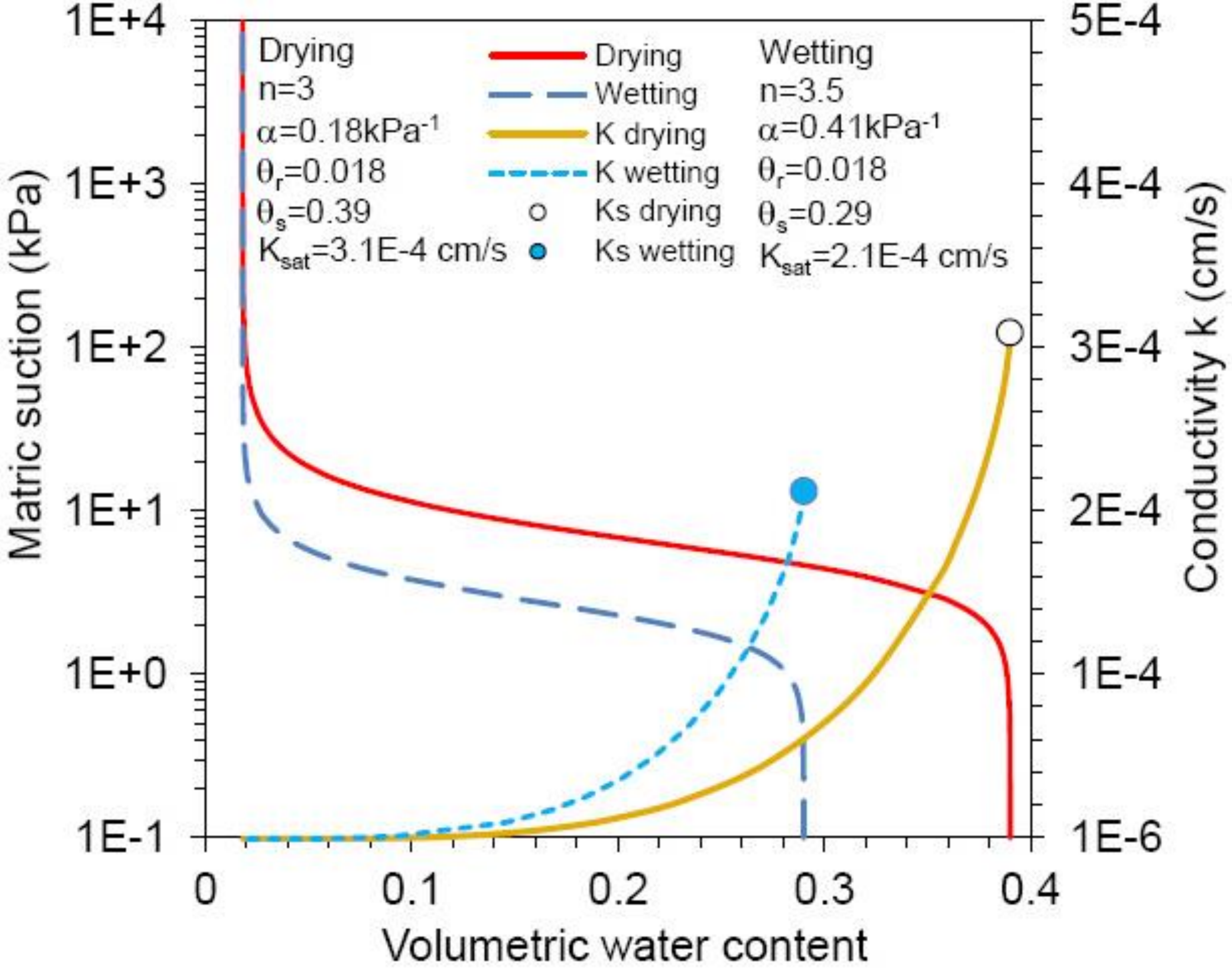
Mualem – Van Genuchten

$$K(S_e) = K_o\, S_e^{L}\{1-[1-S_e^{n/(n-1)}]^{1-1/n}\}^2$$

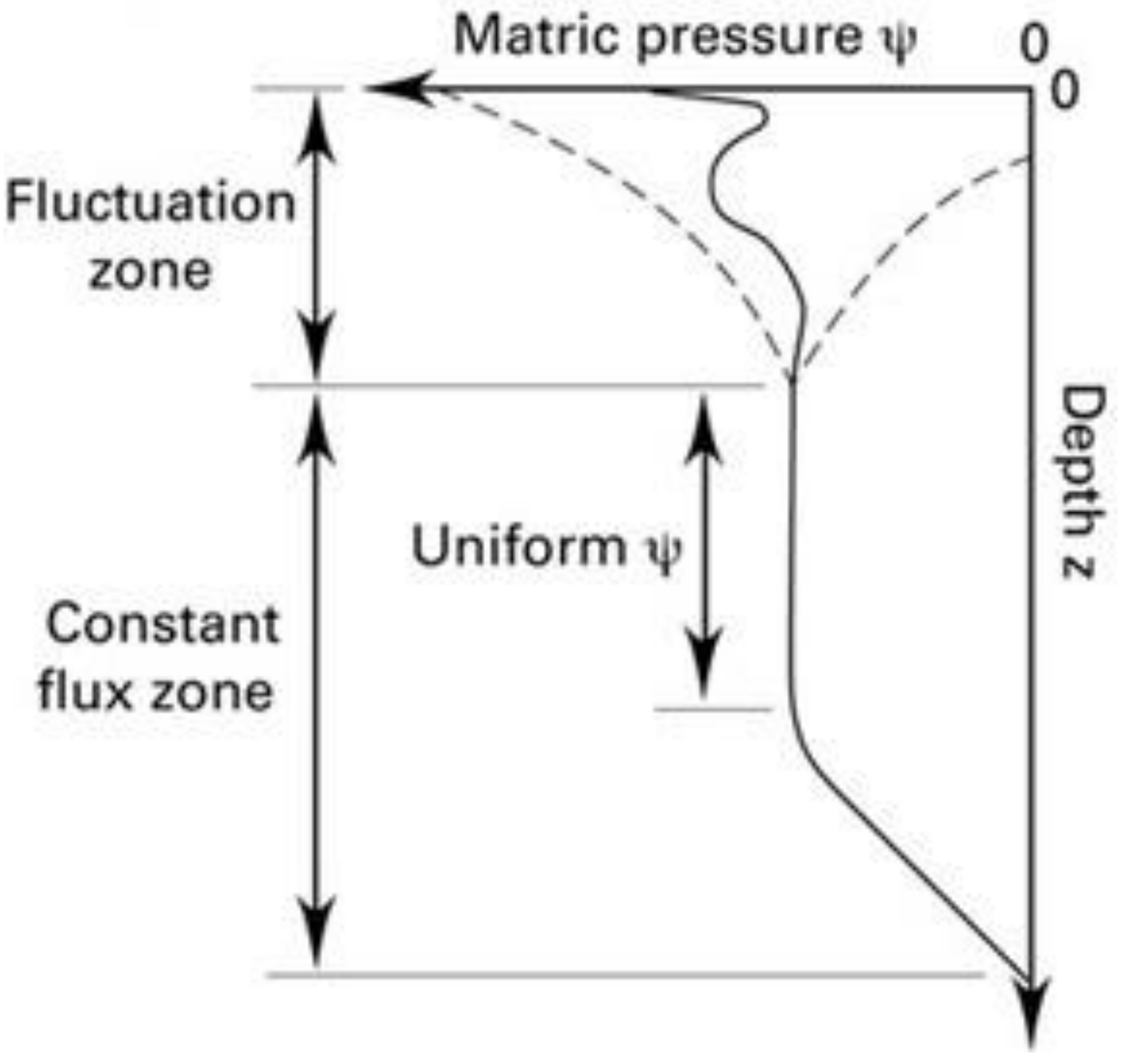




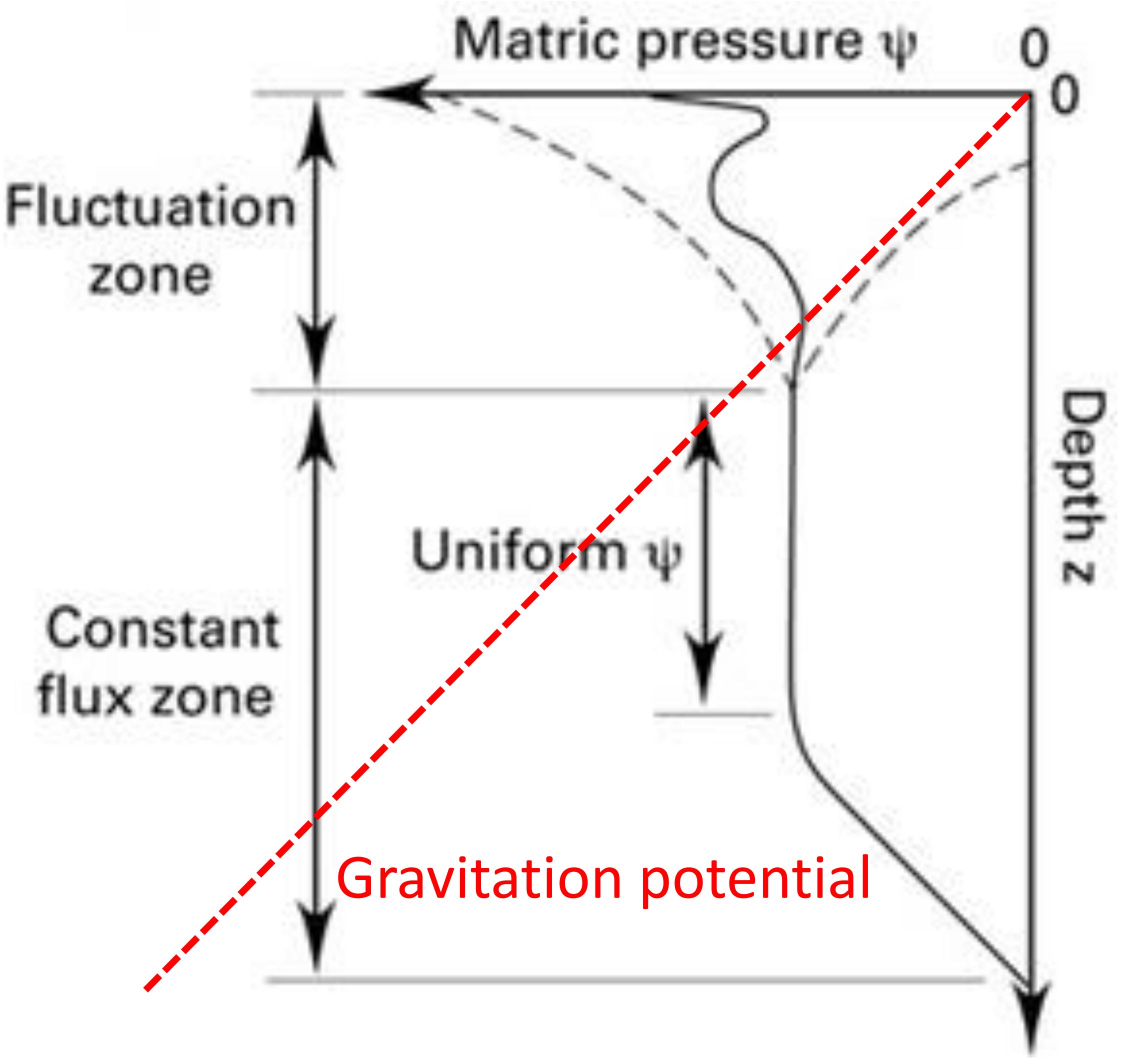
Soil Water Movement



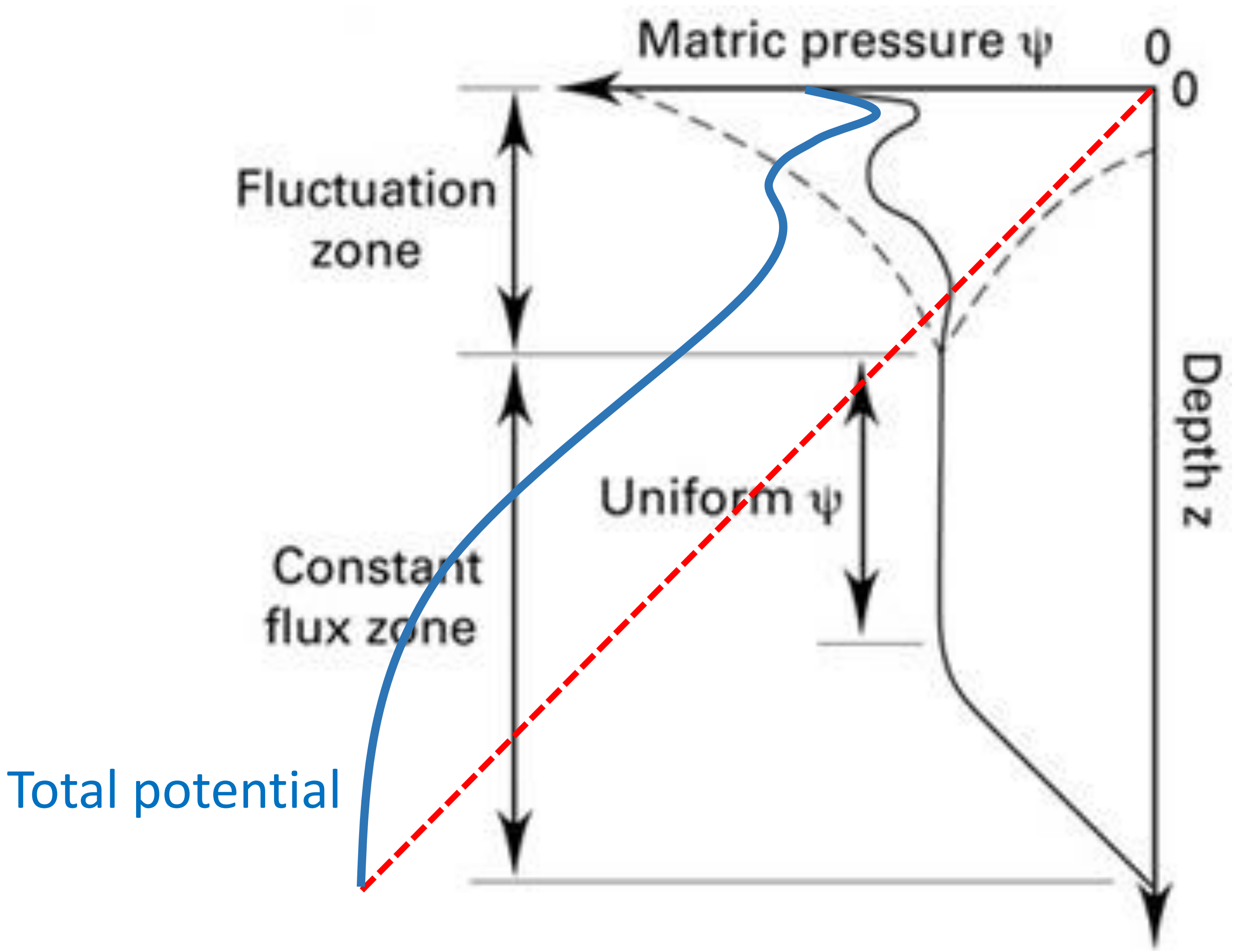
Soil Water Movement



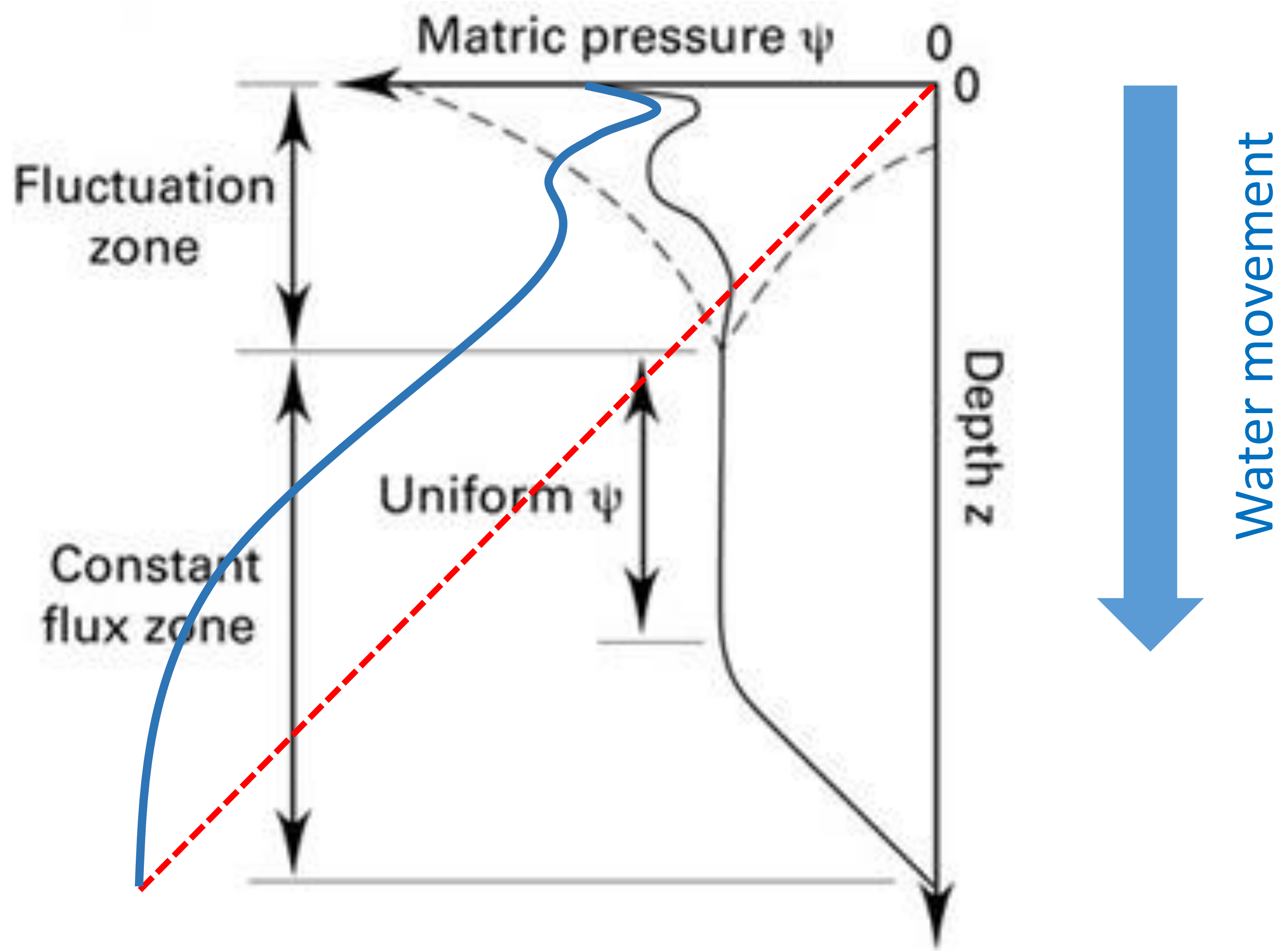
Soil Water Movement



Soil Water Movement

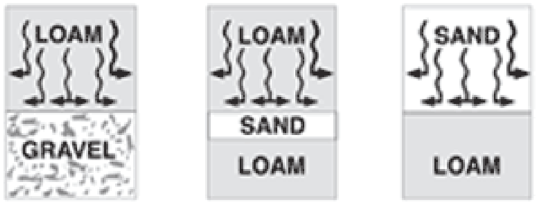


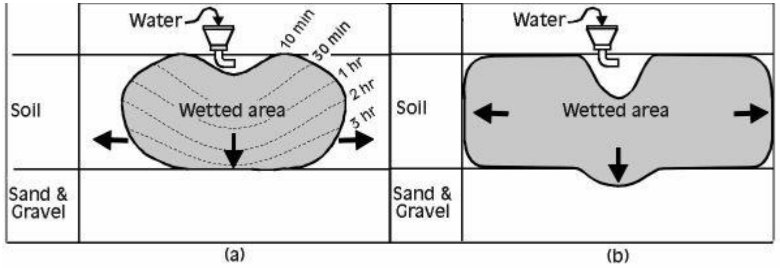
Soil Water Movement

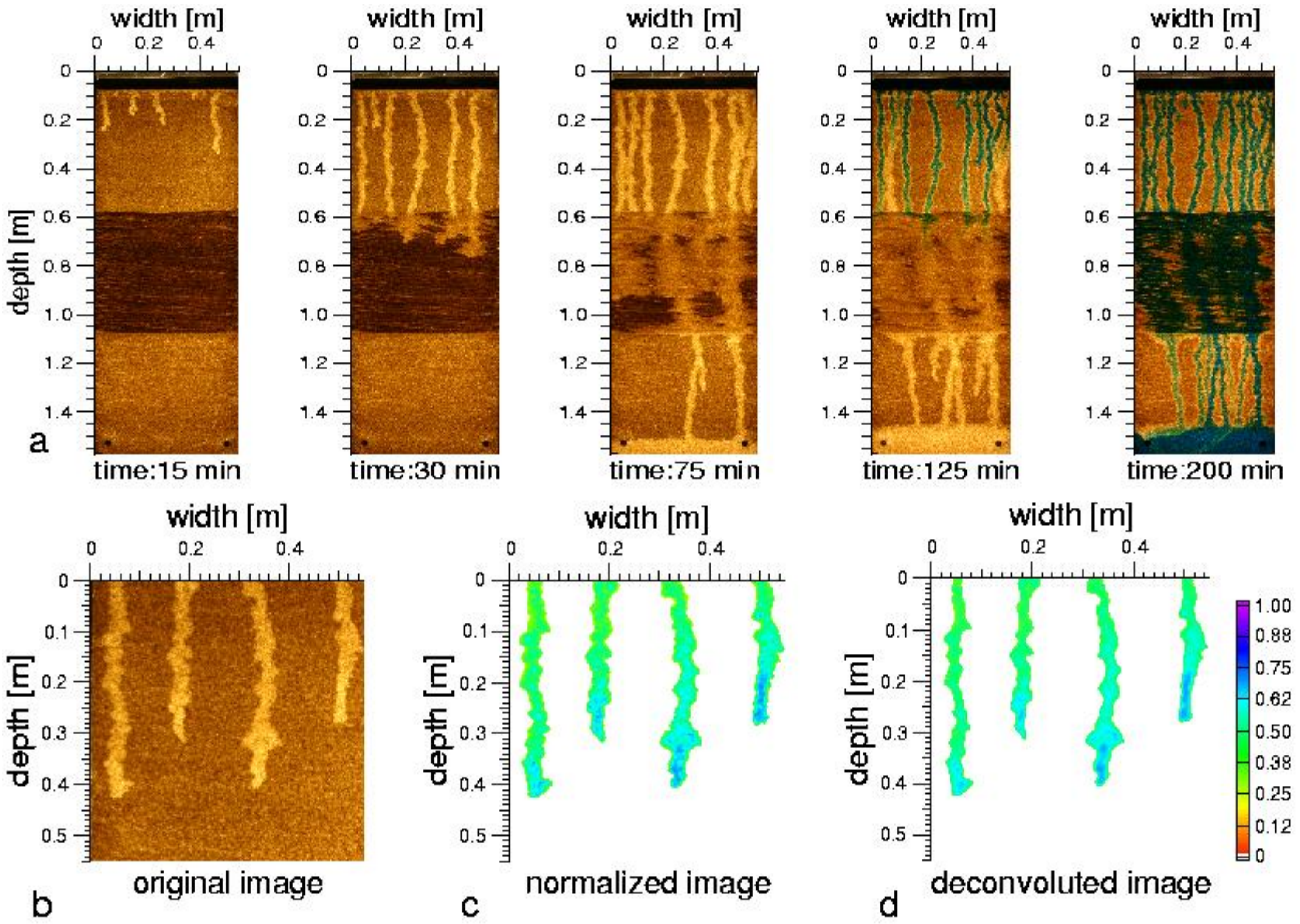


Soil Water Movement

Implications



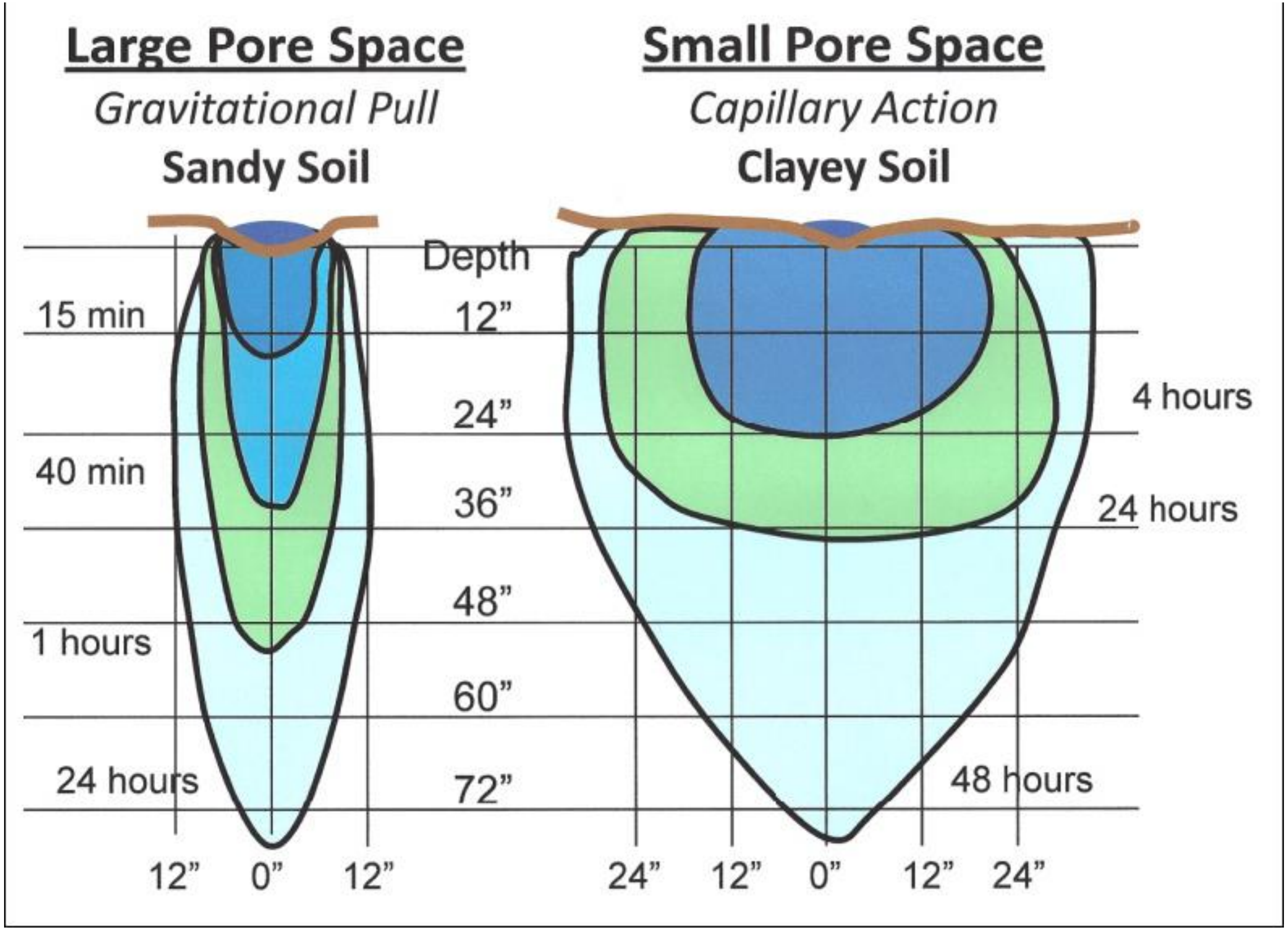




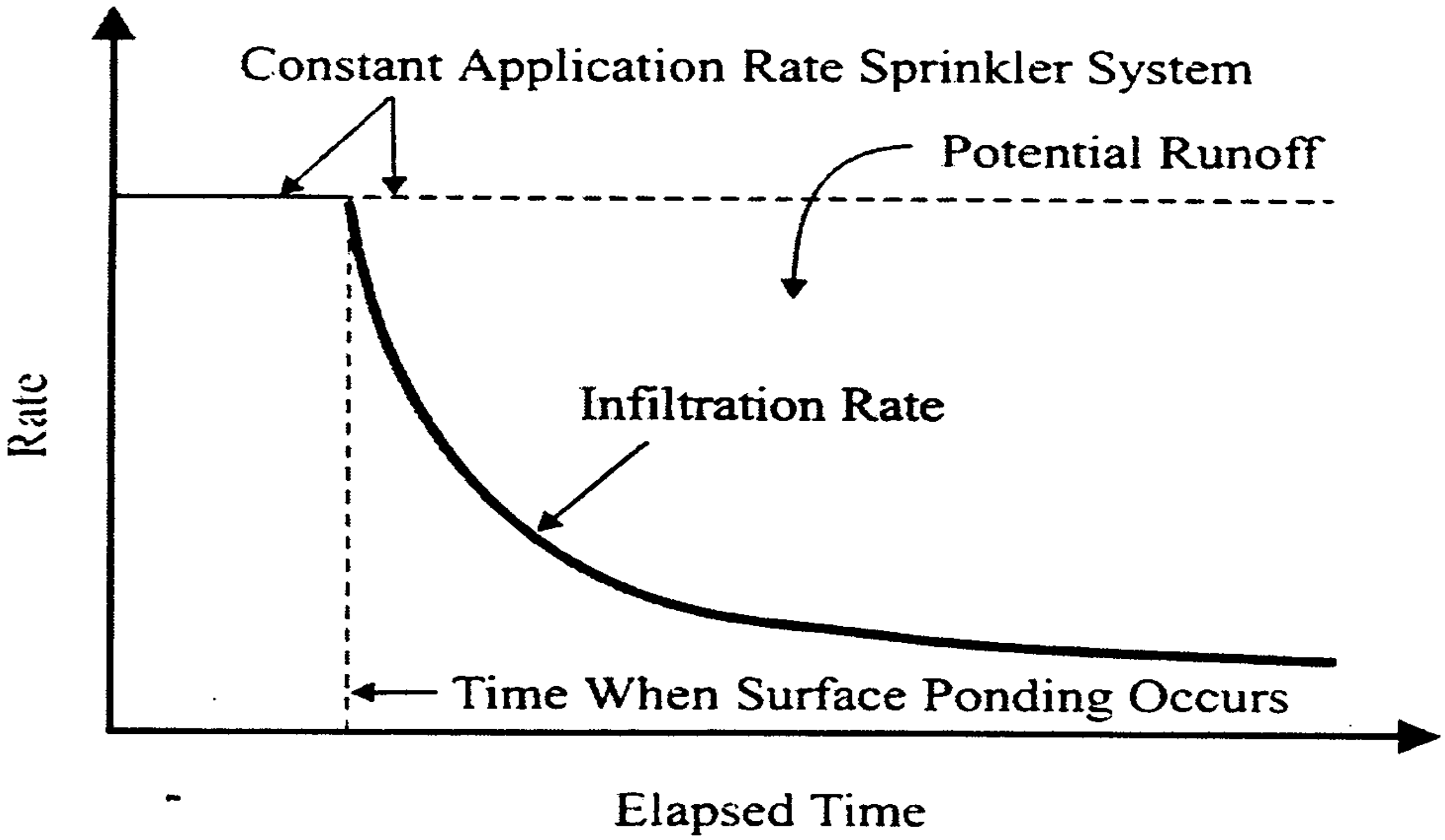
Soil Water Movement

Soil Water Infiltration

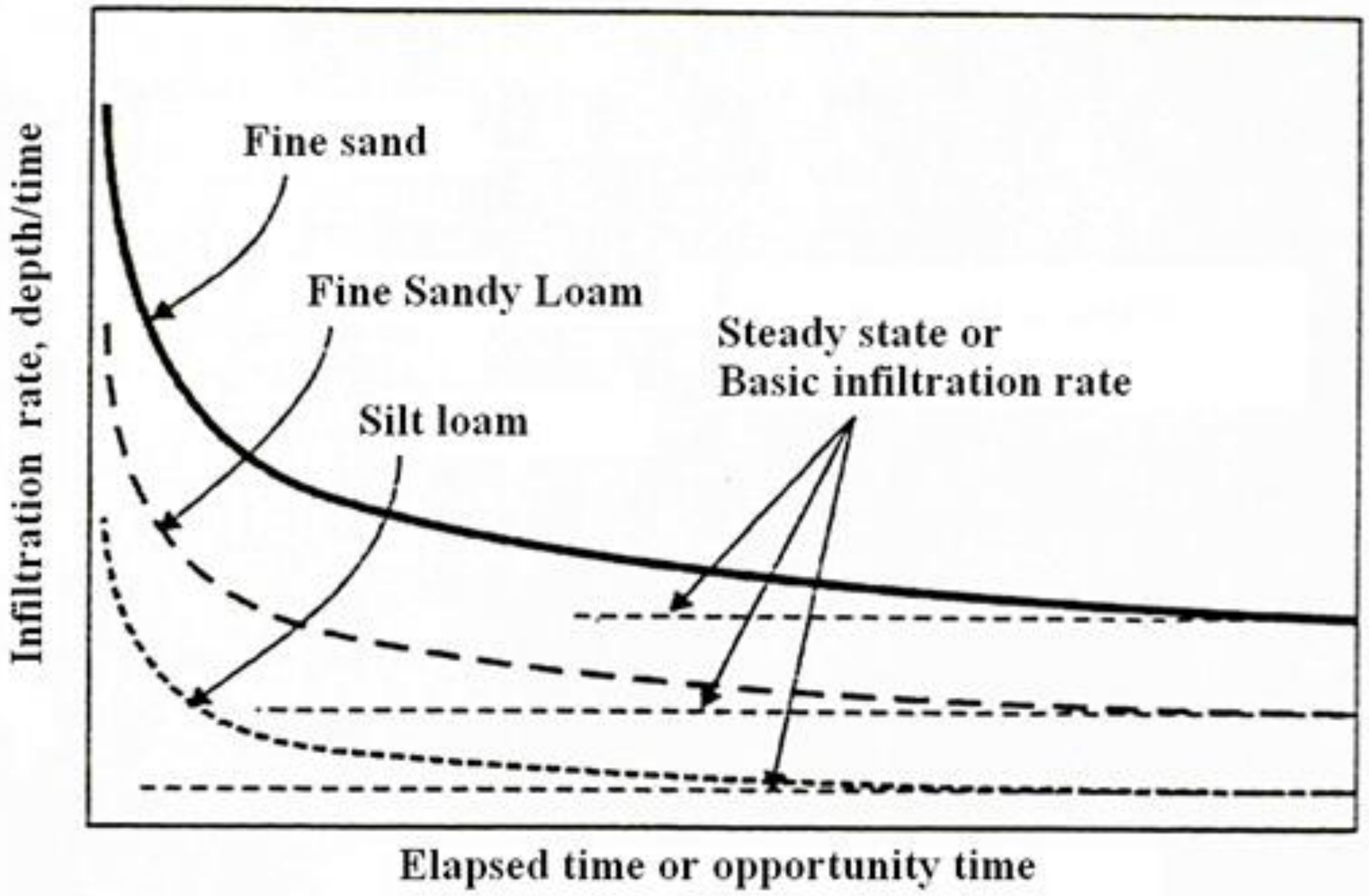
Soil Water Infiltration



Soil Water Infiltration



Soil Water Infiltration

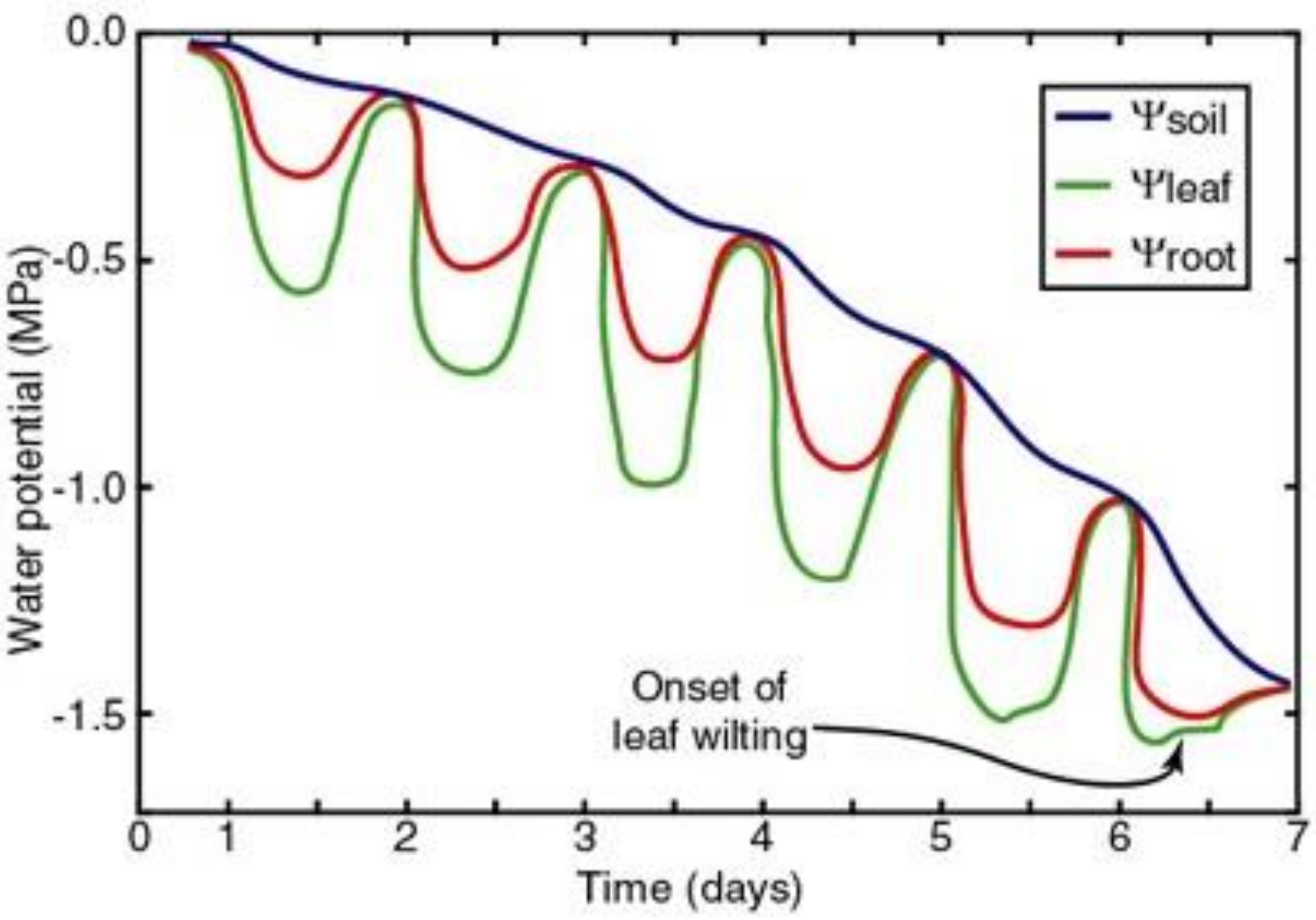


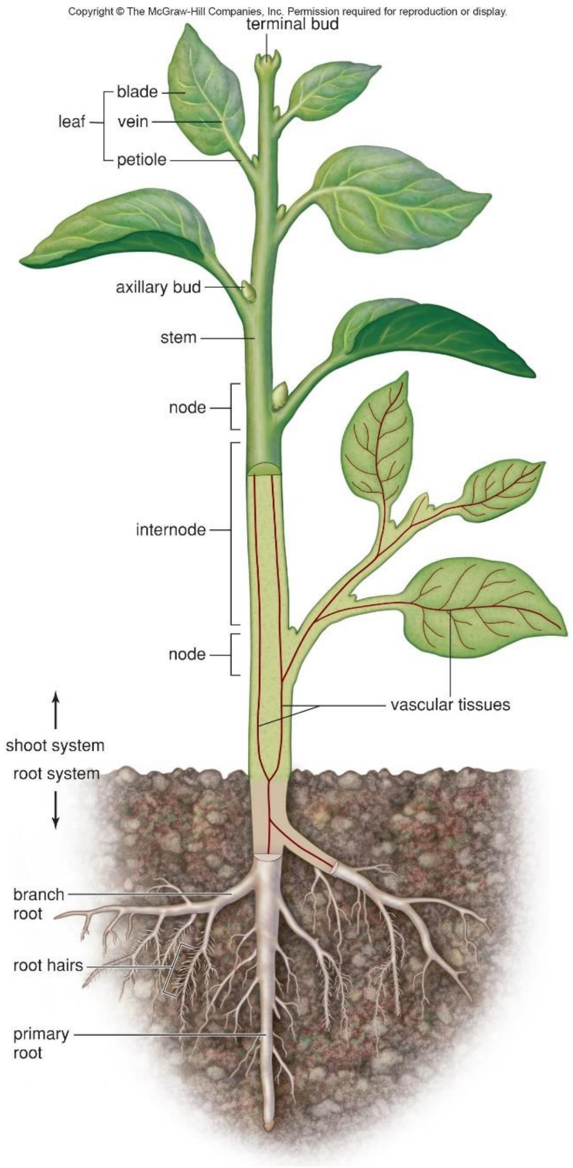
Soil Water Infiltration

Recommended Infiltration Rates based on USDA Soil Textural Classification			
	Short –Term InfiltrationRate (in/hr)	Correction Factor, CF	Estimated Long-term (Design) Infiltration Rate (in/hr)
Type 1. Clean sandy gravels	20	2	10
Type 2. Sand	8	4	2
Type 3. Loamy Sand	2	4	0.5
Type 4. Sandy Loam	1	4	0.25
Type 5. Loam	0.5	4	0.13

Soil Water Infiltration

Soil Water Availability – Process over time





Soil Water Availability - > from the View of a Plant

Total available water capacity within the plant root zone

AWC = available water capacity of the soil; depth of H_2O/depth of soil

Rd = depth of the plant root zone (cm)

If different soil layers have different AWC's, need to sum up the layer-by-layer TAW's

TAW = (AWC1) (L1) + (AWC2) (L2) + . . . (AWCN) (LN)

- L = thickness of soil layer, (cm)
- 1, 2, N: subscripts represent each successive soil layer

Water movement underlies different forces and potentials

– > Gravitation and Matric Potential are controlling

Thank you for your attention