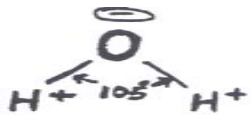
Soil Water

3 Phases

- Solid
- Liquid
- Gas

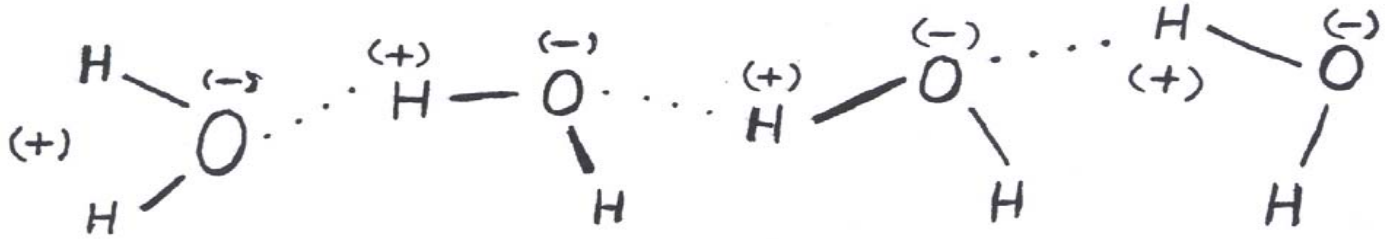
Bent Molecule

- Neutral, but POLAR



Polarity controls movement and retention in soil

1. COHESION

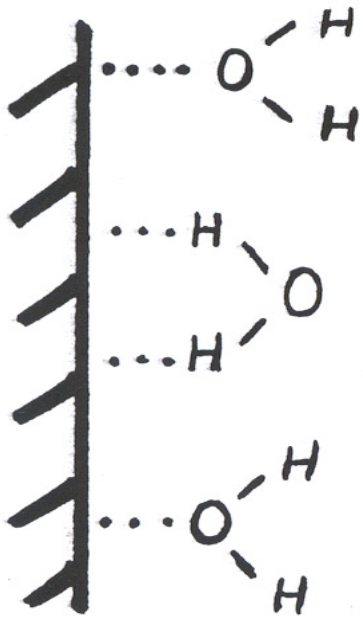


(hydrogen bonding)

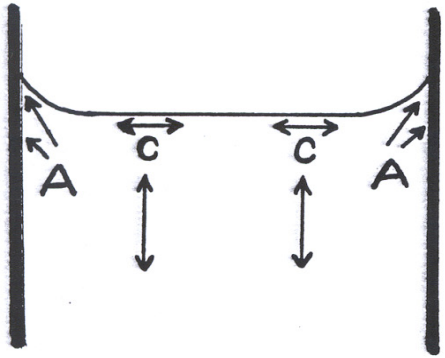
- **responsible for POLYMERIZATION**

- **accounts for relatively high BOILING POINT SPECIFIC HEAT VISCOSITY SURFACE TENSION**

2. ADHESION



responsible for capillary rise



Meniscus - curved air/ water interface

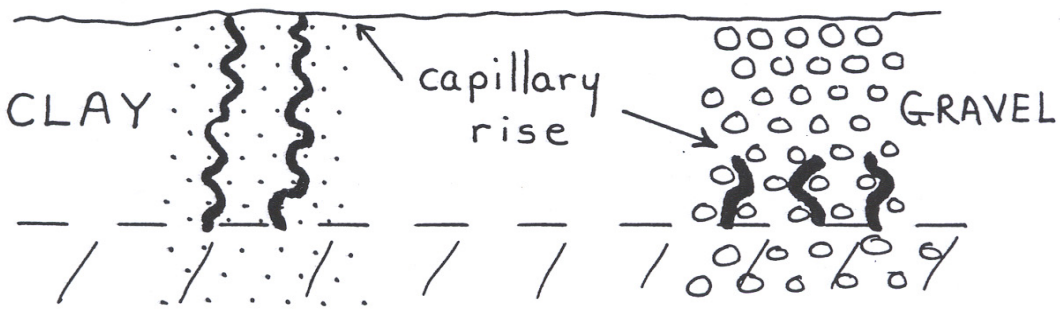
A = adhesion
C = cohesion

Capillarity is caused by:

ADHESION - attraction of water molecules to walls of tube

COHESION - attraction of water molecules to each other, producing surface tension.

SOIL ANALOGY - pores in moist soils behave like thin tubes, hold water by capillarity.

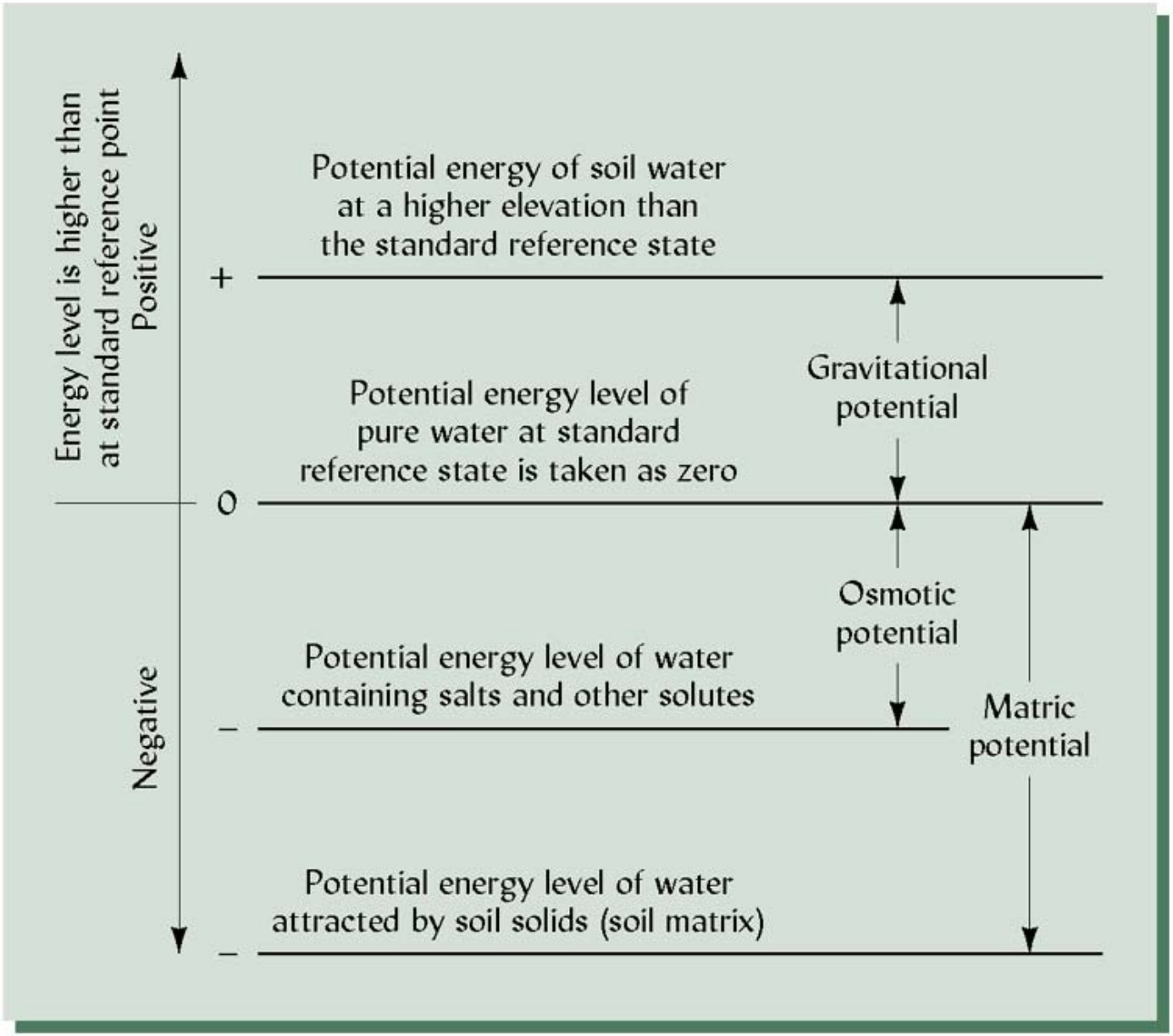


2 Stages of Water Movement

1) Infiltration

2) Subsurface Water Flow

Figure 5.8


Energy level is higher than at standard reference point
Positive
Negative
+
0
−
−
Potential energy of soil water at a higher elevation than the standard reference state
Potential energy level of pure water at standard reference state is taken as zero
Potential energy level of water containing salts and other solutes
Potential energy level of water attracted by soil solids (soil matrix)
Gravitational potential
Osmotic potential
Matric potential

Forms of Water Potential – Ψ

Ψ_G **Gravitational Potential** (+ value)

- determined by the height of water above a reference point

- water flows downward under gravity

Ψ_M **Matric Potential** (- value)

- determined by the strength of the attraction of water to the soil matrix

- most important for unsaturated flow (dry soils)

- water flows from zones of wet soil to zones of dry soil (less negative → more negative)

Ψ_S **Solute (Osmotic) Potential** (- value)

- determined by the concentration of solutes in the soil water

- more negative for high solute concentrations

- water flows from zones of low solute to high solute concentrations

- most important for root-water interaction

Ψ_P **Pressure Potential (+ or – value)**

- determined by amount of pressure imposed on soil water

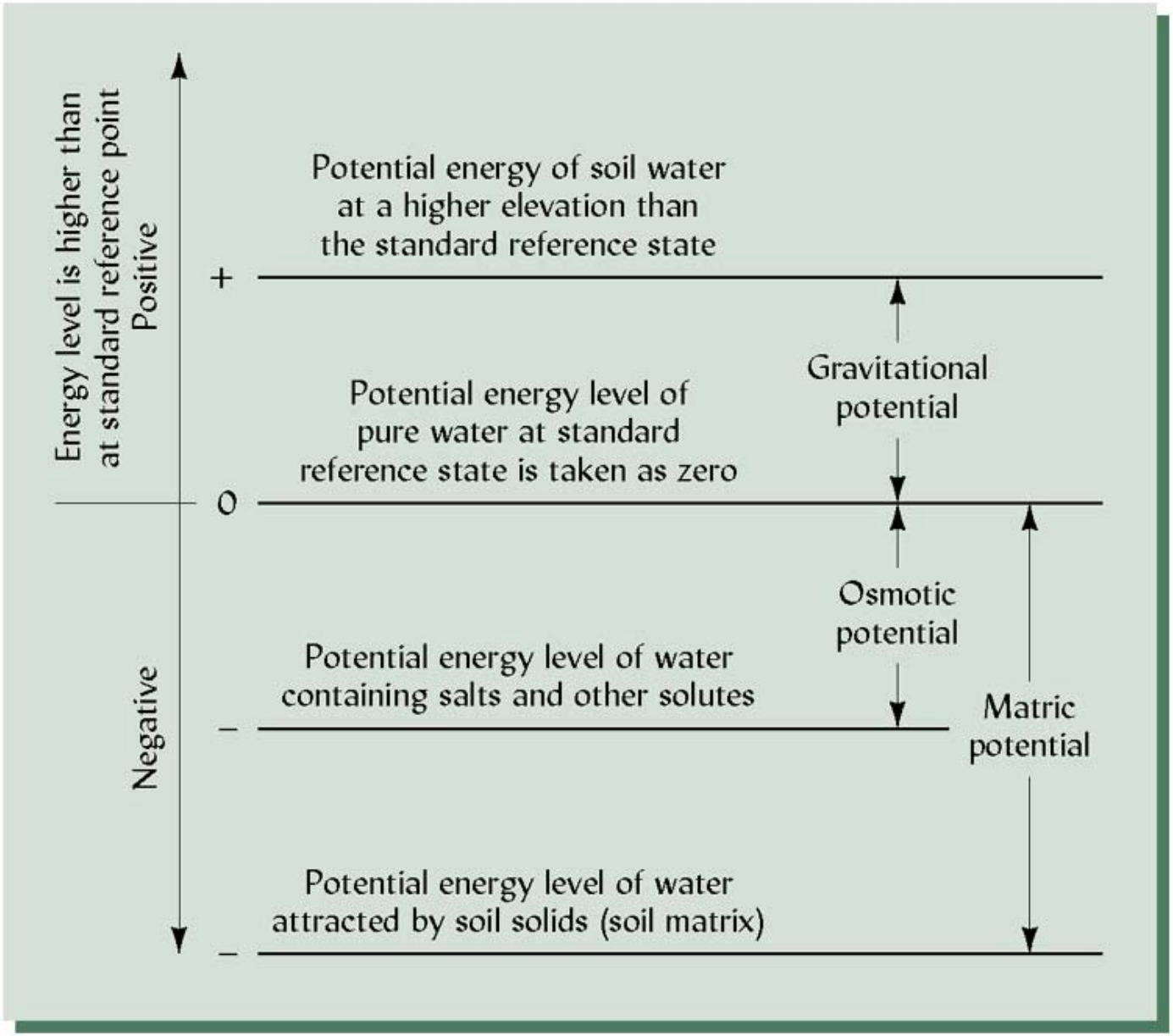
- usually zero, but there are exceptions

Flooded Soils

Soils with water tables – ie artesian wells

$$\Psi_{TOTAL} = \Psi_g + \Psi_m + \Psi_s + \Psi_p$$

Figure 5.8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2 Stages of Water Movement

1) Infiltration

2) Subsurface Water Flow

Infiltration Rate ~ cm/hr

in general

$$\text{Infiltration rate} = \text{hydraulic conductivity} \times \frac{\Delta\Psi}{\Delta X}$$

Hydraulic Conductivity is:

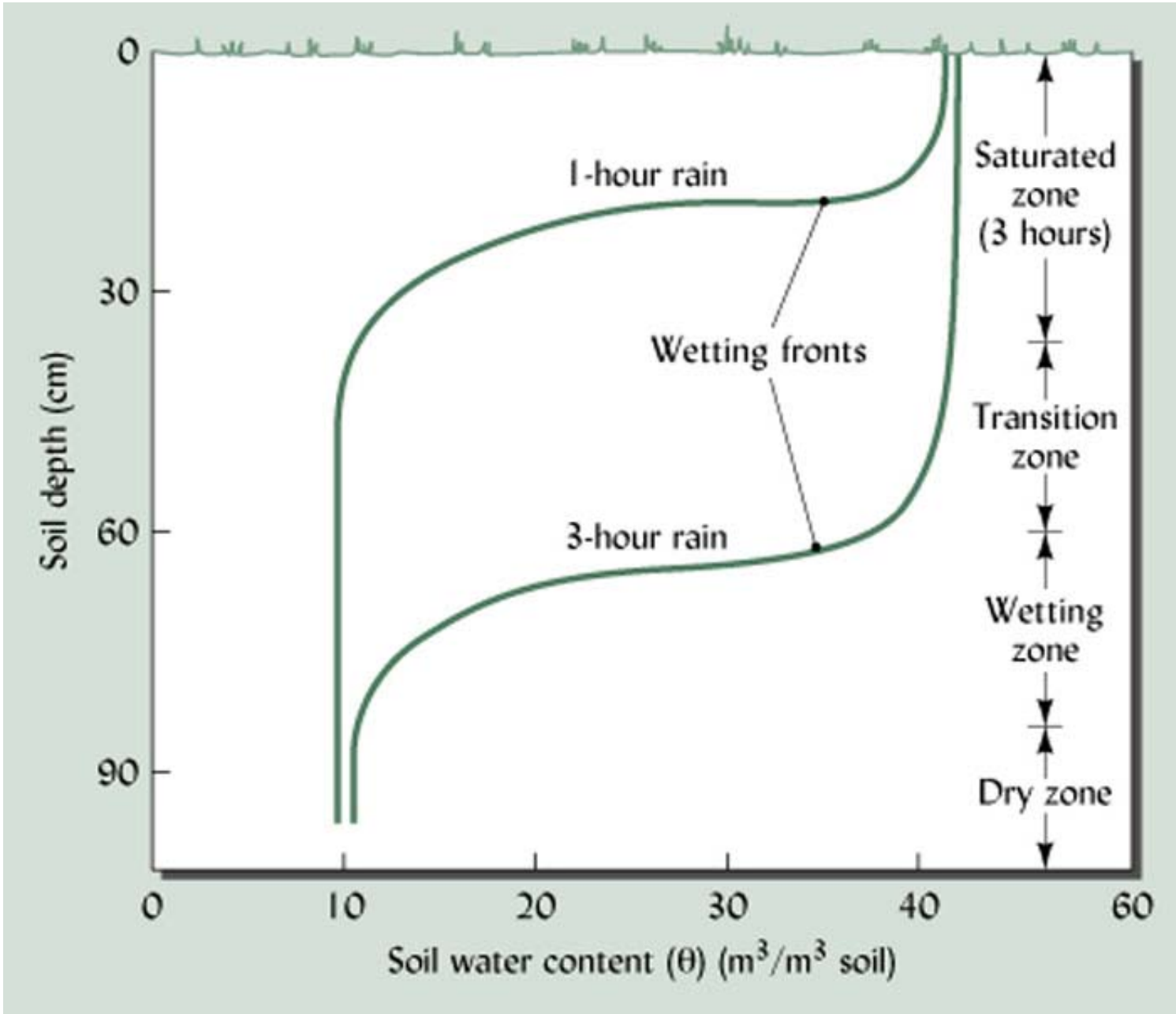
a measure of characteristics unique to each soil type which affects water flow

it is a function of:

1) soil water content

2) size distribution and tortuosity of pores

Figure 5.27


0
30
60
90
Soil depth (cm)
1-hour rain
3-hour rain
Wetting fronts
Saturated zone (3 hours)
Transition zone
Wetting zone
Dry zone
0
10
20
30
40
60
Soil water content (θ) (m³/m³ soil)

Volumetric Water Content -

- volume of water in soil relative to total soil volume

$$\theta = \frac{V_W}{V_T} = \frac{V_W}{V_S + V_P}$$

θ (saturated) = 40-50% (sands)
$\geq$ 50% (clays)

θ (saturated) - depends on total porosity

Importance of Water Content -

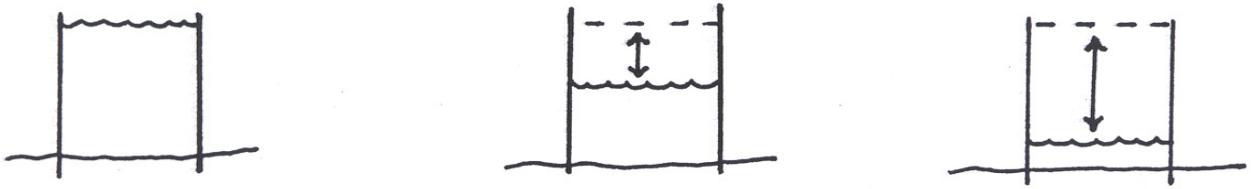
- impact on plant growth --> too little, too much

- effects on physical properties --> s t r e n g t h , p l a s t i c i t y , compactibility, trafficability, etc.

WATER MOVEMENT IN SOILS

Infiltration - entry of water into soils

Infiltration rate - depth of water entering soil in a unit of time (e.g. cm/hr)



t = 0 t = 1 hr. t = 2 hrs.

Factors influencing infiltration rate:

1. Height of water column above soil
2. Number & size of soil pores
3. Water content of soil
4. Nature of soil surface

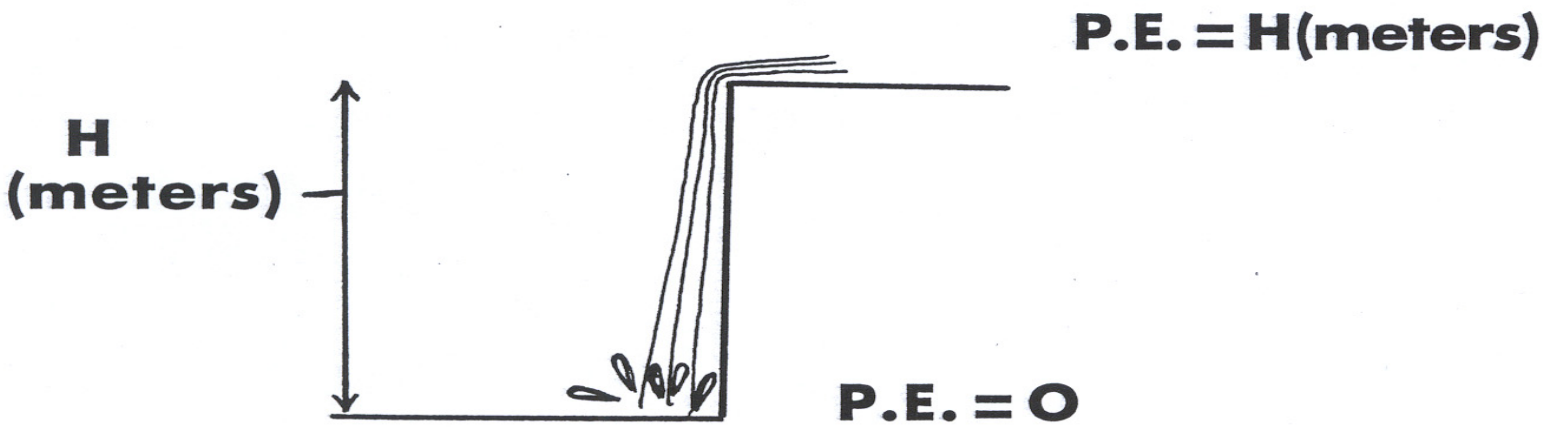
Sandy Soils - rapid infiltration rates (Why?)

Clays, Clay Loams - slow infiltration rates (Why?)

GRAVITATIONAL POTENTIAL Ψg

energy of water that is potentially available to be released when water moves from a high position to a lower position.

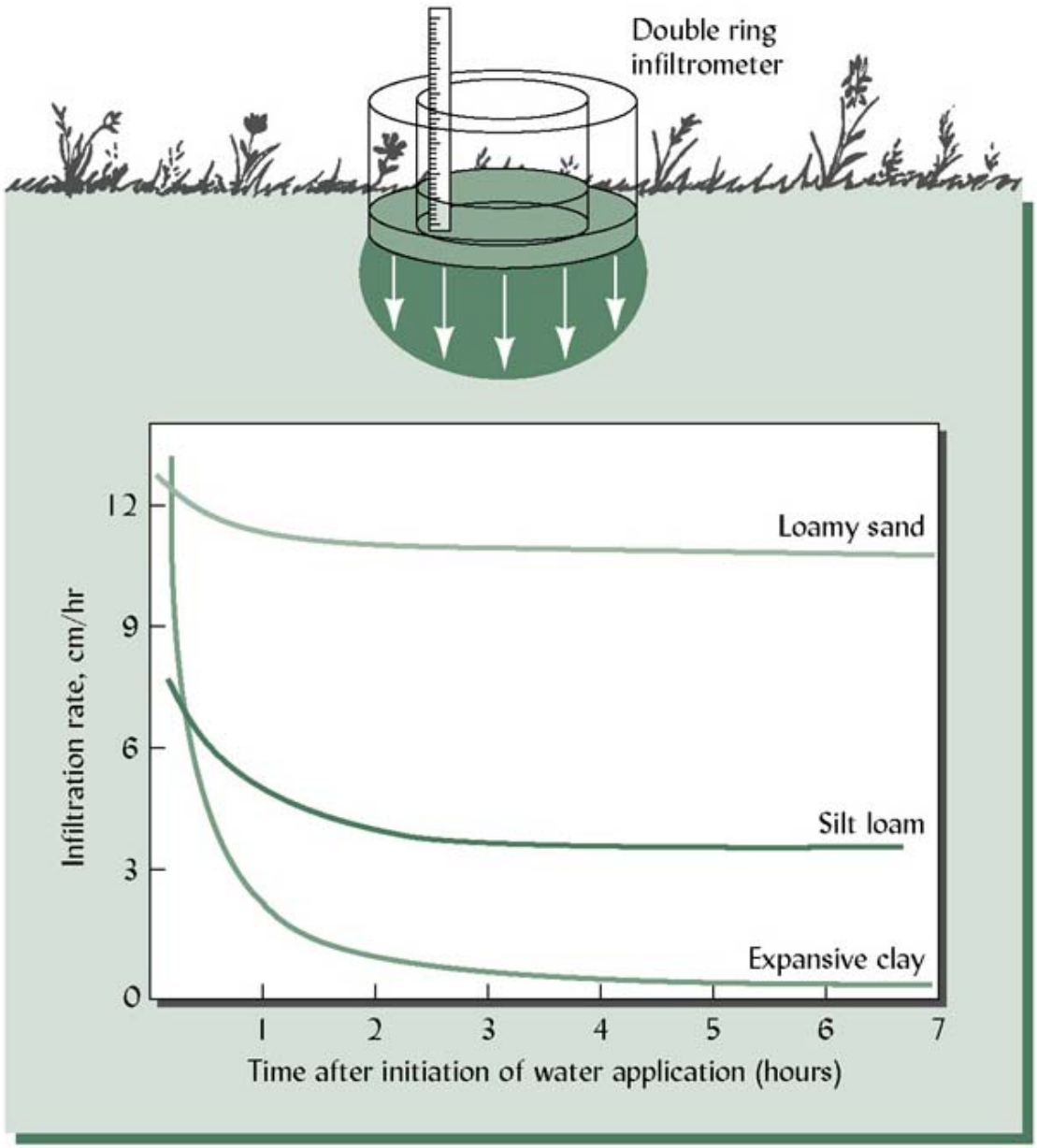
e.g. water flowing downward under force of gravity.

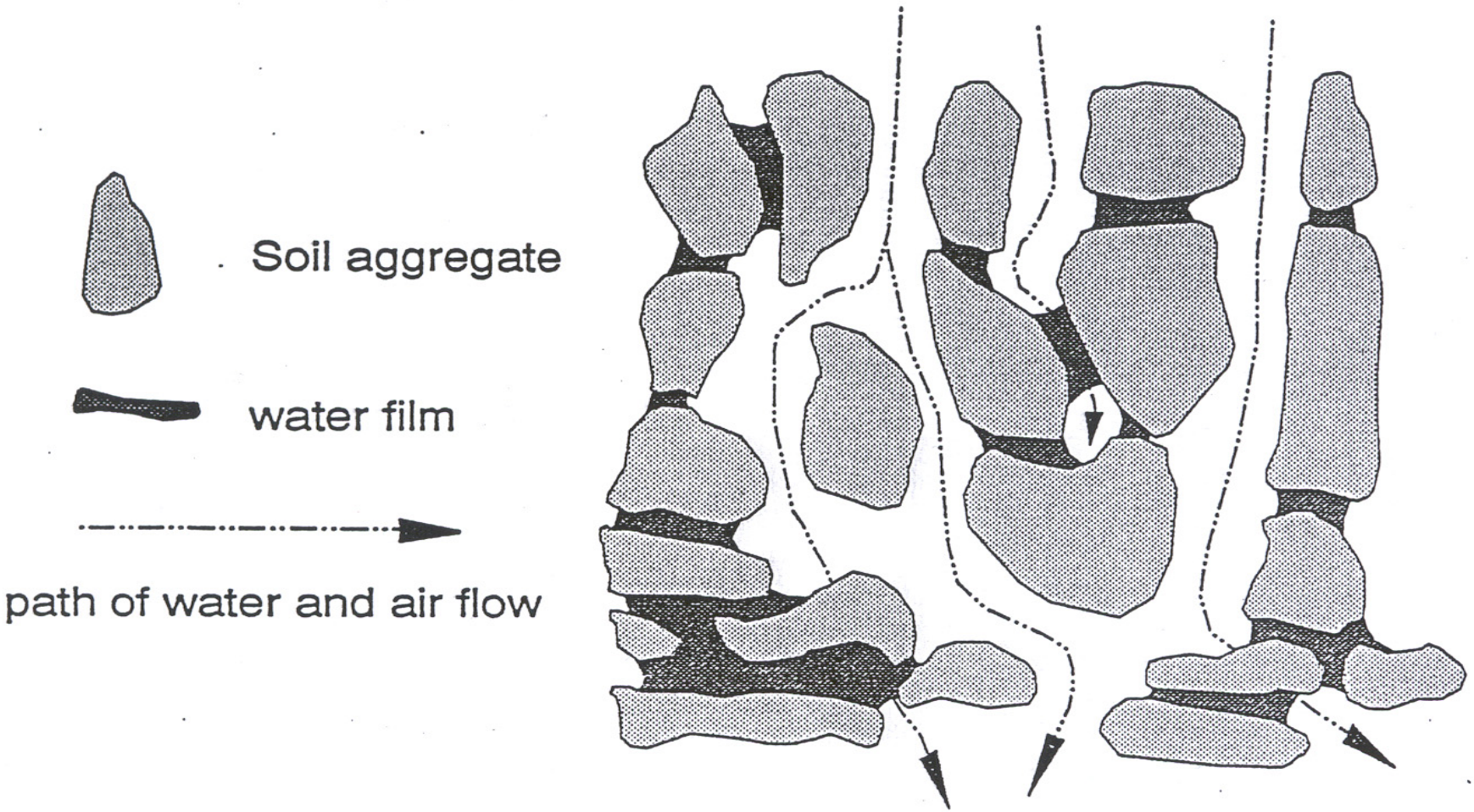


Reference Point - base of soil profile
bottom of rooting zone

Ψg is a positive value

Figure 5.25


Double ring
infiltrometer
Infiltration rate, cm/hr
12
9
6
3
0
Loamy sand
Silt loam
Expansive clay
1
2
3
4
5
6
7
Time after initiation of water application (hours)


Soil aggregate
water film
path of water and air flow

2 Stages of Water Movement

1) Infiltration

2) Subsurface Water Flow

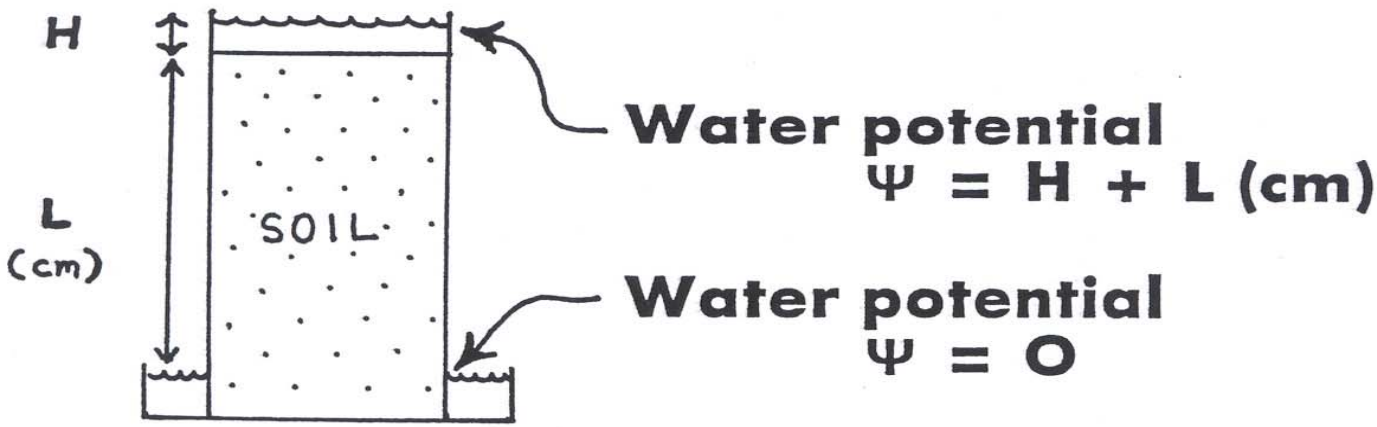
Saturated Flow

- occurs when pores are water-filled

- most rapid in larger pores (e.g. sands)

- flow in response to potential gradients:

Gravity (Ψ_G) & Pressure (Ψ_P)



- water drains freely from large pores by gravity and pressure Ψ's

Unsaturated Flow

- more common that saturated flow

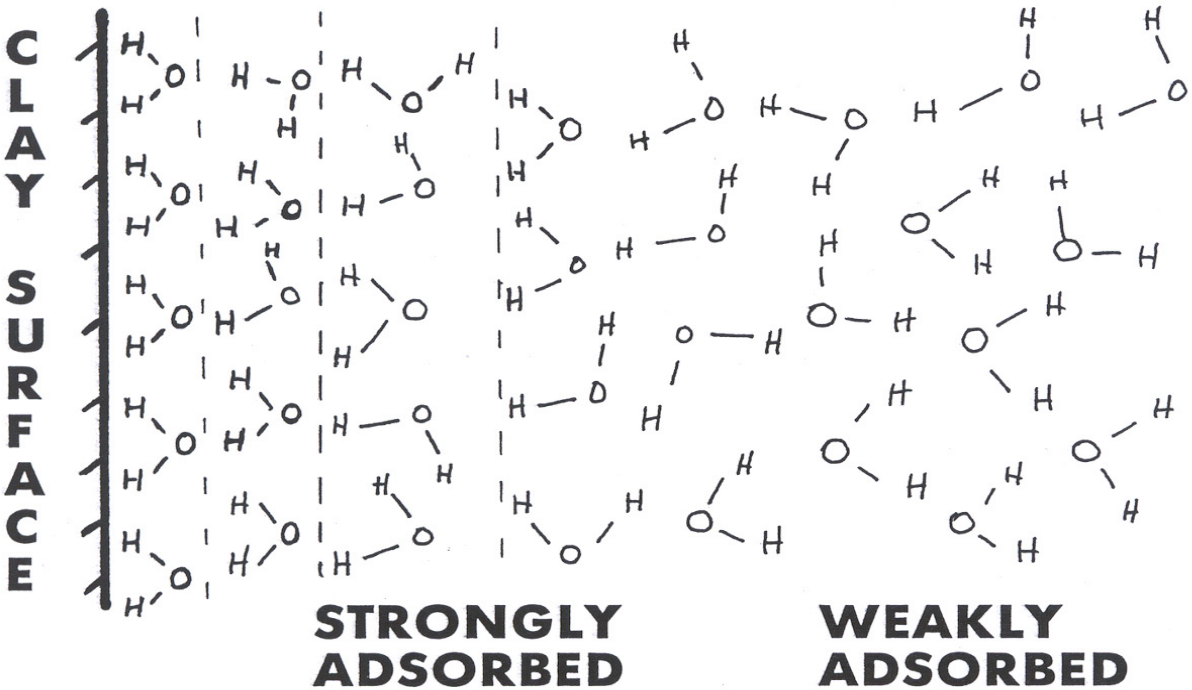
- more important than saturated flow?

- controlled by Matric Potential (Ψ_M)

- movement from areas of less negative to more negative potential

MATRIC POTENTIAL Ψm

- second main force of water retention
- due to adhesion (polarity)
- most important for fairly dry soils, water near particle surface.



Effect of Matric Potential is to reduce the free energy

Ψm is a negative value

Capillary Rise

Capillarity is the tendency for water to rise against the gravity

Function of Water Adhesion and Cohesion

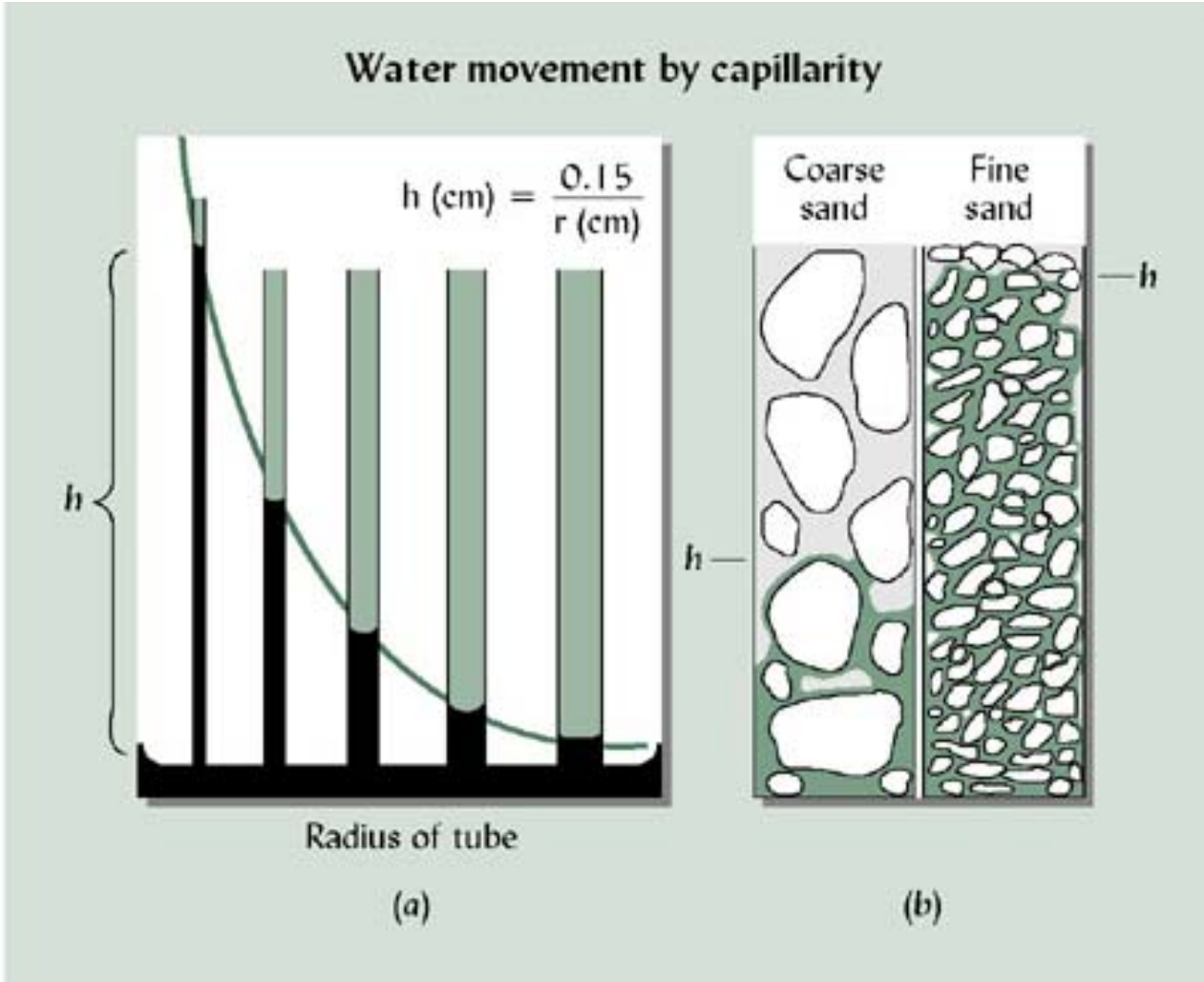
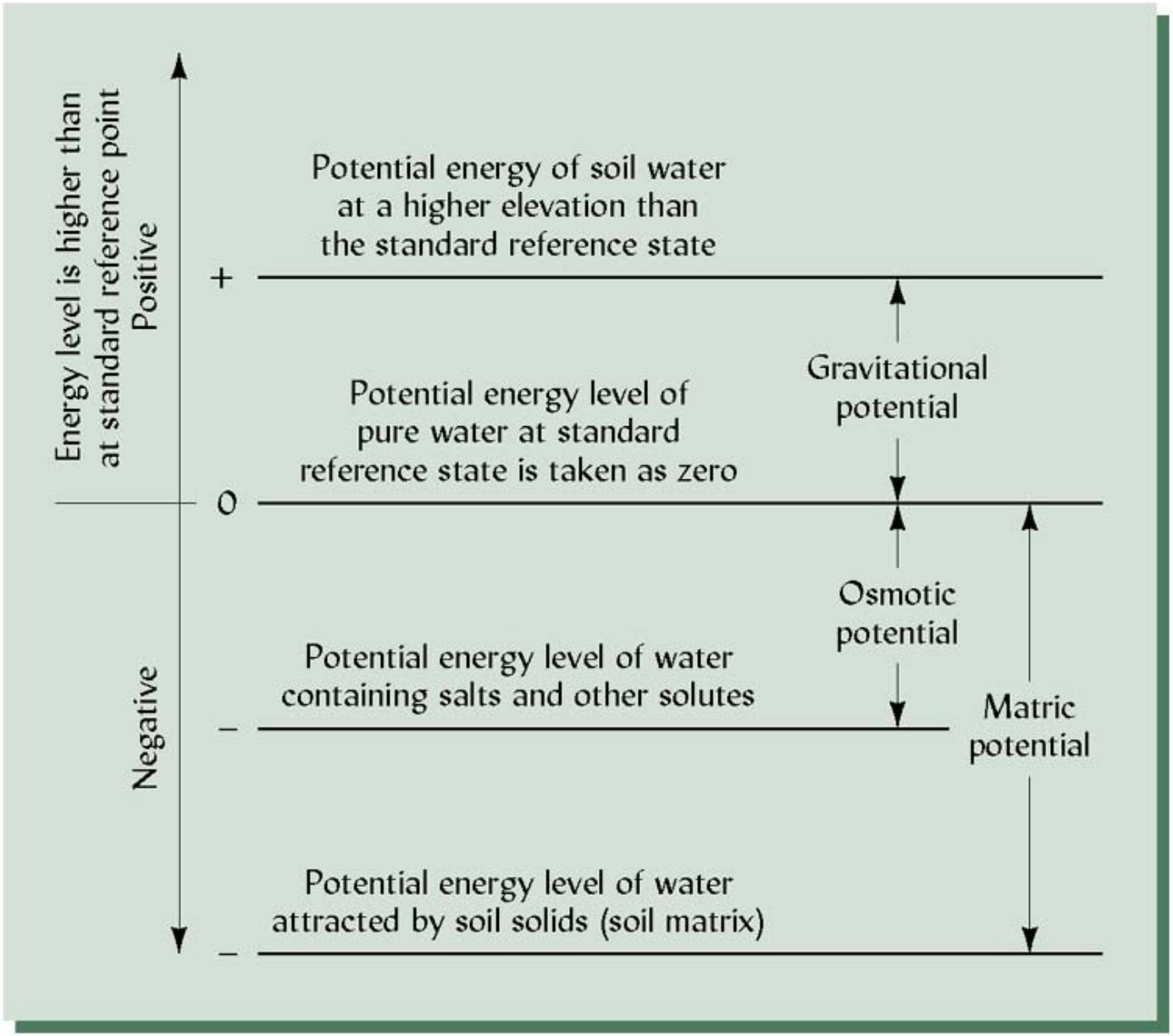


Figure 5.6

Figure 5.8


Energy level is higher than at standard reference point
Positive
Negative
+
0
−
−
Potential energy of soil water at a higher elevation than the standard reference state
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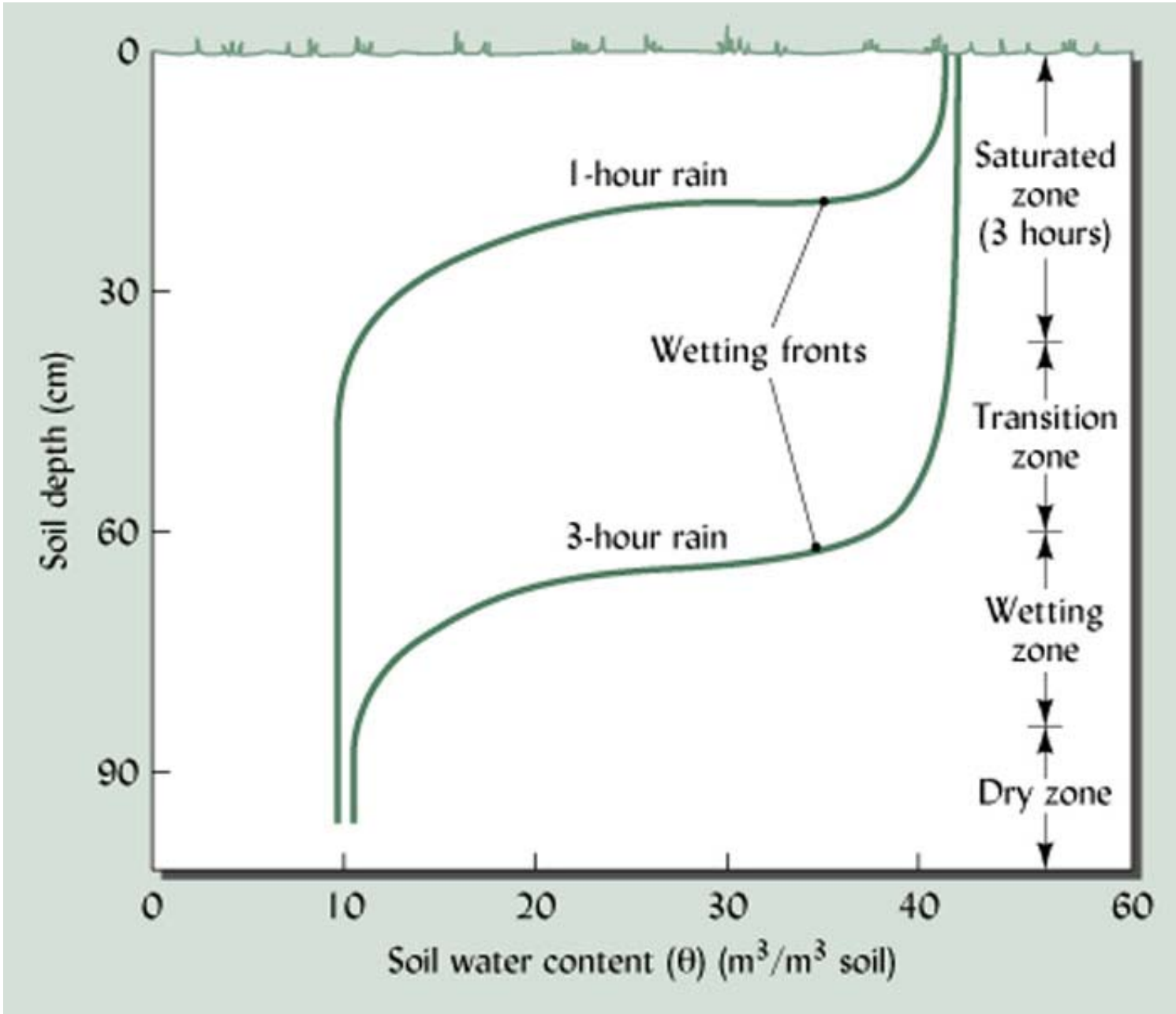
Gravitational potential
Osmotic potential
Matric potential

Figure 5.27


0
30
60
90
Soil depth (cm)
1-hour rain
3-hour rain
Wetting fronts
Saturated zone (3 hours)
Transition zone
Wetting zone
Dry zone
0
10
20
30
40
60
Soil water content (θ) (m³/m³ soil)

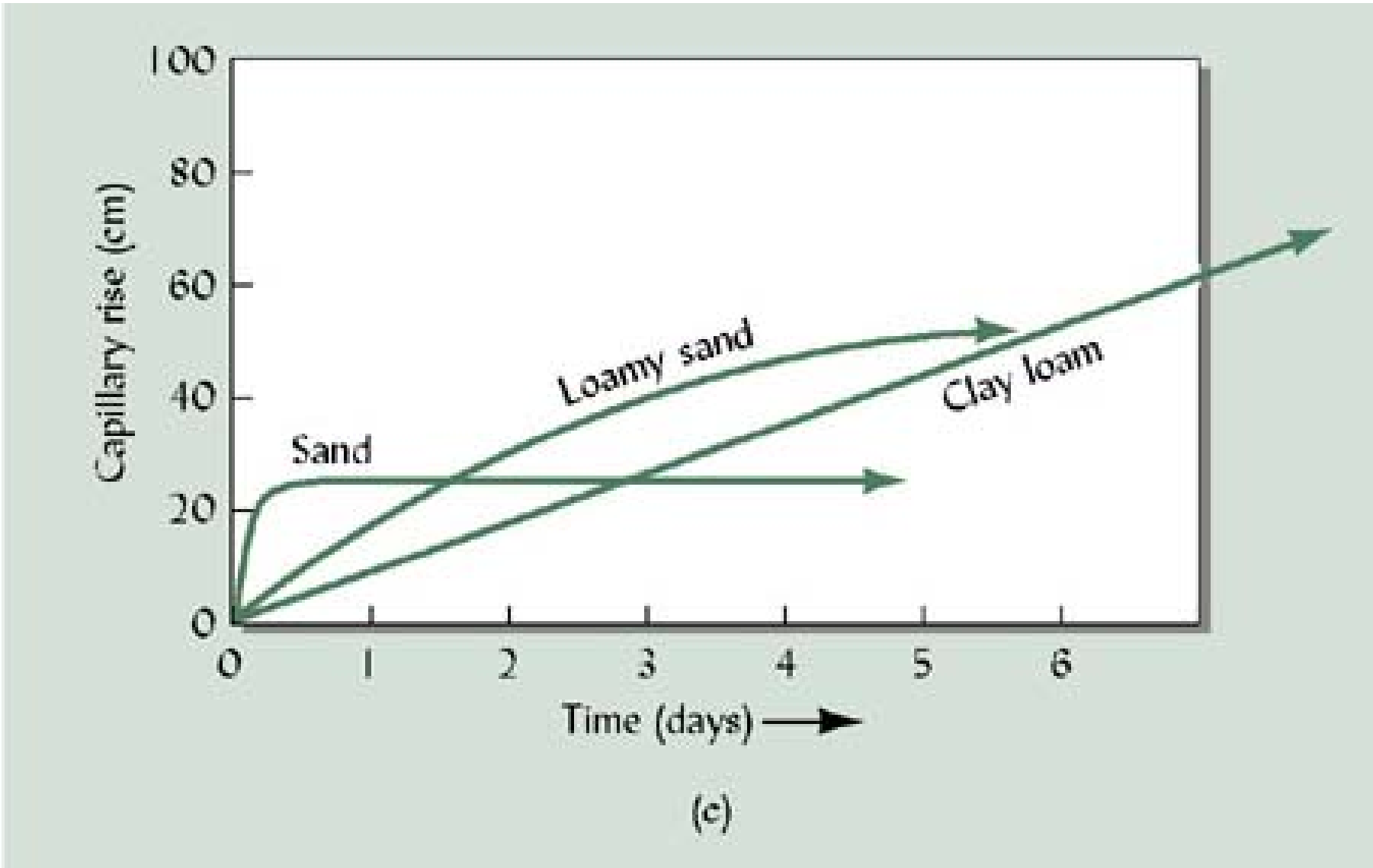
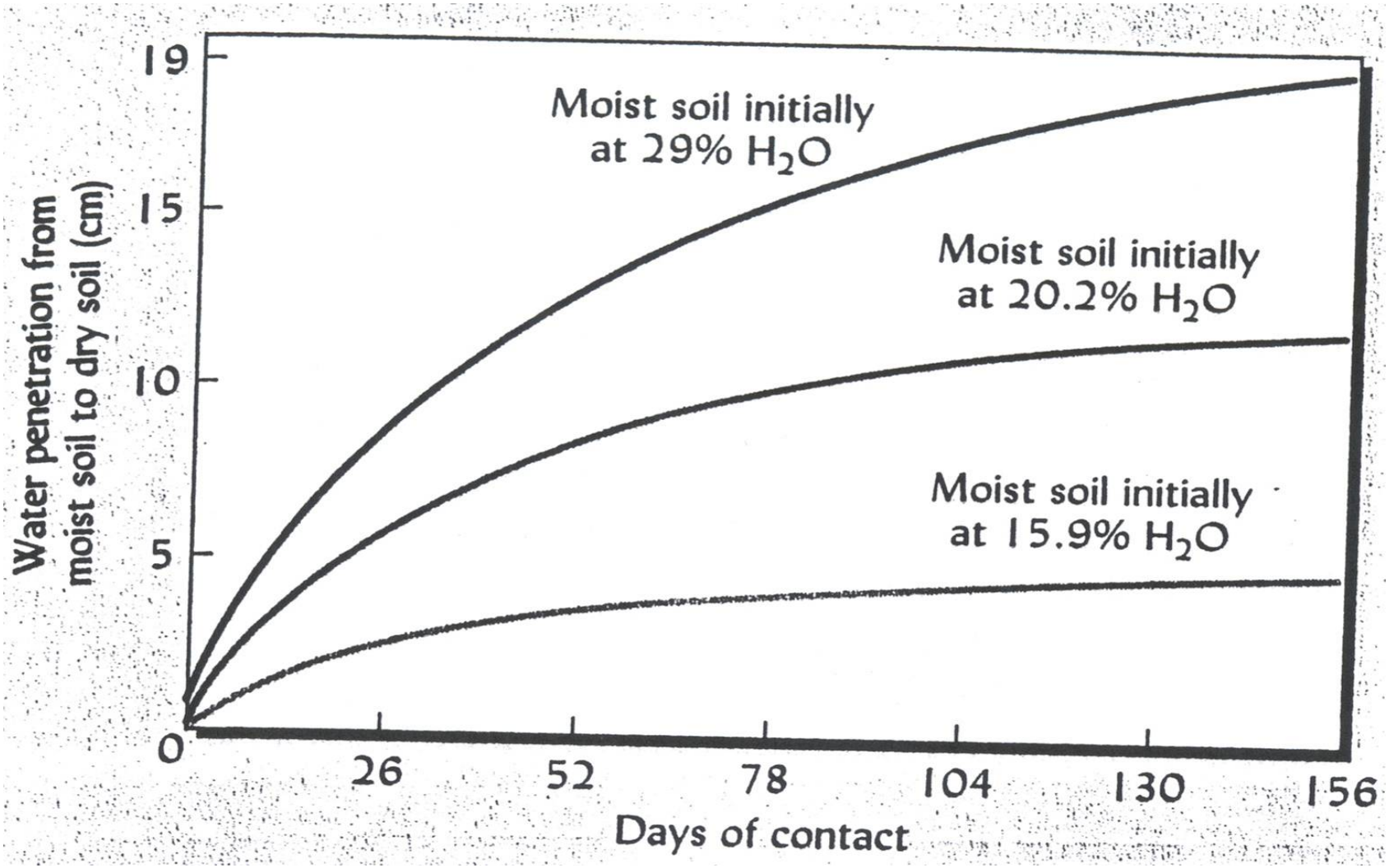

100
80
60
40
20
0
Capillary rise (cm)
Sand
Loamy sand
Clay loam
0
1
2
3
4
5
6
Time (days)
(c)

Figure 5.6


Water penetration from moist soil to dry soil (cm)
19
15
10
5
0
Moist soil initially at 29% H_2O
Moist soil initially at 20.2% H_2O
Moist soil initially at 15.9% H_2O
26
52
78
104
130
156
Days of contact

5.24

Water Movement vs. Water Storage

The soil matrix retains water against the pull of gravity

- this is controlled by the matric potential (Ψ_M)
- and is a function of

Capillarity – important in wet soils

Adsorption – important when soil is below field capacity

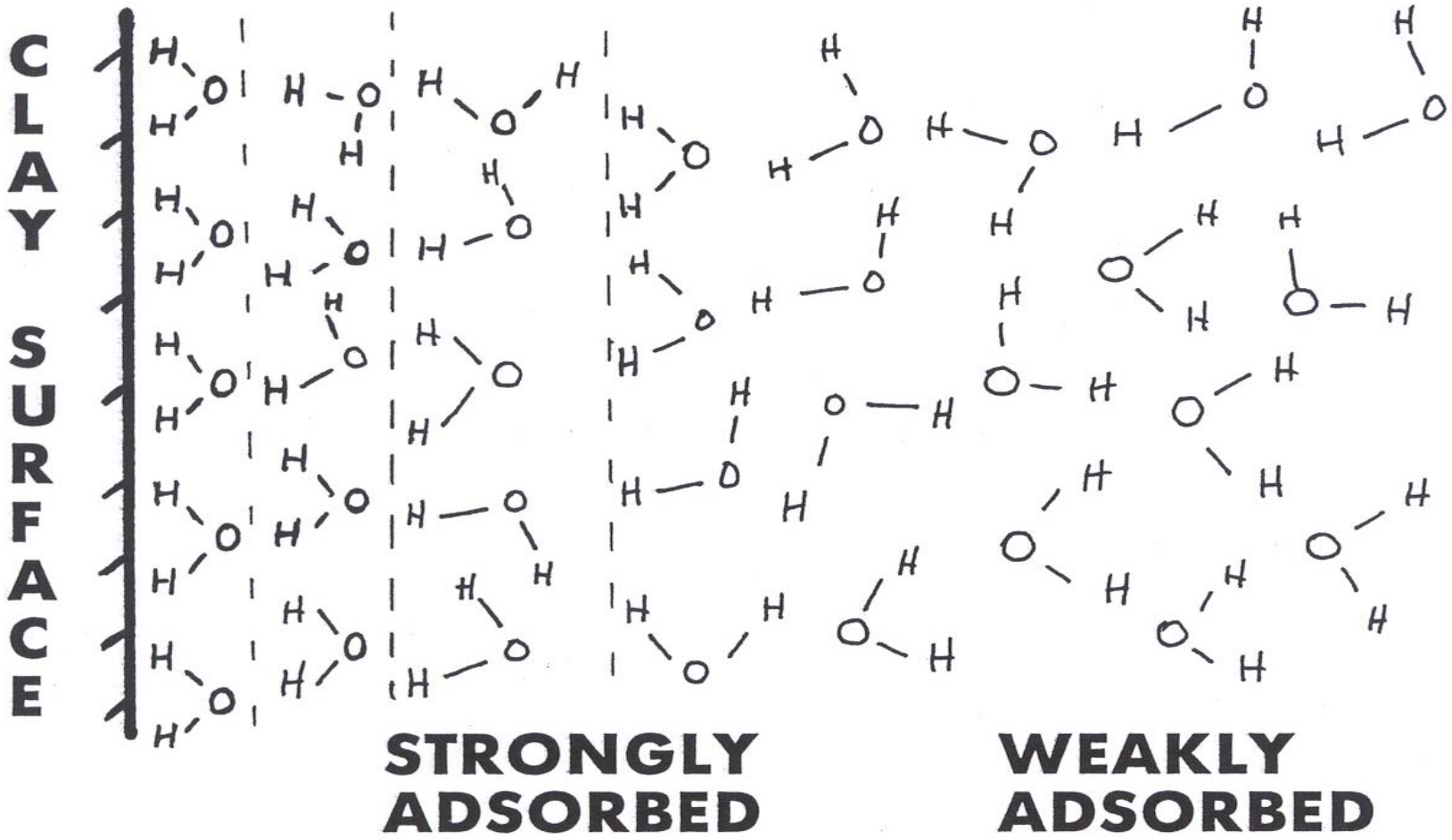

CLAY SURFACE
STRONGLY ADSORBED
WEAKLY ADSORBED

Figure 5.2

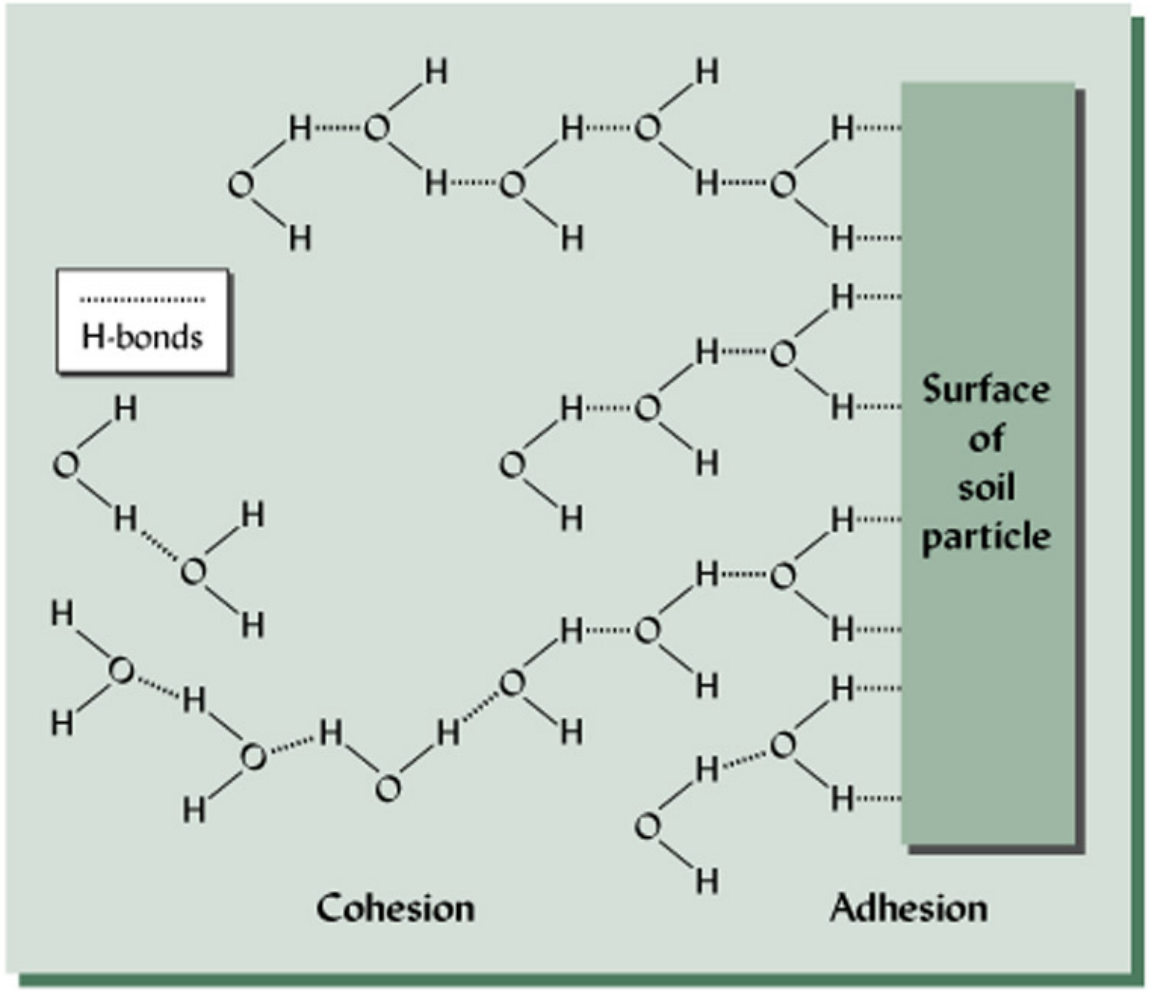
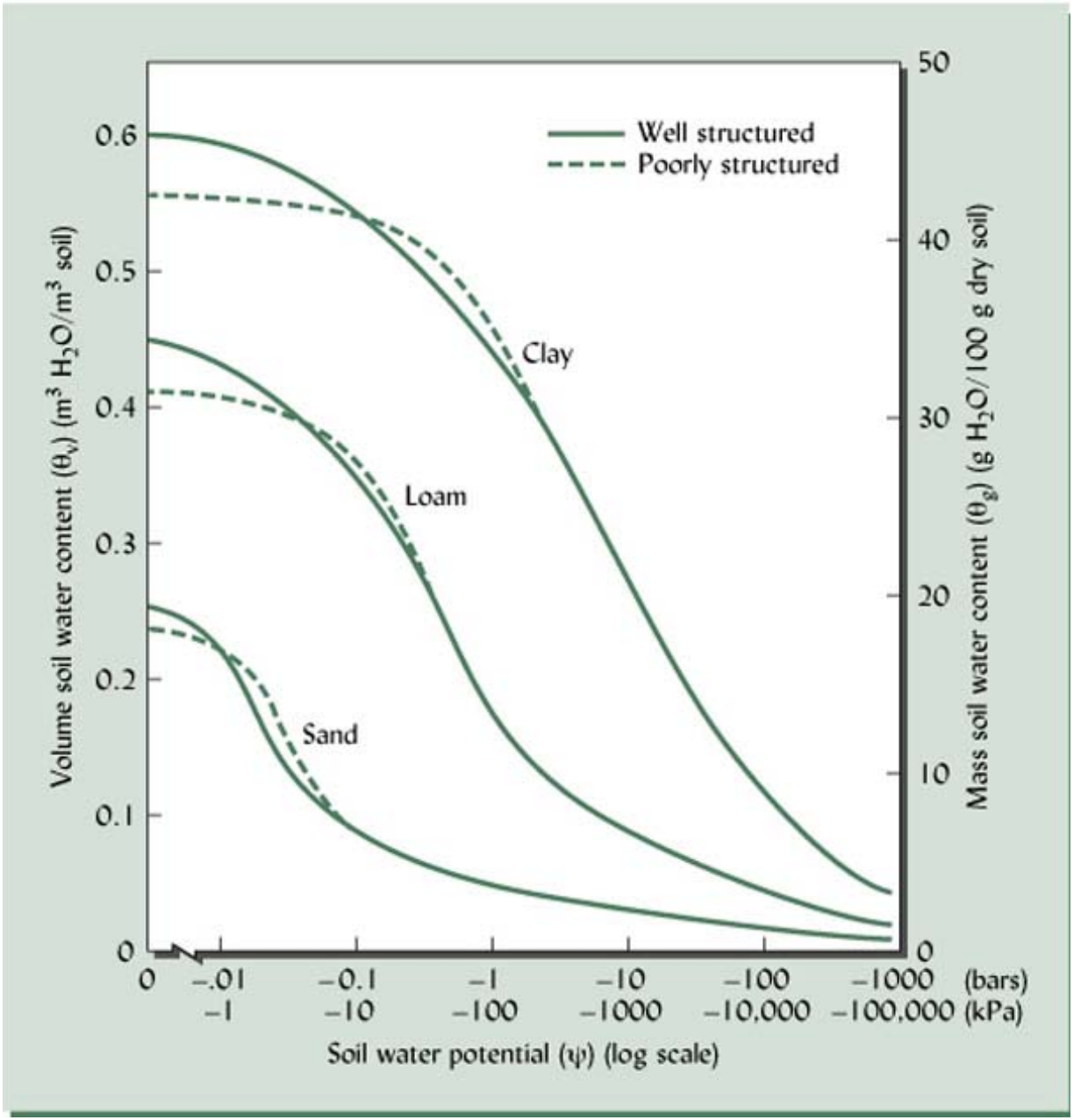
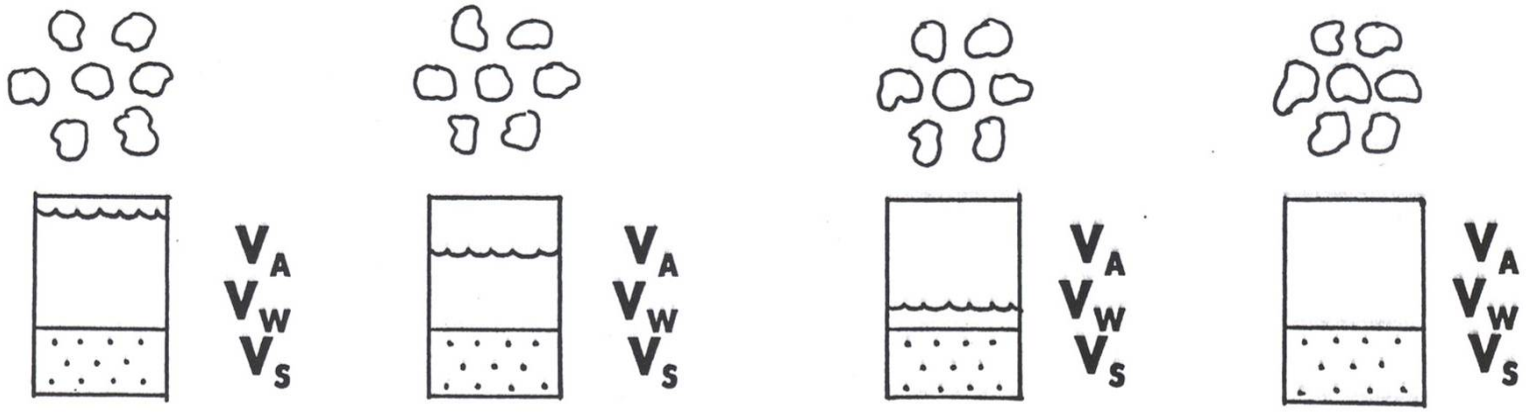


Figure 5.12


Well structured
Poorly structured
Clay
Loam
Sand
Volume soil water content (θ_v) (m^3 H_2O/m^3 soil)
Mass soil water content (θ_g) (g H_2O/100 g dry soil)
0.6
0.5
0.4
0.3
0.2
0.1
0
50
40
30
20
10
0
0 −.01 −0.1 −1 −10 −100 −1000 (bars)
−1 −10 −100 −1000 −10,000 −100,000 (kPa)
Soil water potential (ψ) (log scale)

DEGREES OF SOIL WETNESS



SATURATED	FIELD-CAPACITY	PERMANENT WILTING POINT	OVEN-DRY

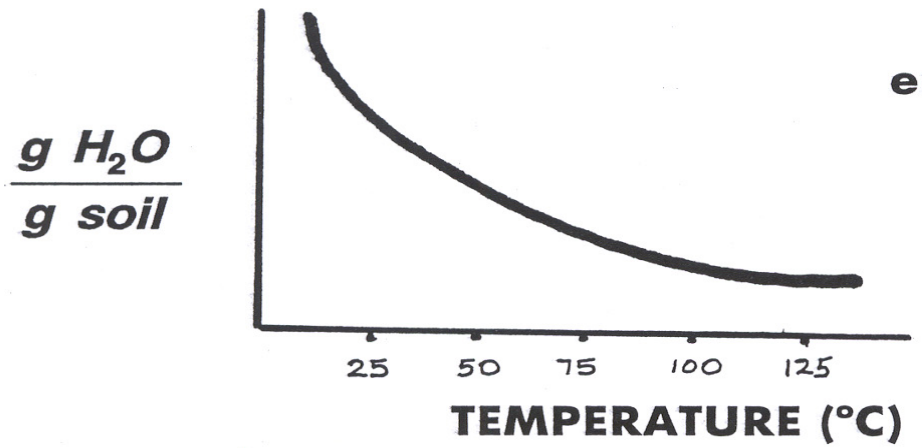
Importance:

Condition for anoxic soils (anaerobic)	Condition of maximum available water after gravitational drainage	Condition of plant death	Reference point for soil weight

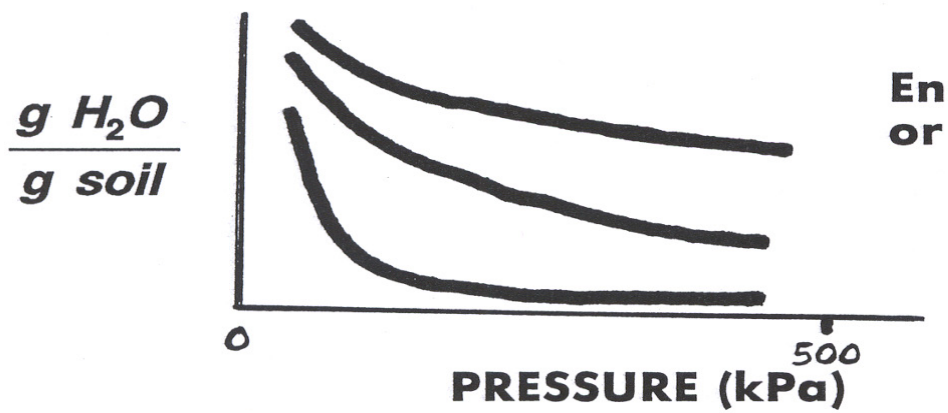
AVAILABLE WATER

Plant available water = water content at field capacity - water content at permanent wilting point

Moisture release curve -
relates soil water content to the energy needed to remove it.



energy = heat



Energy = suction or pressure

Figure 5.34

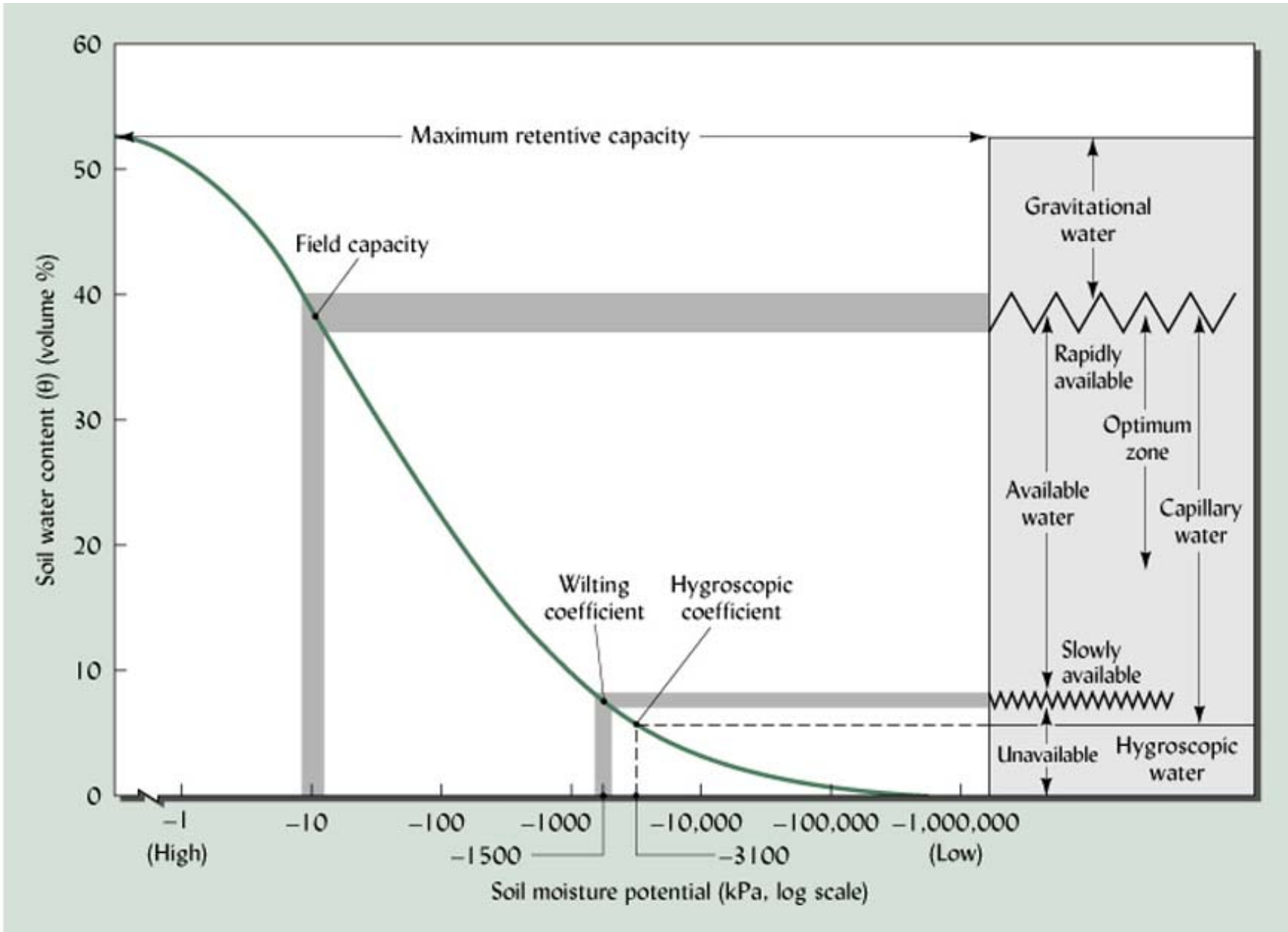
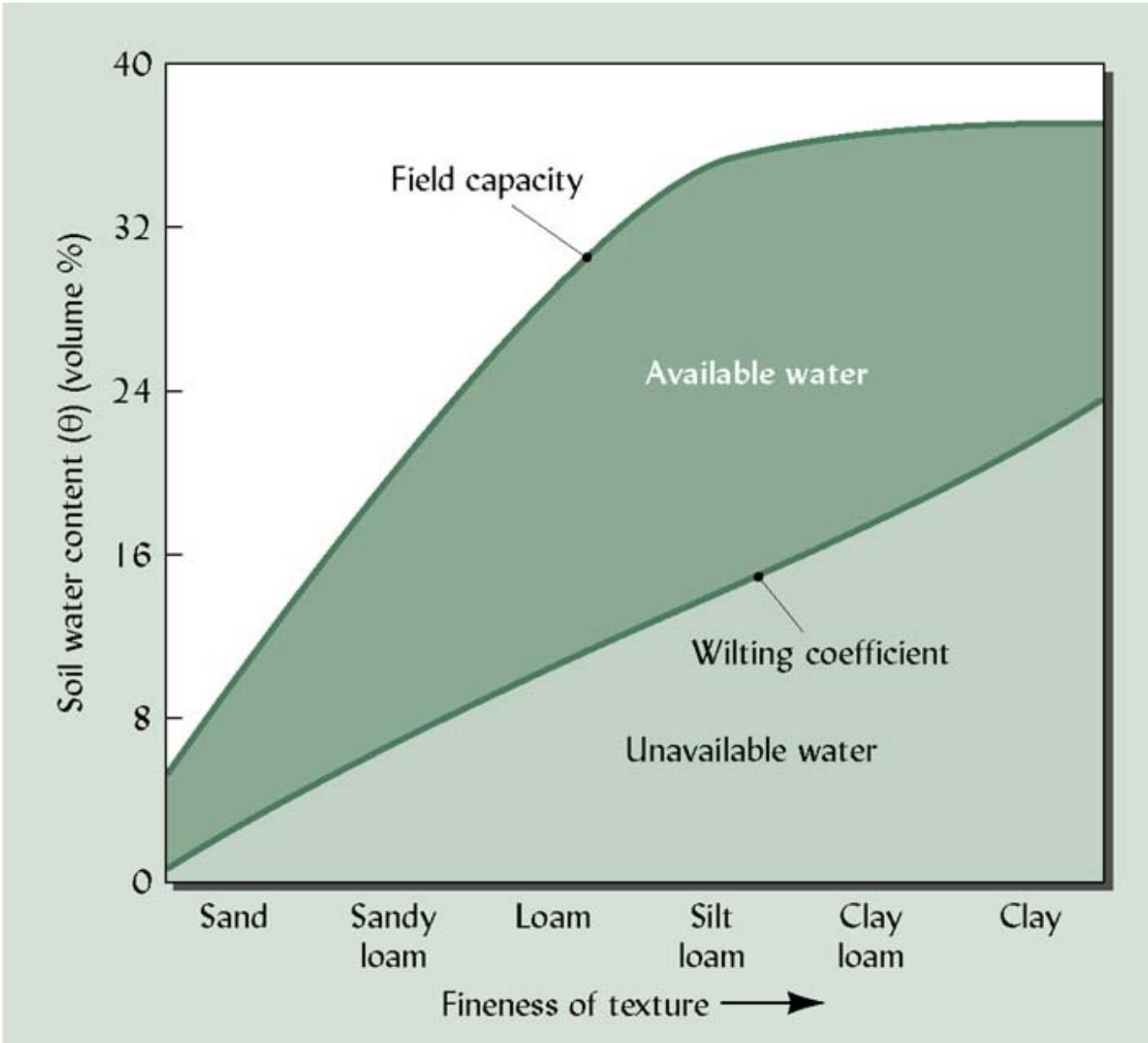
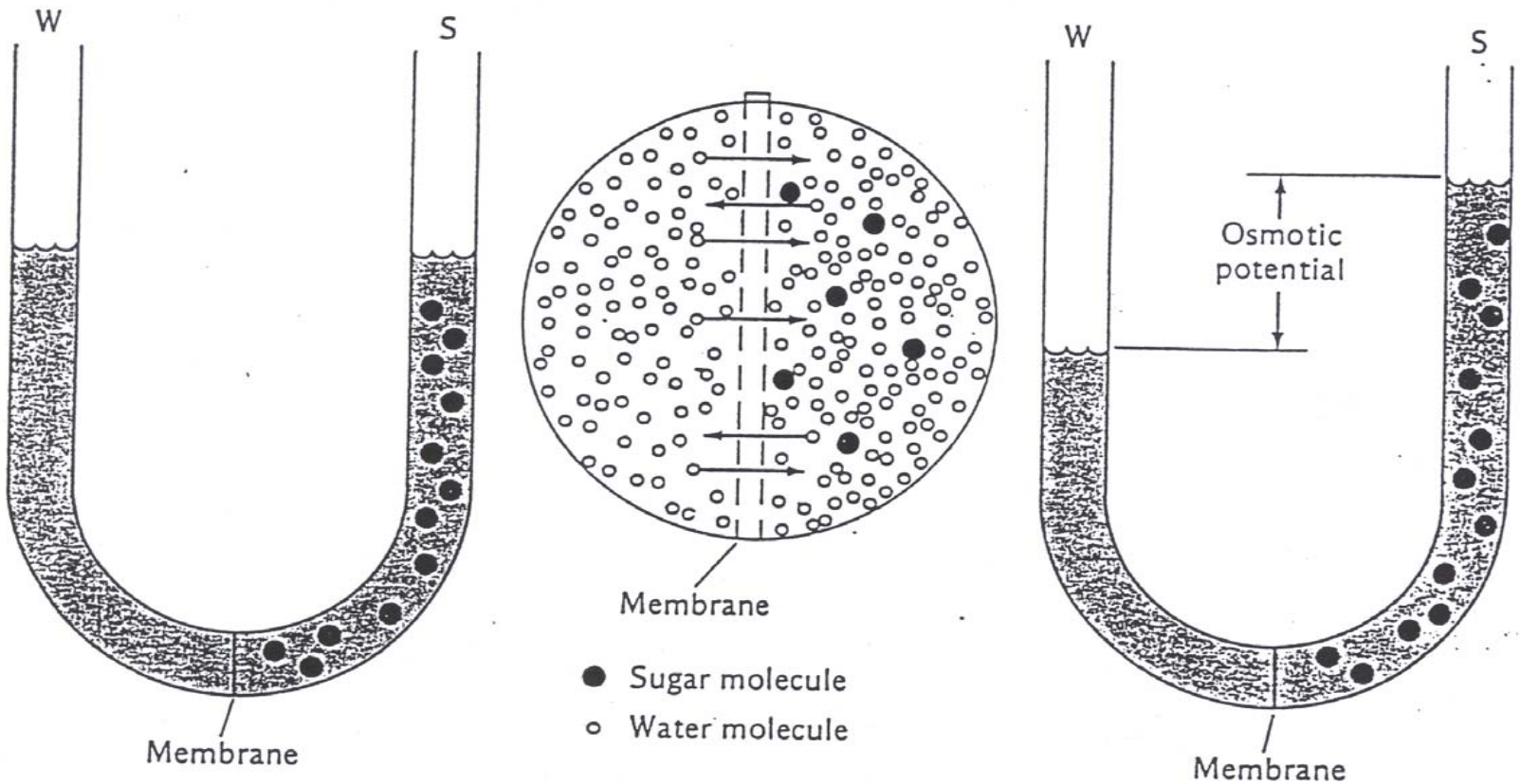

Maximum retentive capacity
Field capacity
Wilting coefficient
Hygroscopic coefficient
Gravitational water
Rapidly available
Optimum zone
Available water
Capillary water
Slowly available
Unavailable
Hygroscopic water
Soil water content (θ) (volume %)
60
50
40
30
20
10
0
−1 (High)
−10
−100
−1000
−1500
−10,000
−3100
−100,000
−1,000,000 (Low)
Soil moisture potential (kPa, log scale)

Figure 5.35


40
32
24
16
8
0
Soil water content (θ) (volume %)
Field capacity
Available water
Wilting coefficient
Unavailable water
Sand
Sandy loam
Loam
Silt loam
Clay loam
Clay
Fineness of texture

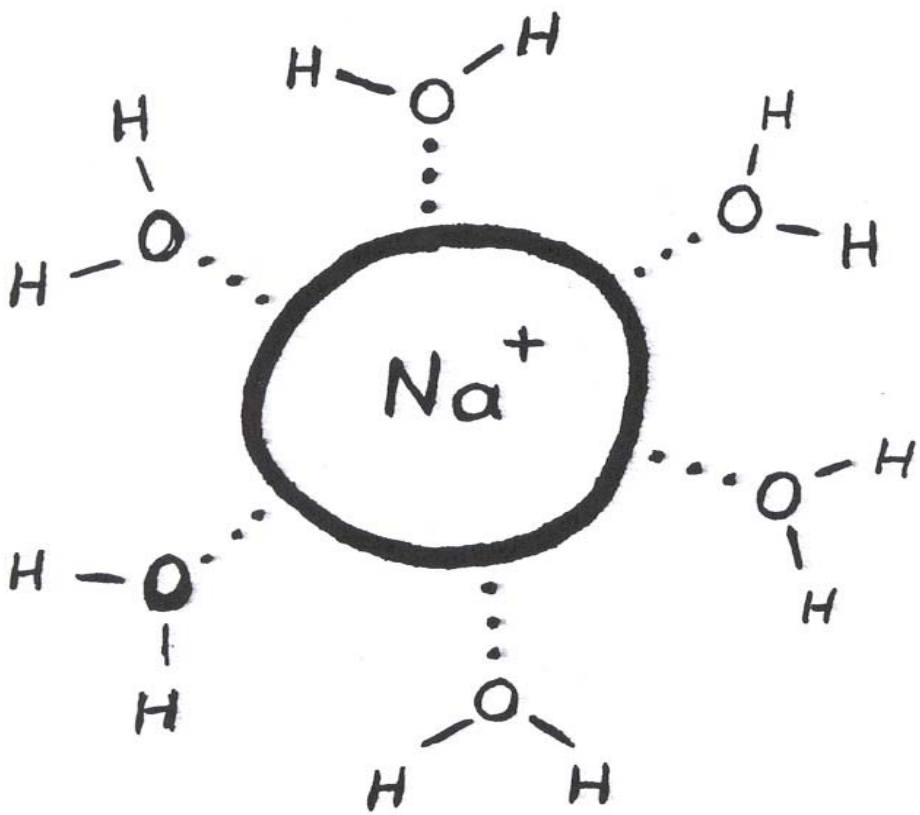
Solute Potential (Ψ_S)

- force that acts across a membrane – ex. root cell membrane
- due to hydration of ions
- important in saline soils



Effect of is to reduce the free energy

Hydration – attraction of ions to surfaces



Pore Water Composition

CATIONS Al^{3+}
Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, H^{+}
NH_4^{+}, Mn^{2+}, etc. Fe^{2+}, Fe^{3+}, etc.

ANIONS Cl^{-}, NO_3^{-}, SO_4^{2-}, $H_2PO_4^{-}$, $HPO_4^{=}$, HCO_3^{-}

ORGANIC COMPOUNDS (dissolved & colloidal)

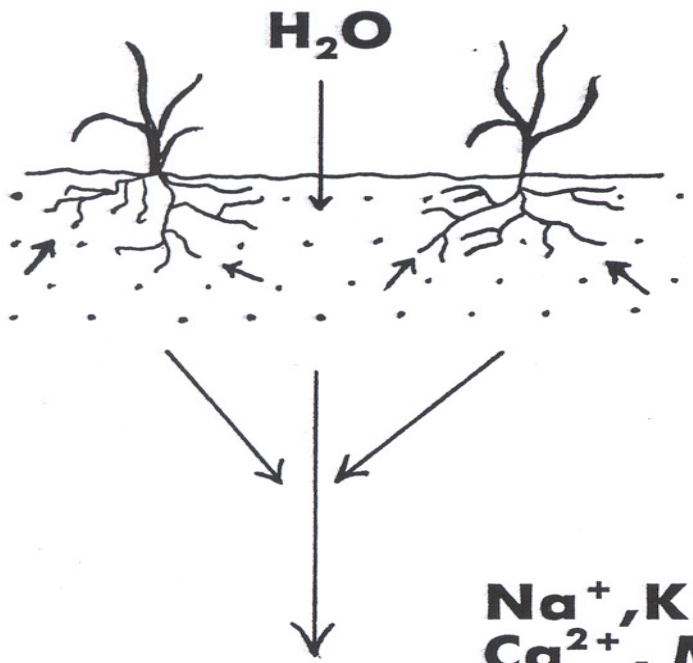
DISSOLVED GASES (esp. CO_2, O_2)

SUSPENDED CLAY PARTICLES

Composition depends on:

- vegetation
- climate
- biological activity
- soil minerals
- time ---> short-term
  ---> seasonal
  ---> long-term

Leaching



Moving water contacts soluble compounds in vegetation or soil moving them through the soil column.

H^+ ions replace base cations.

Na^+, K^+,
Ca^{2+}, Mg^{2+}
NO_3^-, Cl^-, etc.

"SOLUTES" added to leachate by <u>dissolution</u> and <u>ion exchange</u>.

Nutrient Uptake -

nutrients for microbial and plant growth are taken from the "SOIL SOLUTION"