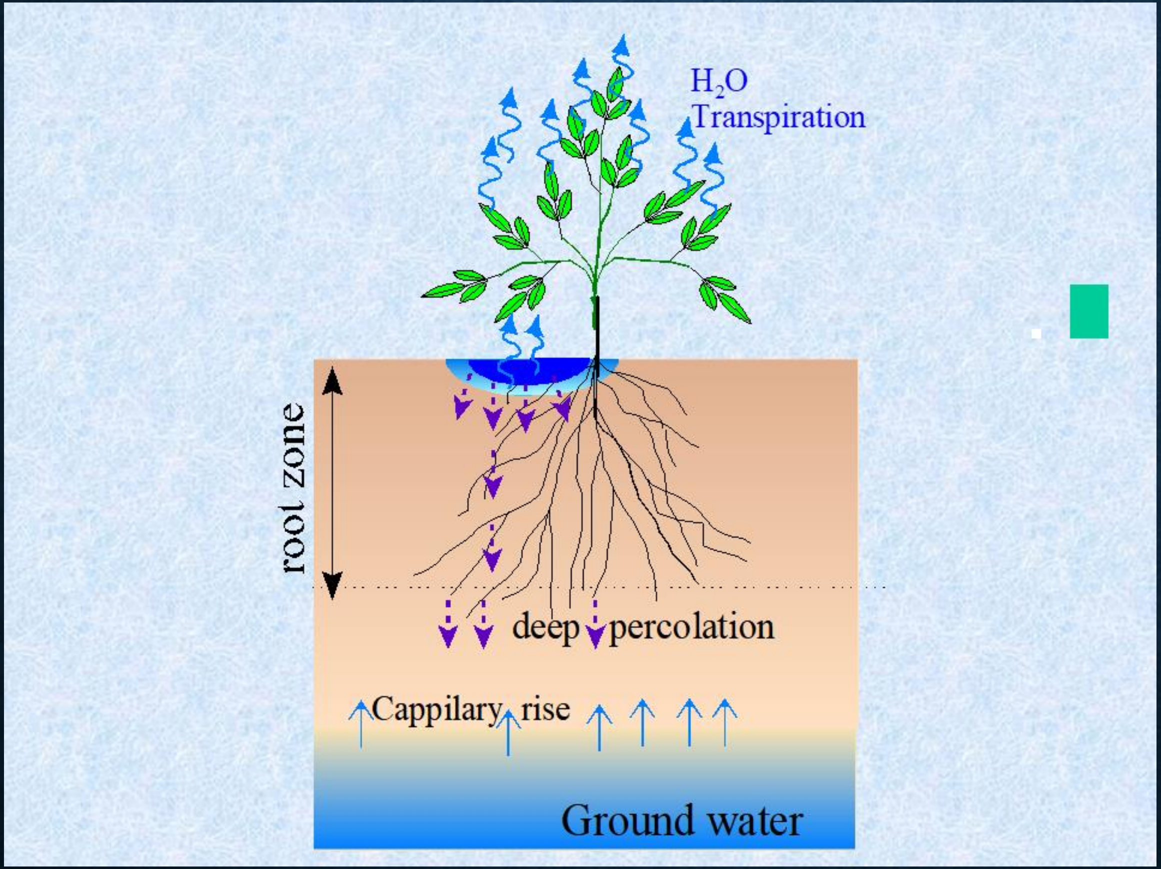
ห้องปฏิบัติการวิจัยการติดตามและการจัดการทางอุทกวิทยาเกษตรด้วยระบบอัจฉริยะ
Research Laboratory for INtelligent system
in Agro-hydrological Monitoring and Management (INAMM)
Department of Irrigation Engineering, Faculty of Engineering at Kamphaeng Saen, Kasetsart University

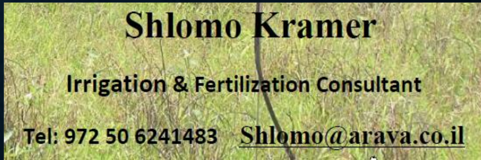
Soil-Water-Plant Relationship

Ekasit Kositsakulchai

Training on Climate Smart Irrigation Technology, 22 May 2018


H_2O
Transpiration
root zone
deep percolation
Cappilary rise
Ground water

Source: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Soil Water

Soil properties

Water retention in soil

Infiltration

Soil Properties

Definition, soil components, soil profile and soil horizon,
soil texture, soil structure, soil density and soil specific gravity,
pore space

Soil

From Wikipedia, the free encyclopedia

For other uses, see Soil (disambiguation).

Soil is a mixture of organic matter, minerals, gases, liquids, and organisms that together support life. The Earth's body of soil is the pedosphere, which has four important functions: it is a medium for plant growth; it is a means of water storage, supply and purification; it is a modifier of Earth's atmosphere; it is a habitat for organisms; all of which, in turn, modify the soil.

soil[1]

/soil/

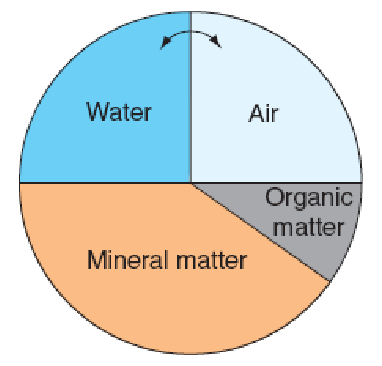
noun

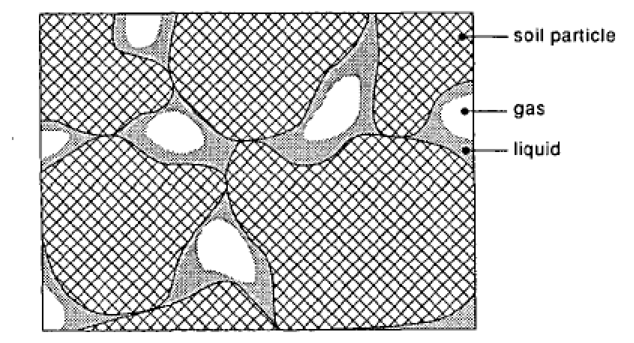
the upper layer of earth in which plants grow, a black or dark brown material typically consisting of a mixture of organic remains, clay, and rock particles.
"blueberries need very acid soil"
synonyms: earth, loam, dirt, clay, gumbo; ground
"acid soil"

- the territory of a particular nation.
  "the stationing of U.S. troops on Japanese soil"
  synonyms: territory, land, domain, dominion, region, country
  "Canadian soil"

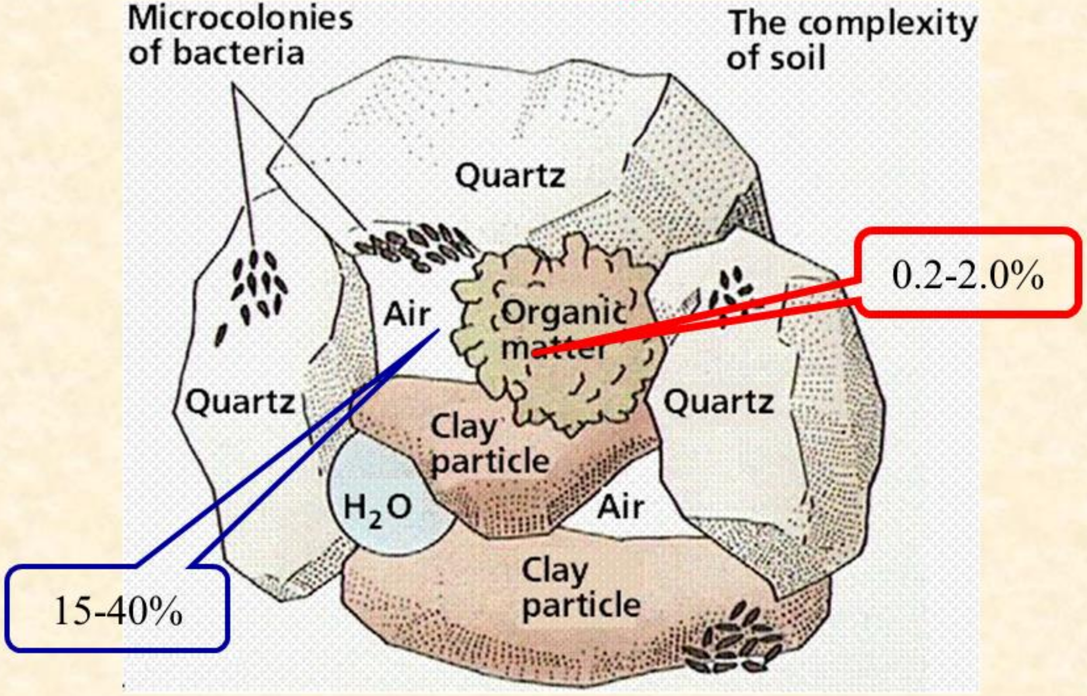
Soil Components

- Soil as a three-phase system
- Solid
  - Inorganic materials
  - Organic materials
- Liquid
  - Water
  - Solution
- Gas
  - Soil pores





The soil is not just soil…



0.2-2.0%

15-40%

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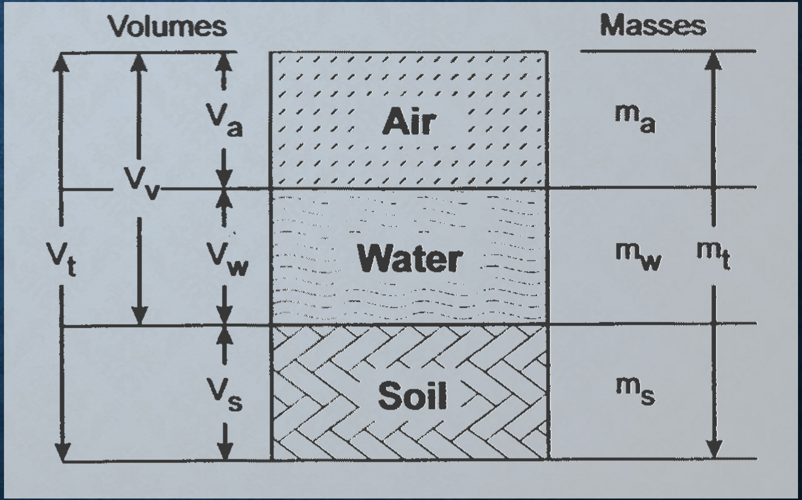
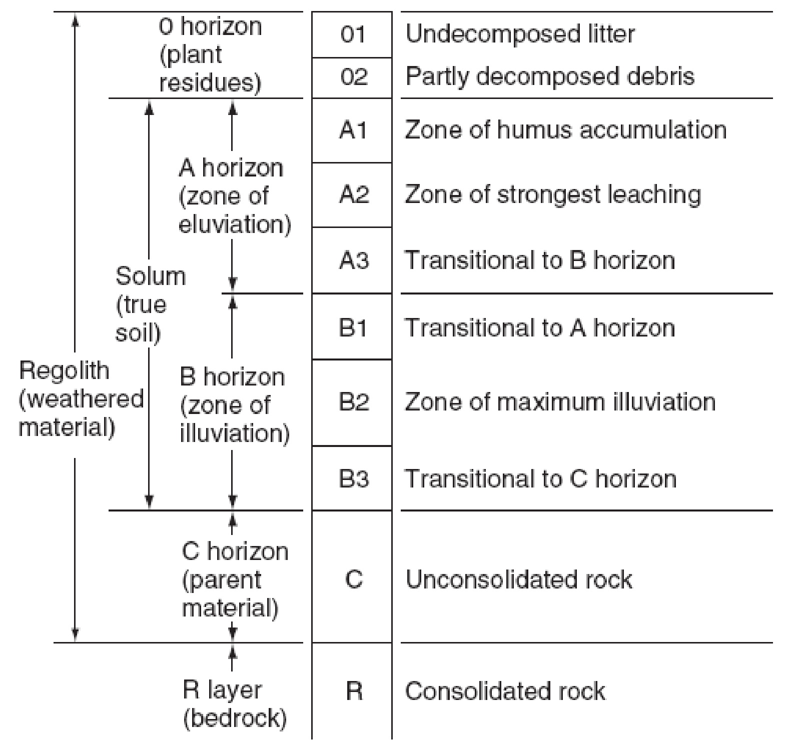
Soil Component

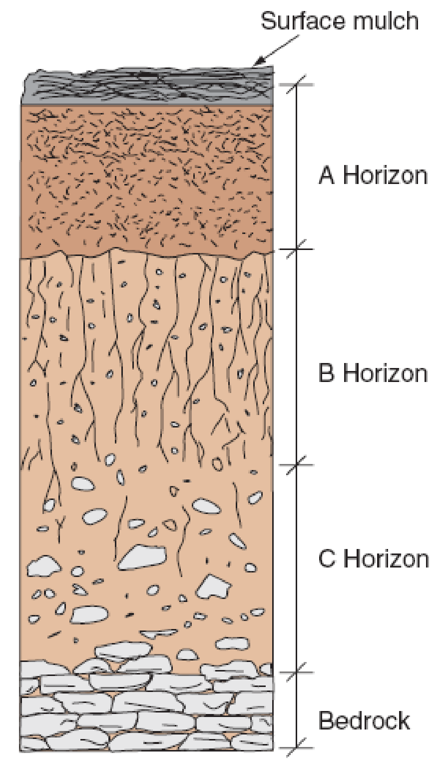
- Vt : total volume
  - Vv : void volume
    - Va : air volume
    - Vw : water volume
  - Vs : soil particle volume
- mt : total mass
  - ma : air mass
  - mw : water mass
  - ms : soil particle mass

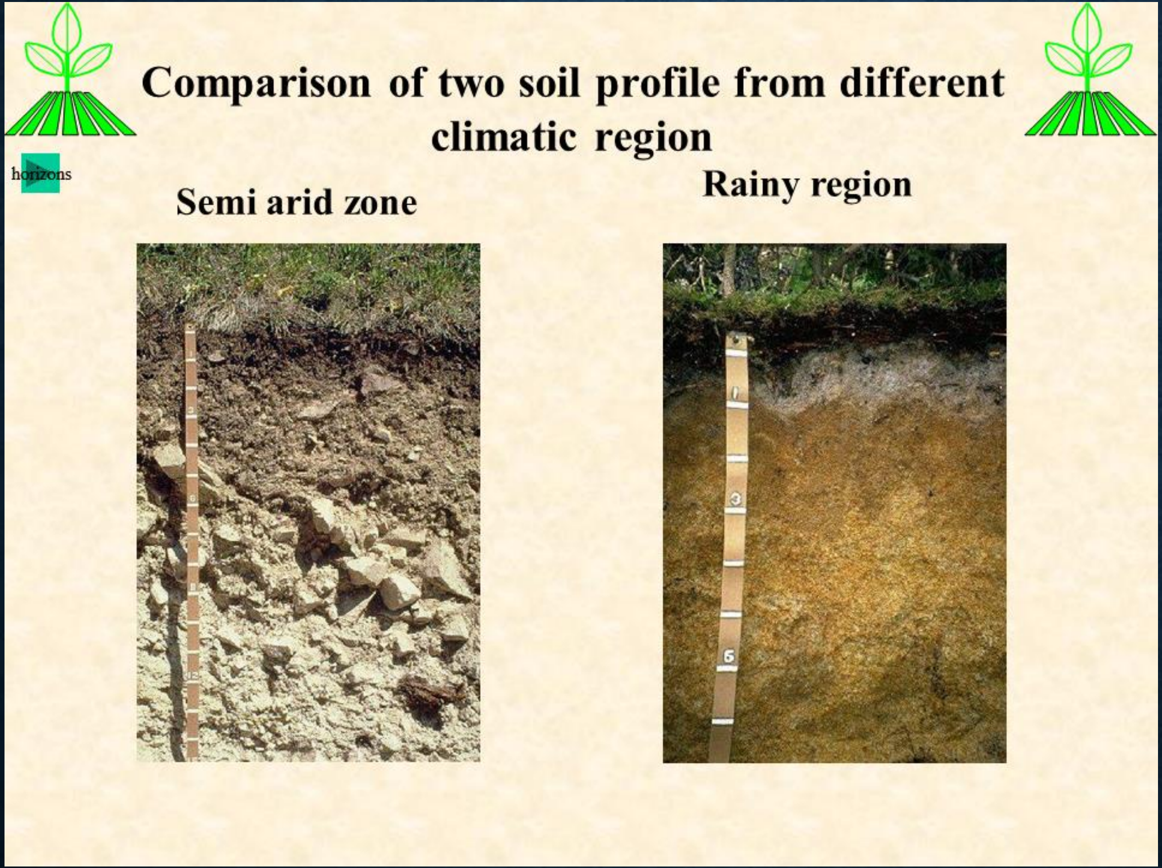


Soil Profile



Regolith (weathered material)		O horizon (plant residues)	01	Undecomposed litter
			02	Partly decomposed debris
	Solum (true soil)	A horizon (zone of eluviation)	A1	Zone of humus accumulation
			A2	Zone of strongest leaching
			A3	Transitional to B horizon
		B horizon (zone of illuviation)	B1	Transitional to A horizon
			B2	Zone of maximum illuviation
			B3	Transitional to C horizon
		C horizon (parent material)	C	Unconsolidated rock
		R layer (bedrock)	R	Consolidated rock





Comparison of two soil profile from different climatic region

horizons

Semi arid zone

Rainy region

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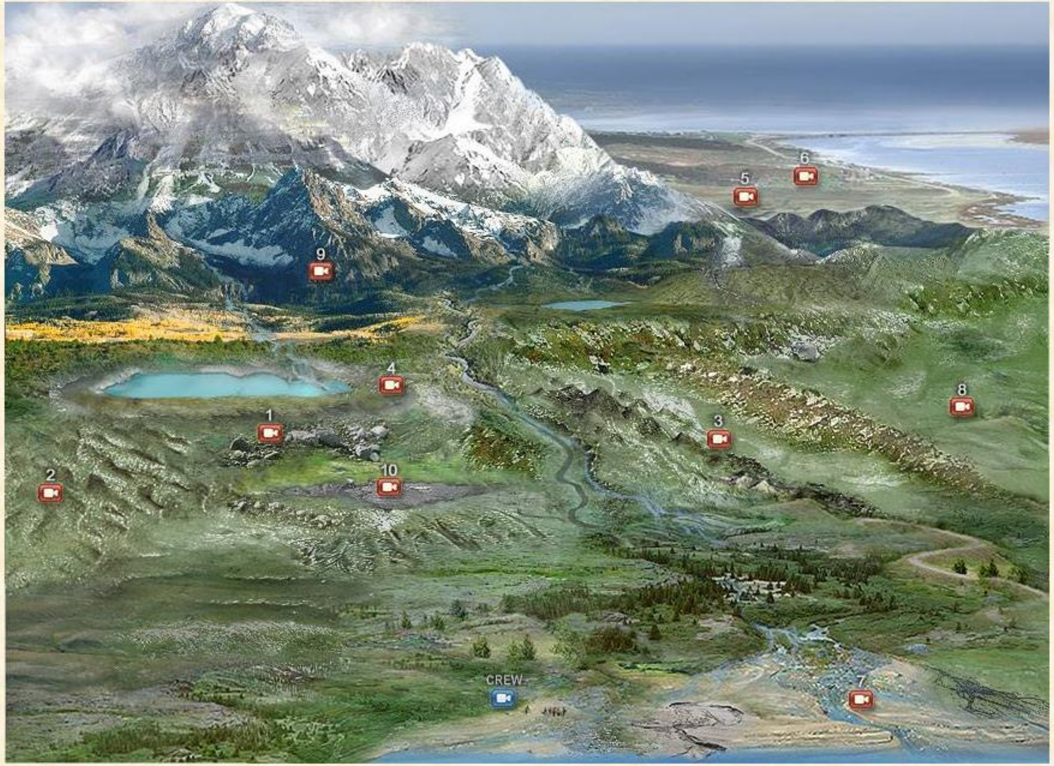
Soil Formation



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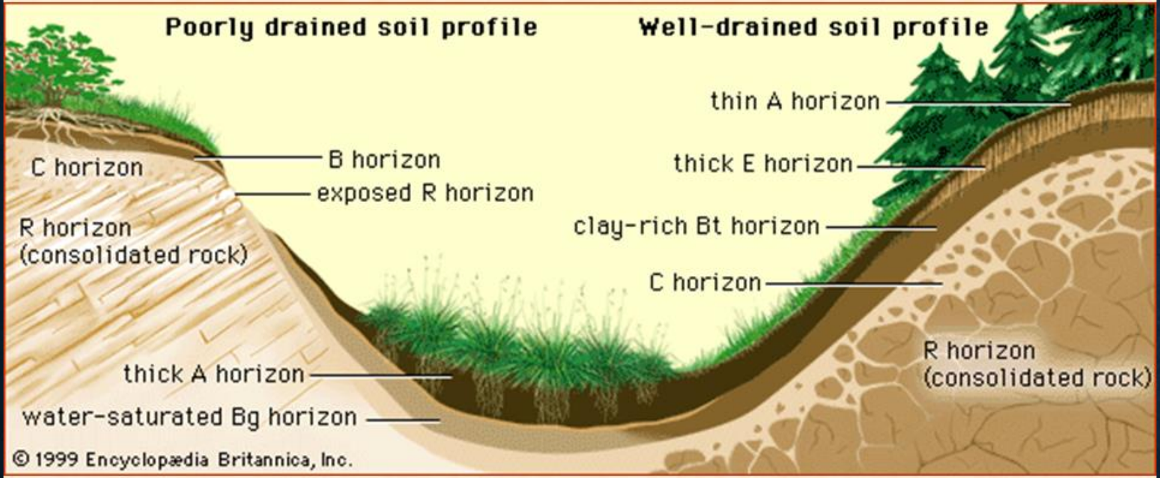
Soil Formation



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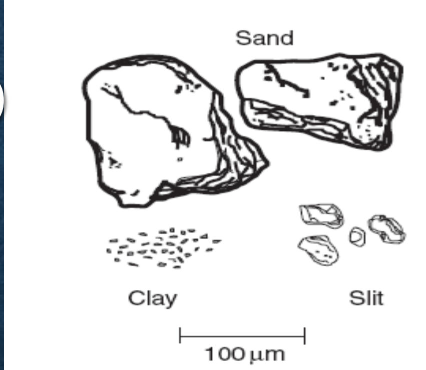
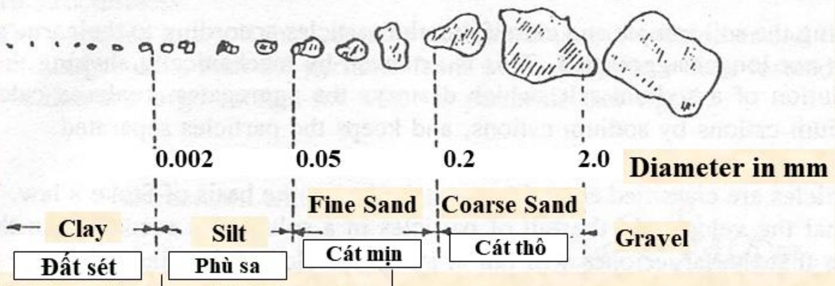
Soil Texture

- A physical property of soil
- Defined from fraction of mass of soil particle (smaller 2 mm)
  - Sand: 0.05 - 2.00 mm
  - Silt: 0.002 - 0.05 mm
  - Clay: < 0.002 mm



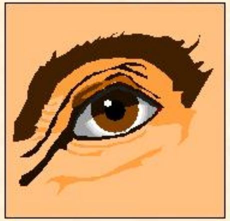
The size fractions in the soil



Visible under electron microscope

Visible under microscope

Visible bye naked eye



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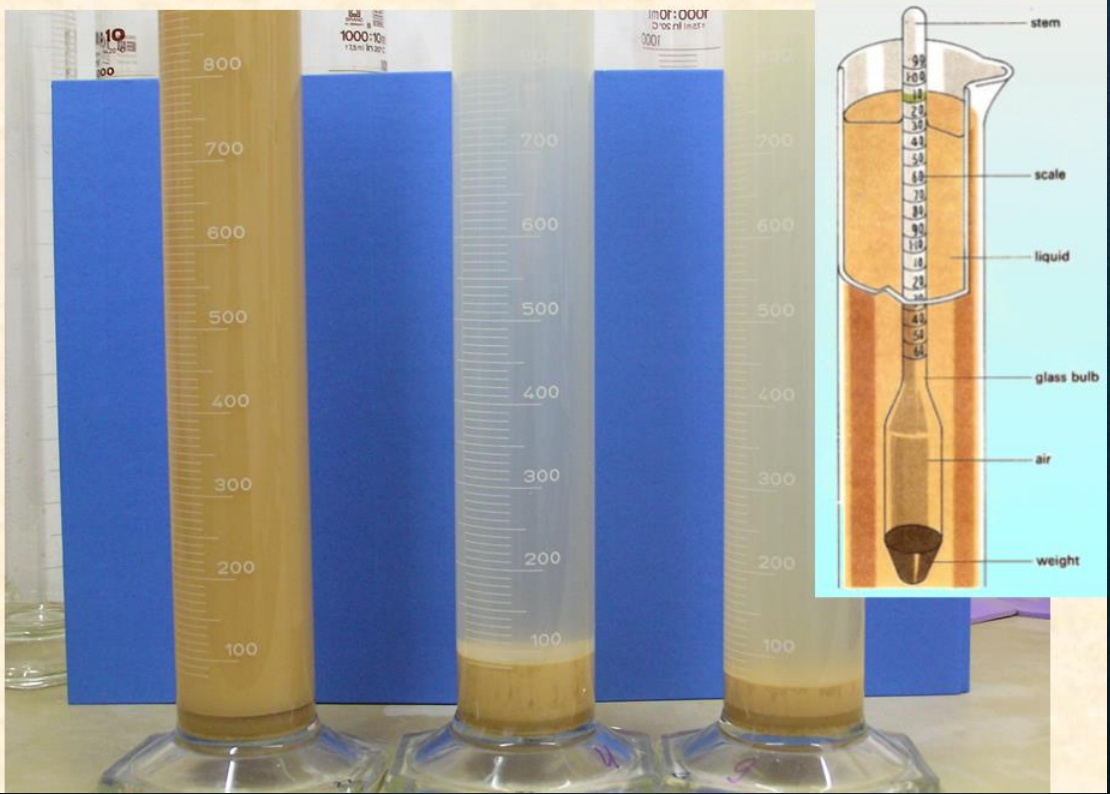
Soil texture analysis (hydrometer method)



Source:

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Soil particle classification system

- USDA
- USPRA
- BSI, MIT
- ISSS
- DIN

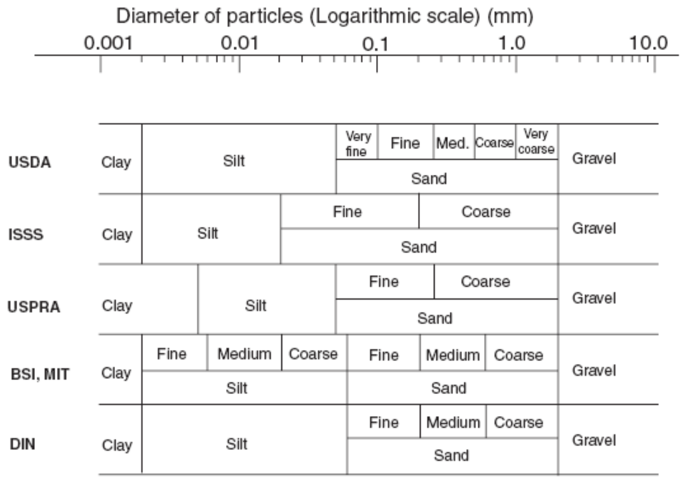
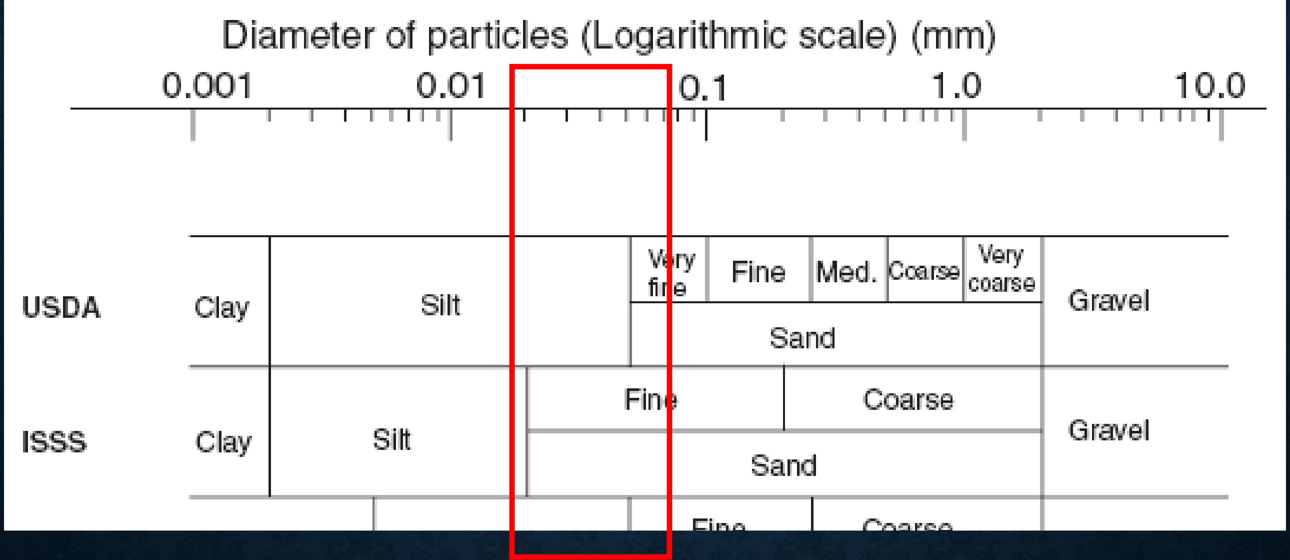


Fig. 3.1. Several conventional schemes for the classification of soil fractions according to particle diameter ranges; U.S. Department of Agriculture (USDA); International Soil Science Society (ISSS); U.S. Public Roads Administration (USPRA); British Standards Institute (BSI); Massachusetts Institute of Technology (MIT); German Standards (DIN).

Soil texture classification

- USDA – U.S. Department of Agriculture
- ISSS – International Soil Science Society



Soil texture classification

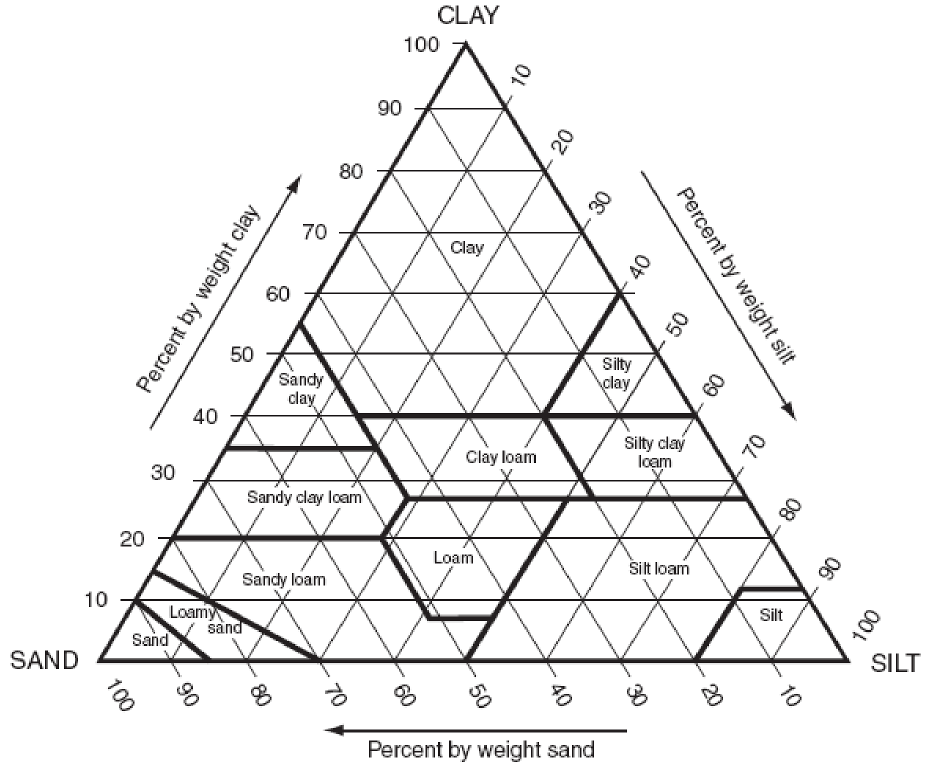
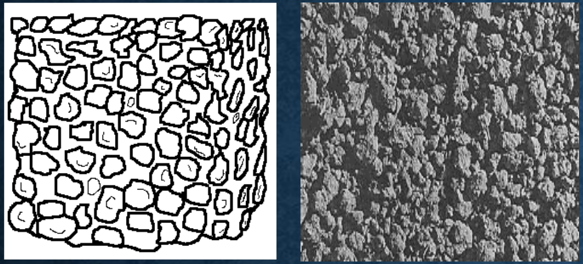
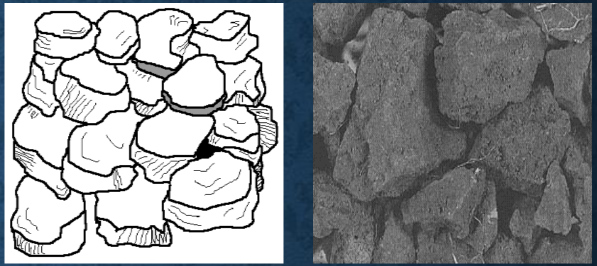


Fig. 3.3. Textural triangle, showing the percentages of clay (below 0.002 mm), silt (0.002–0.05 mm), and sand (0.05–2.0 mm) in the conventional soil textural classes.

Soil Structure

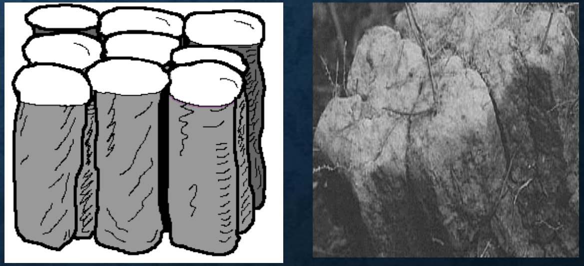


Granular



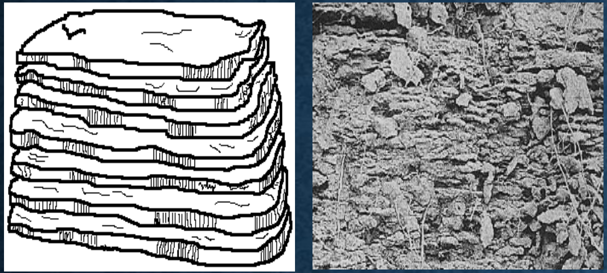
Blocky

Prismatic

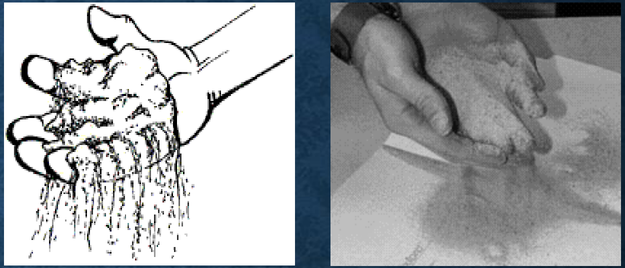


Columnar

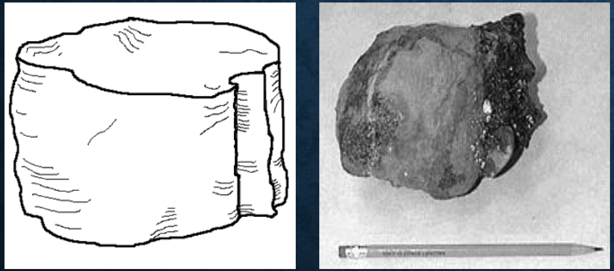
Soil Structure



Platy

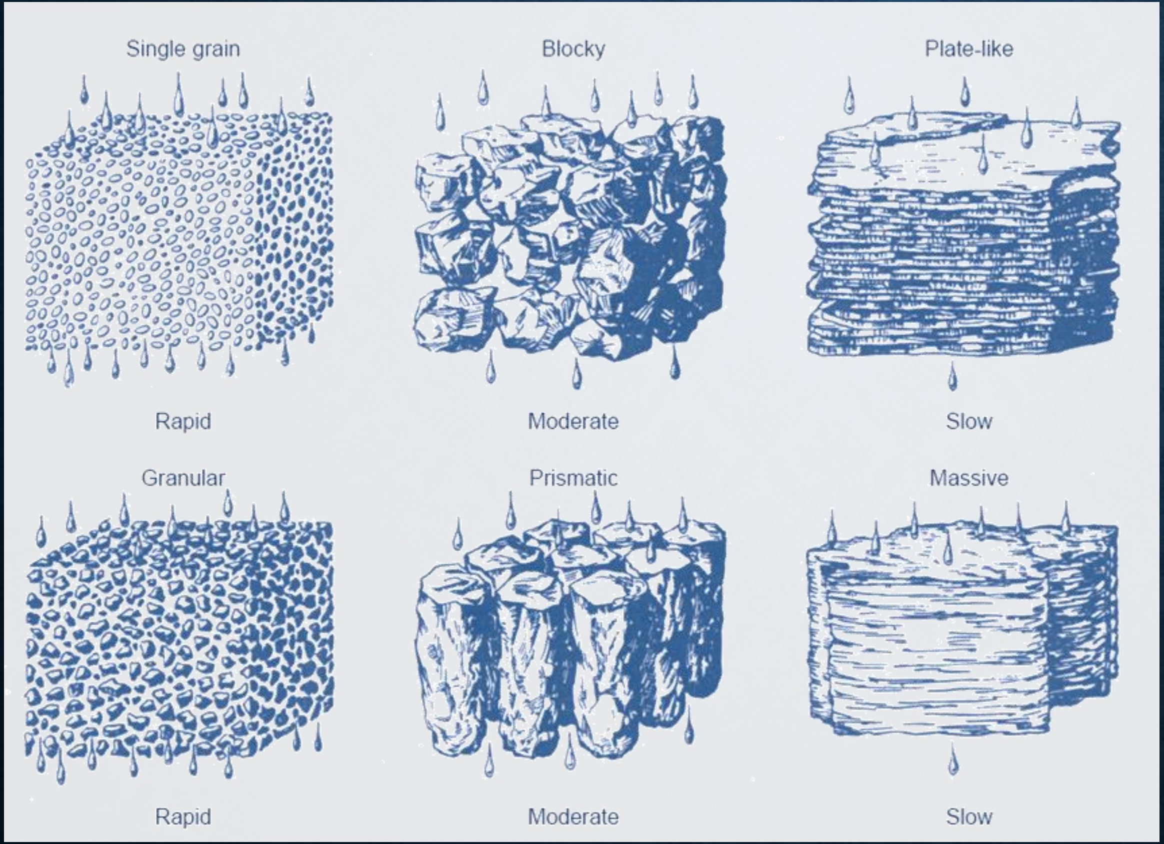


Single grained



Massive

Influence of soil structure on soil water flow



Soil Density and Soil Specific Gravity

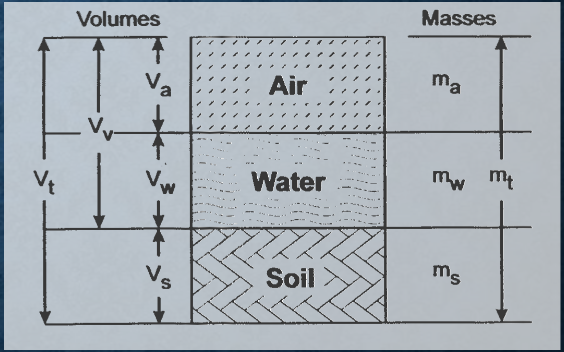
Soil density

- particle density

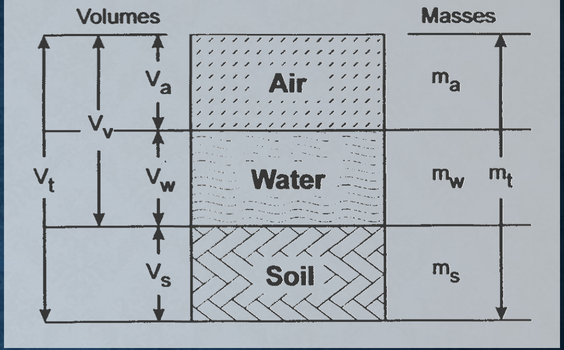
$$\rho_s = \frac{m_s}{V_s}$$

- bulk density

$$\rho_b = \frac{m_s}{V_t} = \frac{m_s}{V_a + V_w + V_s}$$



Specific gravity



- real specific gravity

$$R_s = \frac{\rho_s}{\rho_w} = \frac{m_s}{V_s \times \rho_w}$$

- apparent specific gravity

$$A_s = \frac{\rho_b}{\rho_w} = \frac{m_s}{V_t \times \rho_w}$$

Pore Space

Porosity

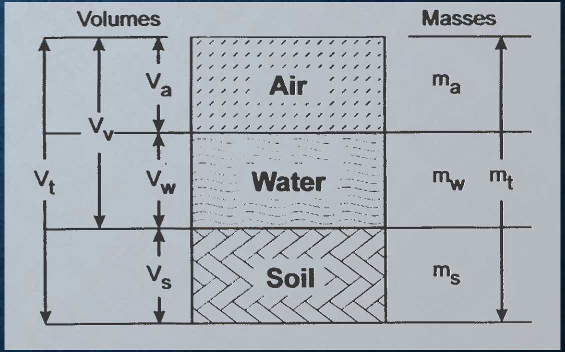
Void ratio

Pore space

- Liquid or gas components between soil particle

- $n = \frac{V_v}{V_t}$

- $e = \frac{V_v}{V_s}$



Porosity of soil

เนื้อดิน	ความพรุน (%)	
	ช่วงค่าปกติ	ค่าเฉลี่ย
Sand	32 – 42	38
Sandy Loam	40 – 47	43
Loam	43 – 49	46
Clay Loam	47 – 51	49
Silty Clay	49 – 53	51
Clay	51 - 55	53

Soil Water

Soil properties

Water retention in soil

Infiltration

Water Retention in Soil

Soil Water Content

- Gravimetric water content
- Volumetric water content
- Degree of saturation

Soil Water Content

- Soil moisture by mass

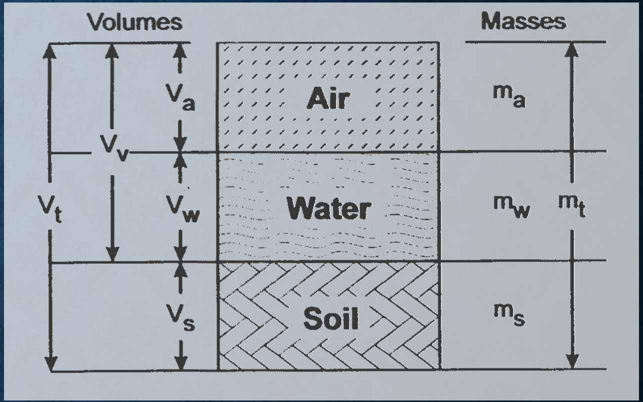
$$\theta_m = \frac{m_w}{m_s}$$

- Soil moisture by volume

$$\theta_v = \frac{V_w}{V_t}$$

- Degree of saturation

$$s = \frac{V_w}{V_v}$$



Soil core sampler

$$\begin{aligned}\rho_w\theta_v &= \rho_b\theta_m \\ \theta_v &= \frac{\rho_b}{\rho_w}\theta_m \\ \theta_v &= A_s\theta_m\end{aligned}$$

- Water content by mass vs by volume

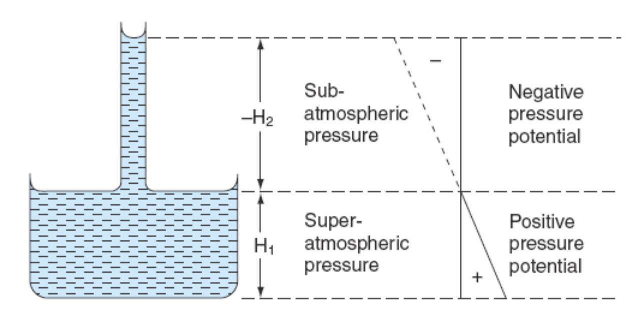
$$\begin{aligned}d &= \theta_v D \\ &= \theta_m A_s D\end{aligned}$$

- Depth of water in soil column

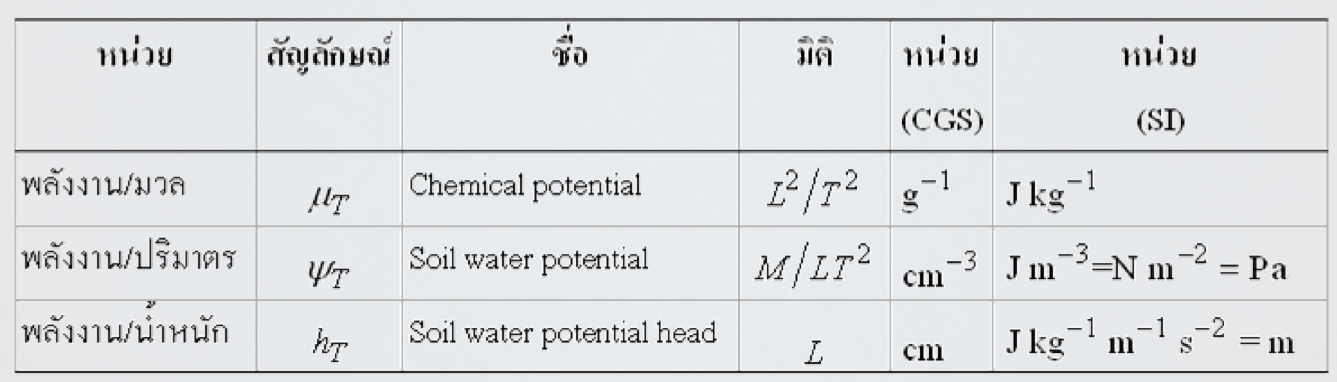
Potential Energy of Water in Soil

Soil water potential

- Gravitational potential
- Osmotic potential
- Matric potential
- Hydrostatic pressure potential



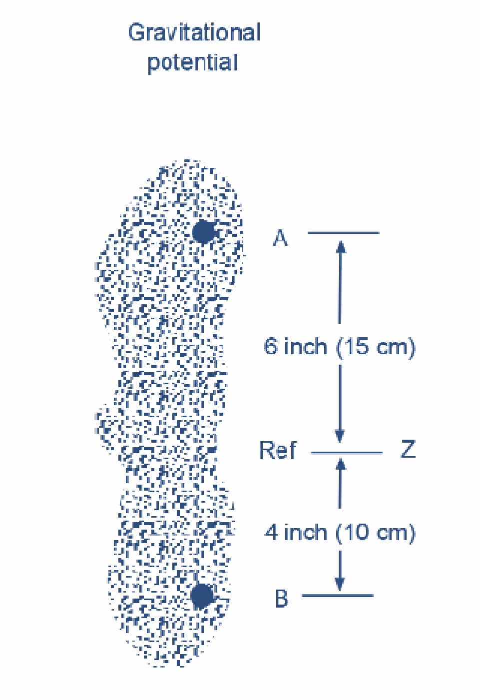
Unit



หน่วย	สัญลักษณ์	ชื่อ	มิติ	หน่วย (CGS)	หน่วย (SI)
พลังงาน/มวล	μ_T	Chemical potential	L^2/T^2	g^{-1}	$\mathrm{J\ kg}^{-1}$
พลังงาน/ปริมาตร	ψ_T	Soil water potential	M/LT^2	cm^{-3}	$\mathrm{J\ m}^{-3} = \mathrm{N\ m}^{-2} = \mathrm{Pa}$
พลังงาน/น้ำหนัก	h_T	Soil water potential head	L	cm	$\mathrm{J\ kg}^{-1}\ \mathrm{m}^{-1}\ \mathrm{s}^{-2} = \mathrm{m}$

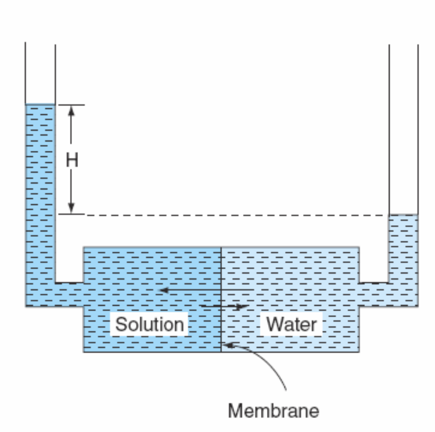
- งานทางด้านชลประทาน/แหล่งน้ำ นิยมใช้
  - พลังงานต่อน้ำหนัก (น้ำ) => เฮด (head)

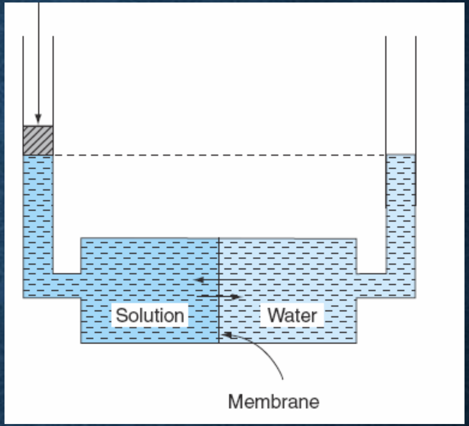
Gravitational potential



- Gravitational potential

Osmotic potential

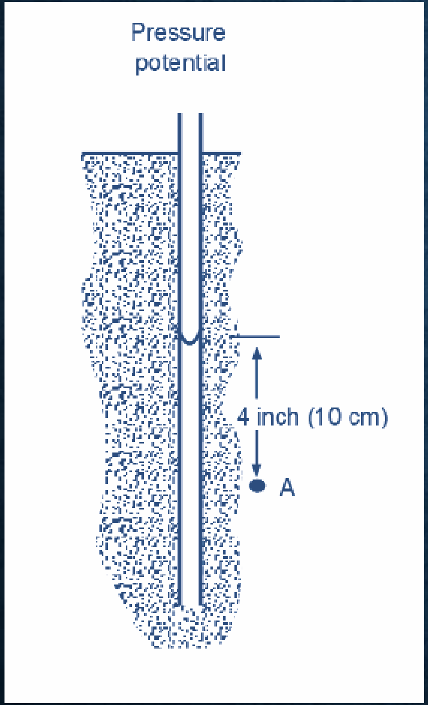




- **Osmosis**

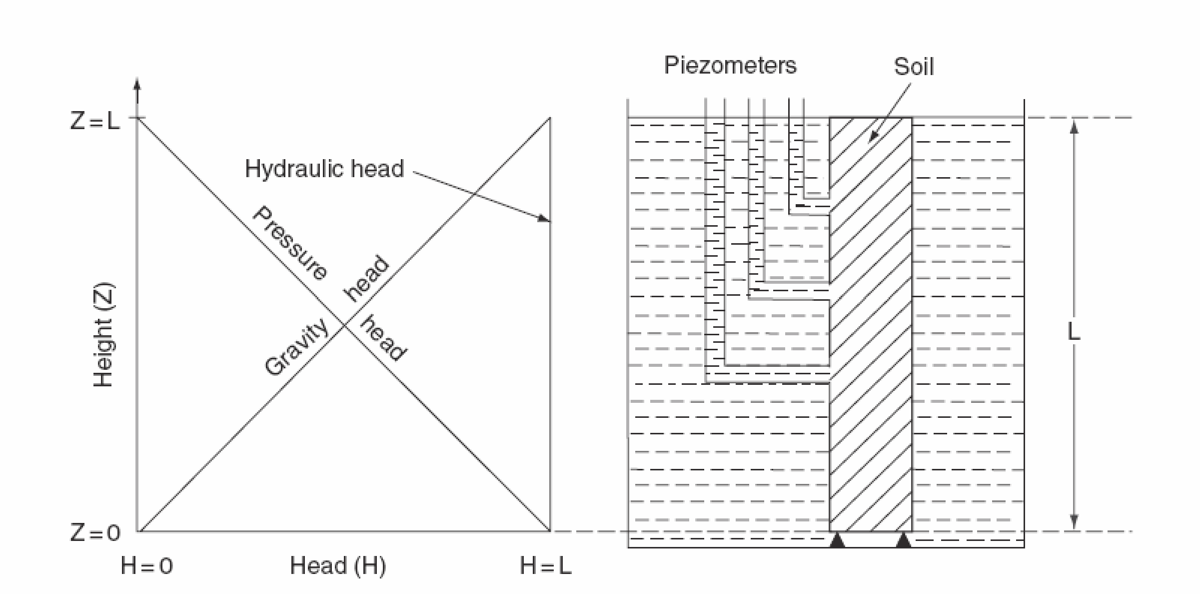
- Osmotic pressure

Pressure potential



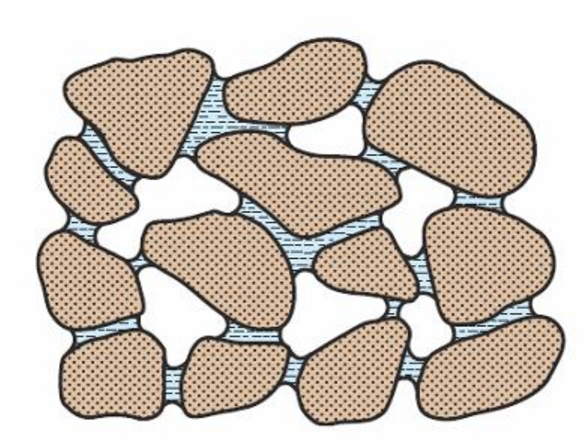
- Pressure potential
- In case of saturated soil

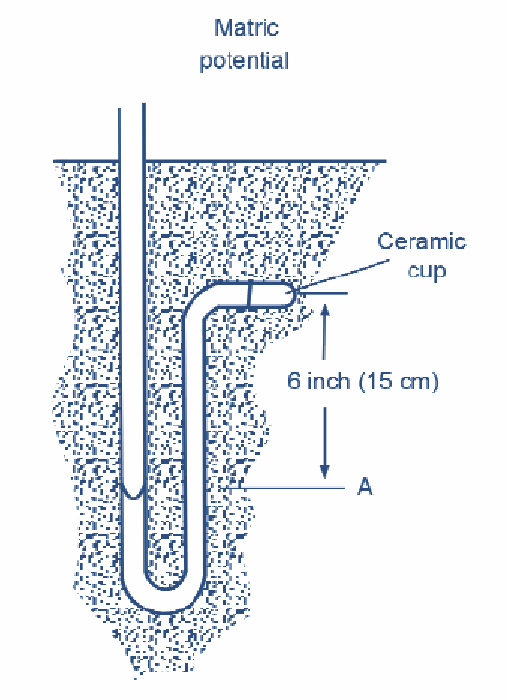
Pressure potential in saturated soil



- Pressure head
- Gravitational head

Unsaturated soil





- Matric potential

Soil water potential

- soil water potential
  - Energy/volume

$$\psi_T = \psi_z + \psi_s + \psi_m + \psi_p + \mathrm{K}$$

- head
  - Energy/weight (of water)

$$h_T = z + s + h + p + \mathrm{K}$$

  - Saturated soil

$$h_T = z + s + p$$

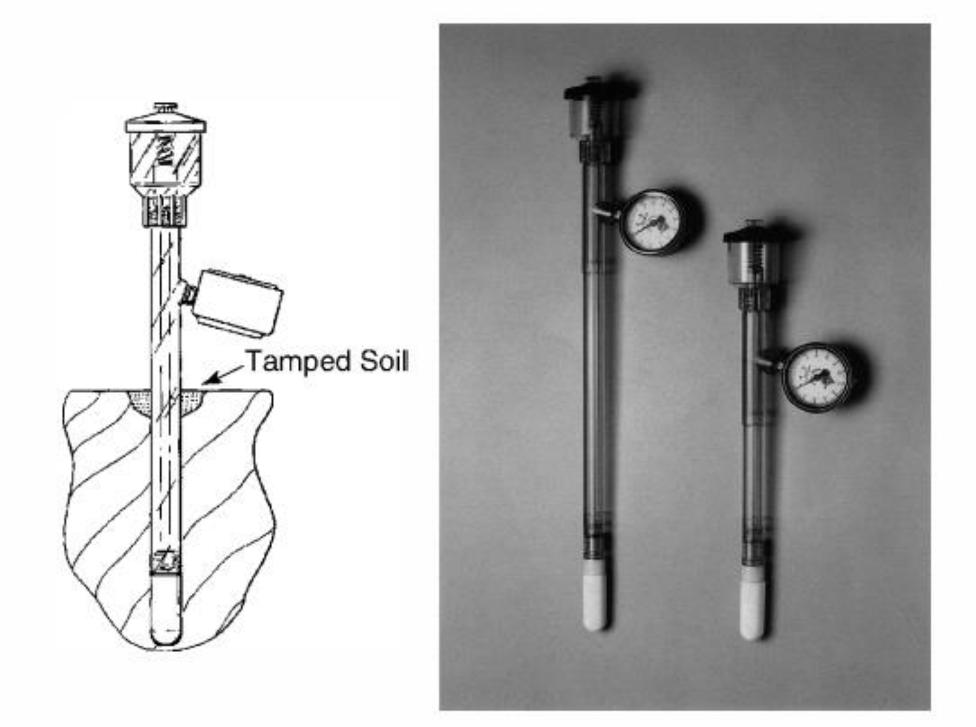
  - Unsaturated soil

$$h_T = z + s + h$$

Soil Moisture Tension

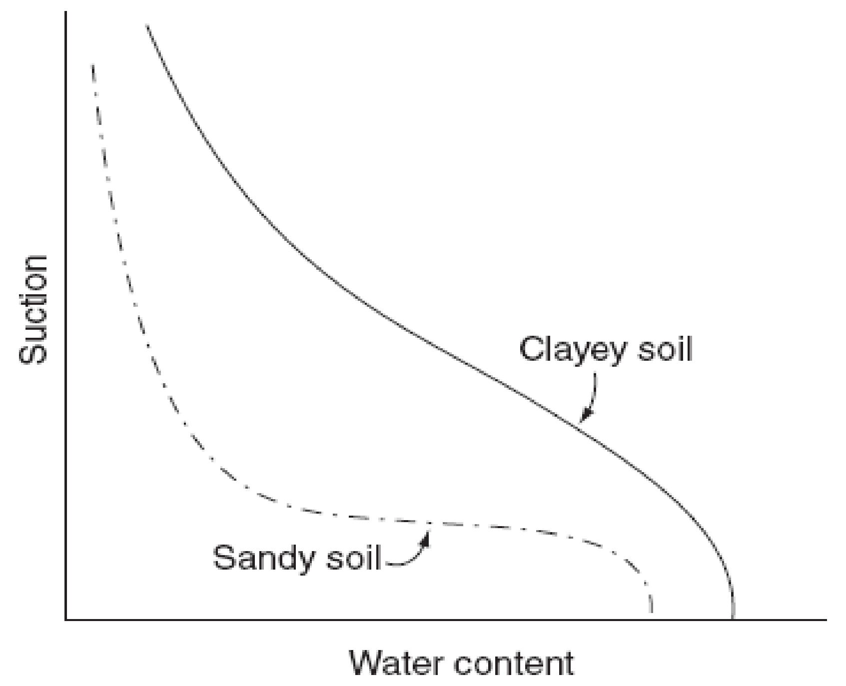
  - Sometimes called "suction"
- Unit of measurement
  - Pascal (Pa) or N/m2
  - bar
  - Head or depth of water in m (or cm)

Tensiometer



Soil-Moisture Characteristic Curve

Soil-Moisture Characteristic Curve



- Relation between (volumetric) water content and matrix potential (h)

Stages of Water Content in Soil

Water content at field capacity (FC)

Water content at permanent wilting point (PWP)

Available water
- TAW: total available water
- RAW: readily available water

Stages of Water Content in Soil

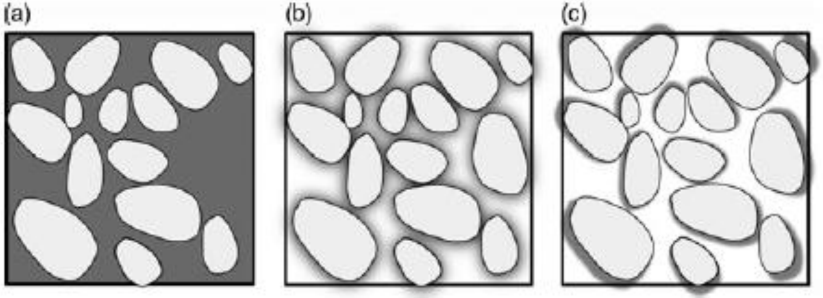
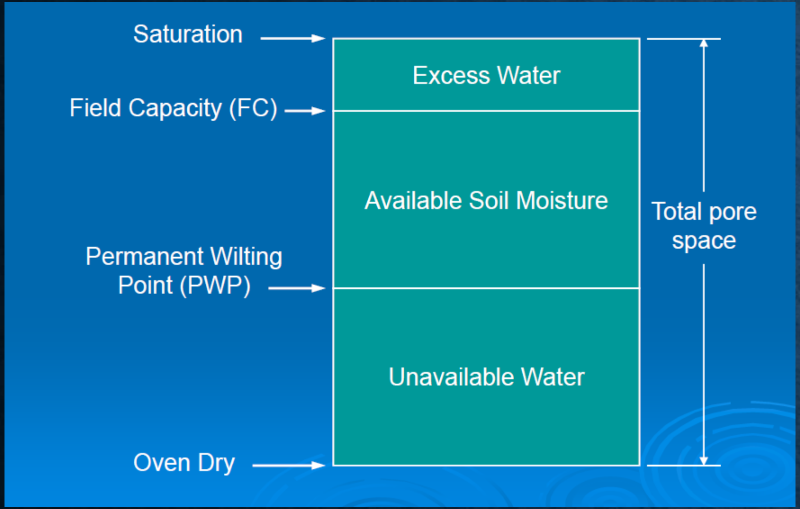


Fig. 5.4. Soil moisture at different stages of moisture content. (a) Saturation – all pores filled with water, little or no air; this situation occurs during and immediately following irrigation or rainfall. (b) Field capacity – water is held in the soil after surplus has drained away under gravitational forces. (c) Permanent wilting point – water attached by surface tension forces to soil particles, cannot be removed by plant root suction.

- From an irrigation point of view, there are different levels of water content in the soil, and four terms are used to identify these water content levels:
  - saturation
  - field capacity
  - permanent wilting point
  - available soil water

Saturation

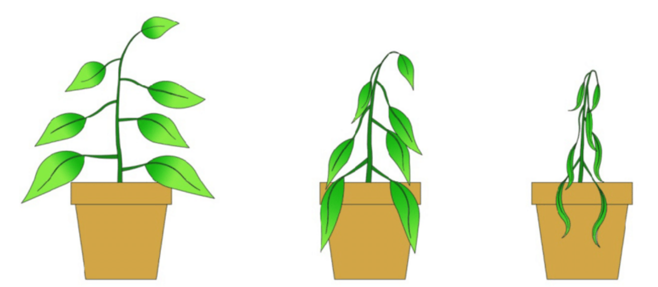


- During and immediately after irrigation all the pore space in the soil is filled with water and the soil is saturated.
- There is little air in the soil, and for most crops (other than rice) if the soil stays saturated the crop will be damaged due to this lack of air for the roots to breathe.
- If there are no drainage problems, the water in the soil will drain away under gravity following irrigation, leaving space for air in the soil’s pore space

Field Capacity, FC

- Field capacity is the quantity of water held in the soil once the water has drained away from the saturated soil.
- This water is held to the soil particles by surface tension forces, and much of it is available for taking up by the plant's roots.
- The volume of water held by the soil at field capacity depends primarily on its texture and structure.
- The forces holding the water in the soil against the gravitational pull are surface tension forces. Soils with small particle size, such as silts and clays, have a large surface area and thus can hold more water.

Permanent Wilting Point, WP

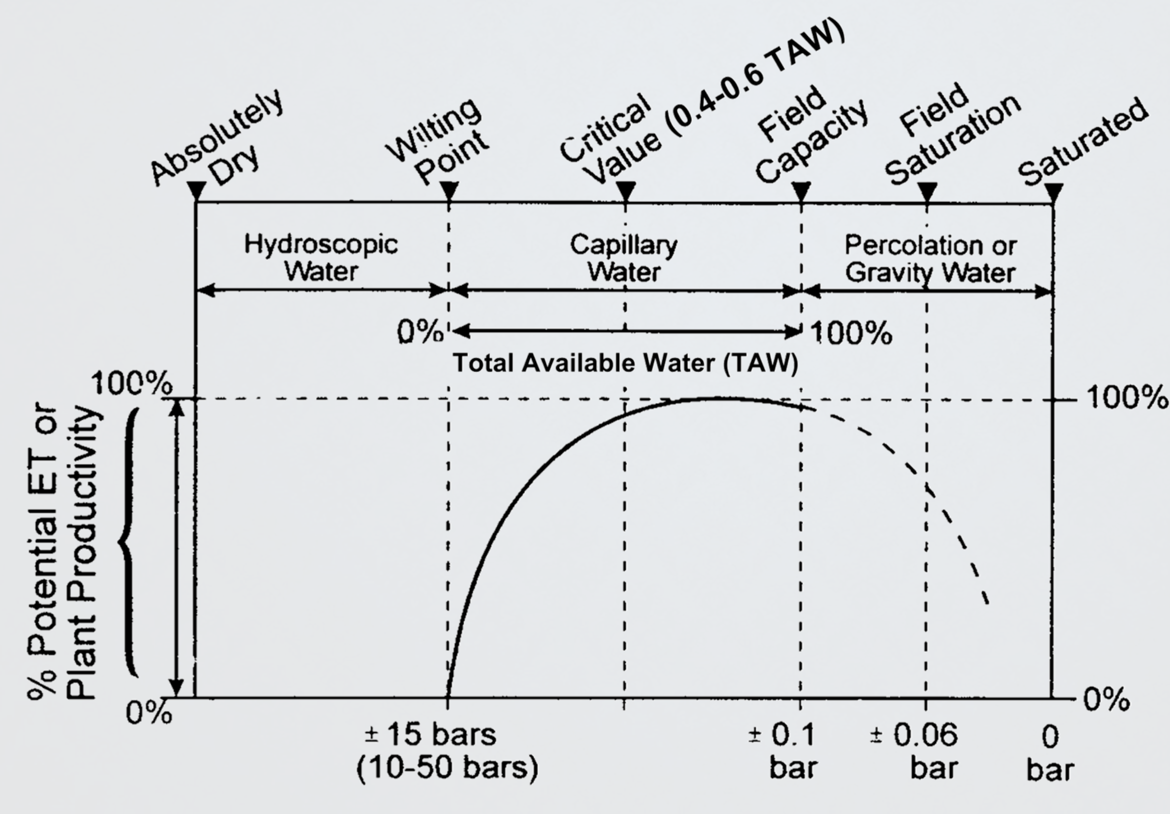


- Water can be removed from the soil by the plant's roots exerting a greater pull or tension than the surface tension holding the water to the soil particle's surface.
- At some point, termed the permanent wilting point, the suction exerted by the plant's roots is not sufficient to remove the water from around the soil's particles.
- At this point, the crop will become stressed, the yield will be reduced and the crop may perish. At permanent wilting point a crop's leaves may droop or wilt; in some crops, there will be a change in appearance in the leaf color.
- The permanent wilting point is affected by the soil texture in the same way as with field capacity, thus for fine-textured soils the moisture content at permanent wilting point is higher than for coarse-textured soils.

Available Soil Moisture (FC - WP)

- The water available to the plant is the difference between the moisture content at field capacity and that at the permanent wilting point.
- Though there may still be water in the soil at the permanent wilting point it cannot be removed by the plant, and is thus unavailable.
- The objective of irrigation is to allow the soil moisture to reduce to a safe limit (above the permanent wilting point) and then to irrigate the soil to bring it back to field capacity.
- The interval between irrigation will thus depend on the available moisture in the soil and the rate at which the soil water is abstracted by the crop

Soil water content vs ET/Productivity



Soil Water

Soil properties

Water retention in soil

Infiltration

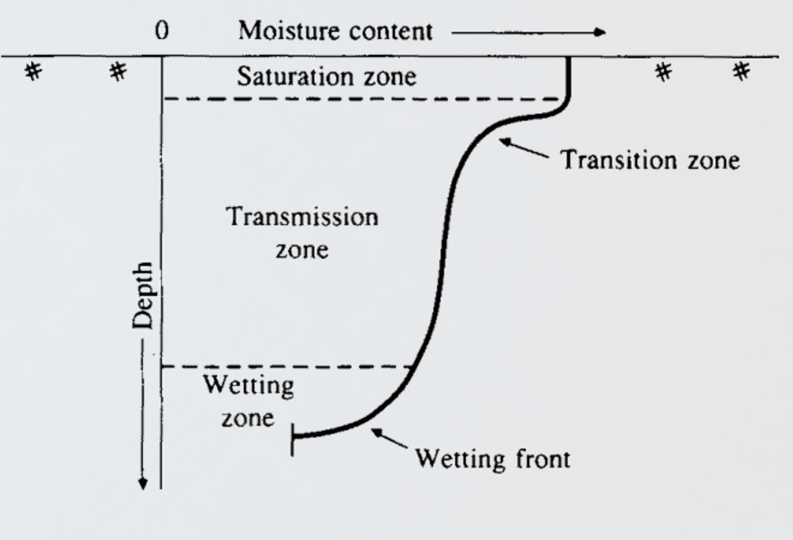
Infiltration

Definition

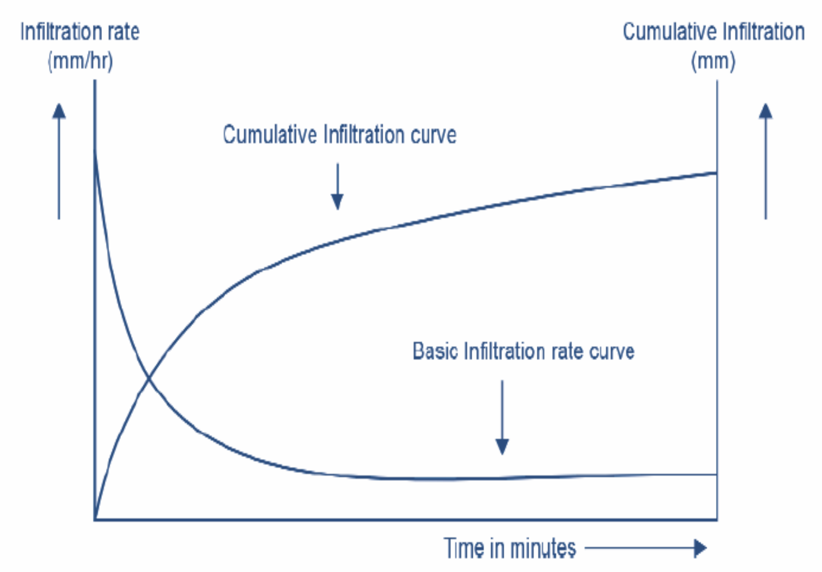
Infiltration equations

Infiltration in Irrigation

- saturation zone
  - เริ่มจากส่วนที่อยู่ใกล้กับผิวดิน
  - จะมีความลึกเพิ่มขึ้นเรื่อย ๆ
- transmission zone
  - เป็นส่วนที่น้ำไหลผ่านชั้นดินที่ยังไม่อิ่มตัว
  - ปริมาณความชื้นตลอดหน้าตัดใกล้เคียงกัน
- wetting zone
  - เป็นส่วนที่ความชื้นกำลังเพิ่มขึ้นอย่างรวดเร็ว
  - ในชั้นดินที่ลึกลงไป ในช่วงเริ่มต้นยังมีความชื้นน้อย
- wetting front
  - เป็นหน้าตัดที่เริ่มเปียกน้ำและกำลังมีการเปลี่ยนแปลงความชื้นอย่างรวดเร็ว
  - ดินมีความชื้นแตกต่างกันมากจนแยกระหว่างดินเปียกกับดินแห้งได้อย่างชัดเจน



- **Infiltration rate (f)**
  - อัตราการซึมมีค่าสูงในช่วงแรก
  - ค่อย ๆ ลดลงเมื่อเวลาผ่านไป จนกระทั่งคงที่
- **Cumulative infiltration (F)**
  - ในขณะเริ่มต้น ปริมาณน้ำที่ซึมผ่านผิวดินจะเป็นศูนย์
  - มีค่าเพิ่มขึ้นตามเวลา
  - โดยในช่วงแรก โค้งปริมาณการซึมผ่านผิวดินมีความชันมาก
  - เมื่อเวลาผ่านไป ความชันของโค้งจะลดลง
  - ในที่สุด กราฟปริมาณการซึมผ่านผิวดินจะเป็นเส้นตรง เนื่องจาก อัตราการซึมผ่านผิวดินคงที่



Relation between infiltration rate and cumulative infiltration

$$F(t) = \int_0^t f(t)\,dt$$

$$f(t) = \frac{dF(t)}{dt}$$

- อินทิเกรต สมการอัตราการซึมผ่านผิวดิน (**f**)
  ได้ สมการปริมาณการซึมผ่านผิวดิน (**F**)
- หาอนุพันธ์ สมการปริมาณการซึมผ่านผิวดิน (**F**)
  ได้ สมการอัตราการซึมผ่านผิวดิน (**f**)

Infiltration equation

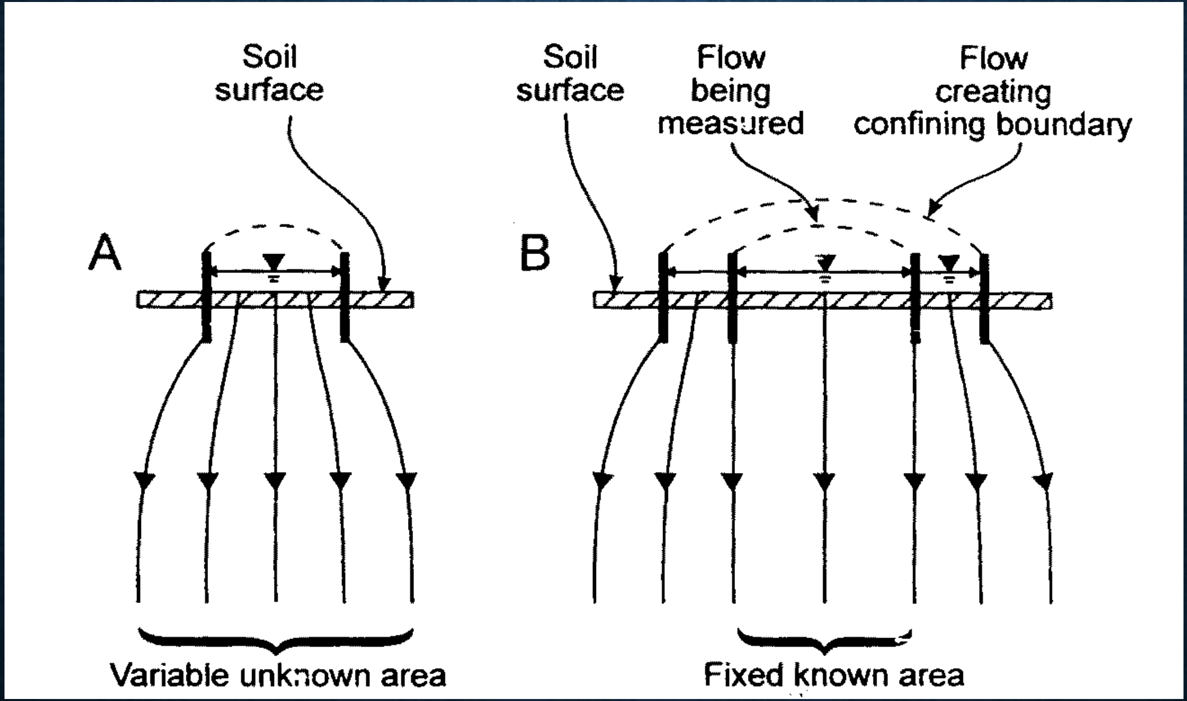
$$F(t) = \gamma t^{a}$$

$$f(t) = a\gamma t^{a-1}$$

- Lewis's equation or Kostiakov's equation

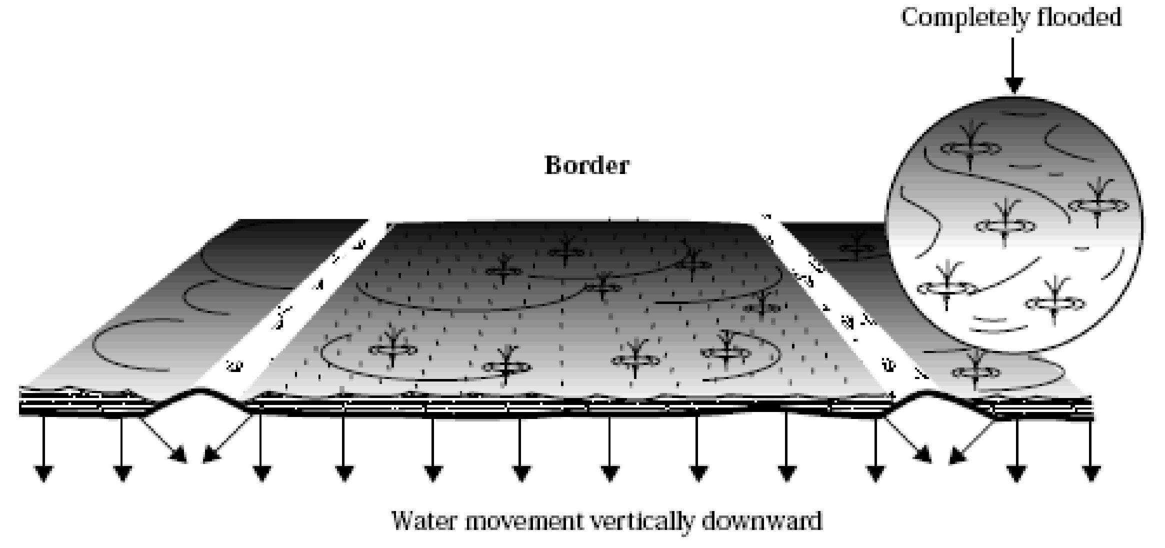
Double-ring infiltrometer

Infiltration measurement by double-ring infiltrometer

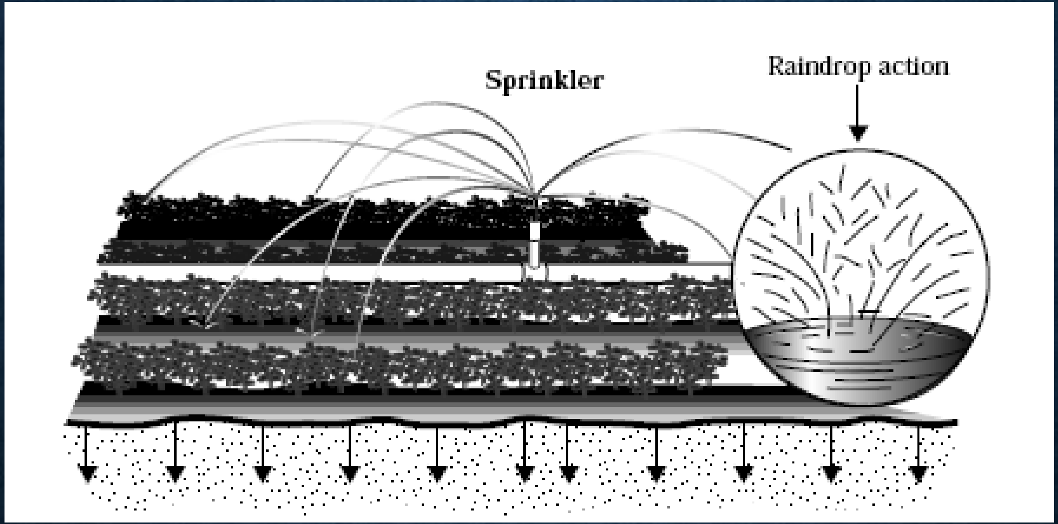


Infiltration in Irrigation

Infiltration in border irrigation

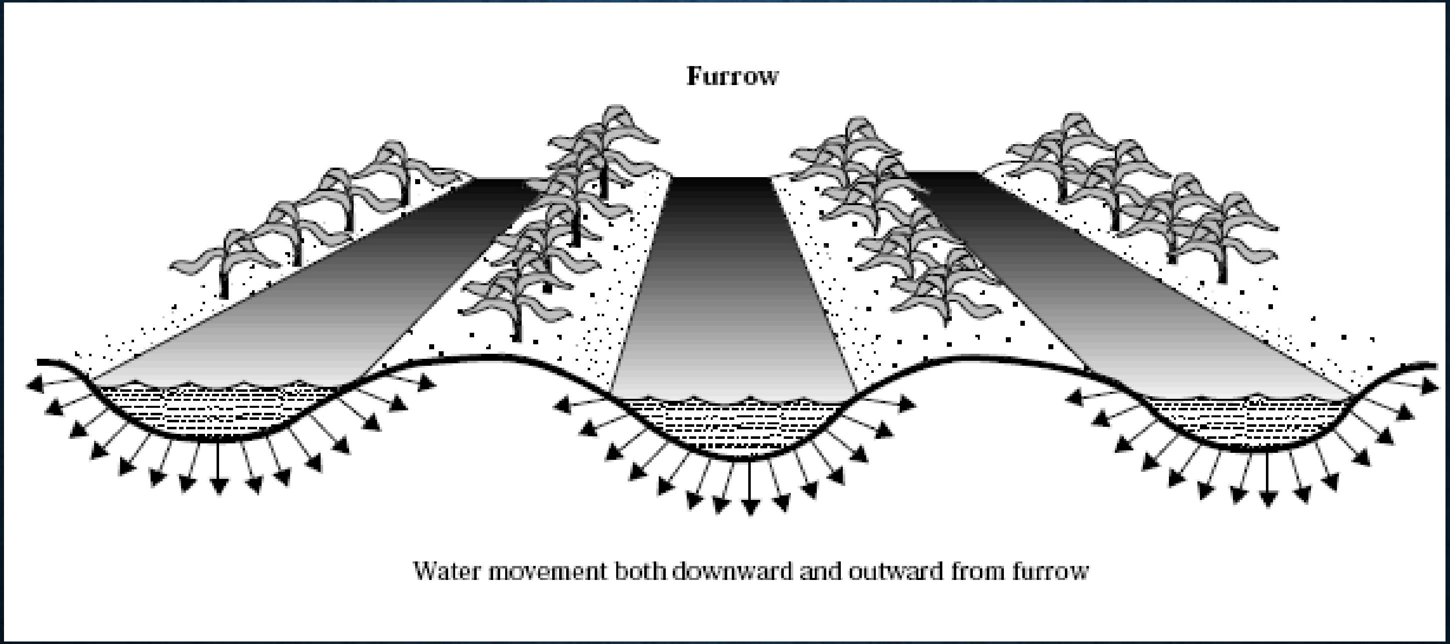


Infiltration in sprinkler irrigation



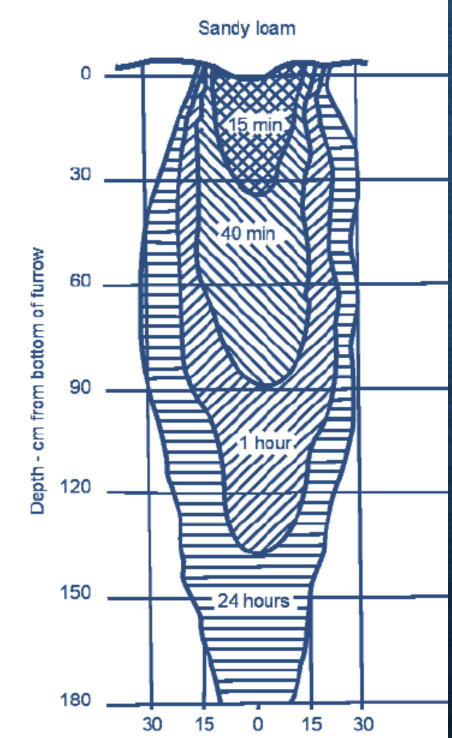
- น้ำซึมทางดิ่งอย่างเดียว
- อัตราการให้น้ำต้องไม่เกินอัตราการซึมผ่านผิวดิน

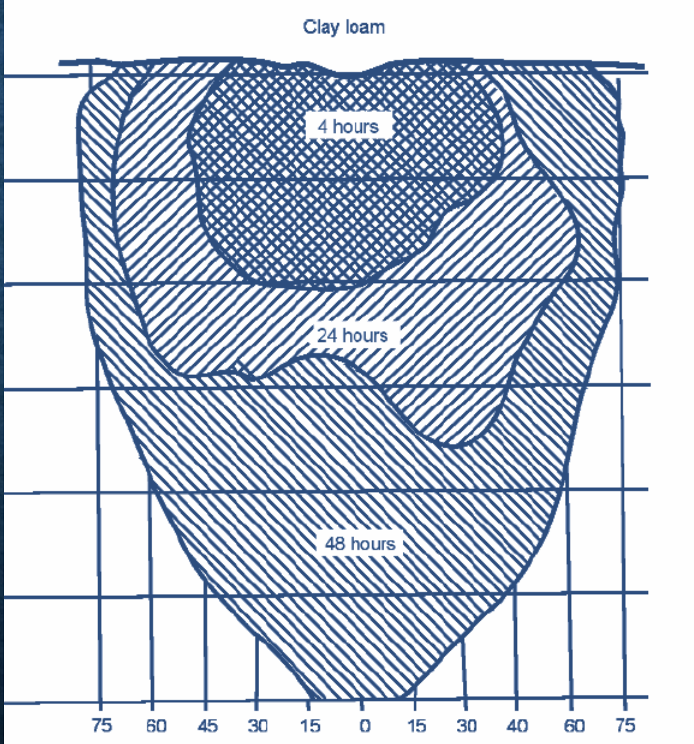
Infiltration in furrow irrigation



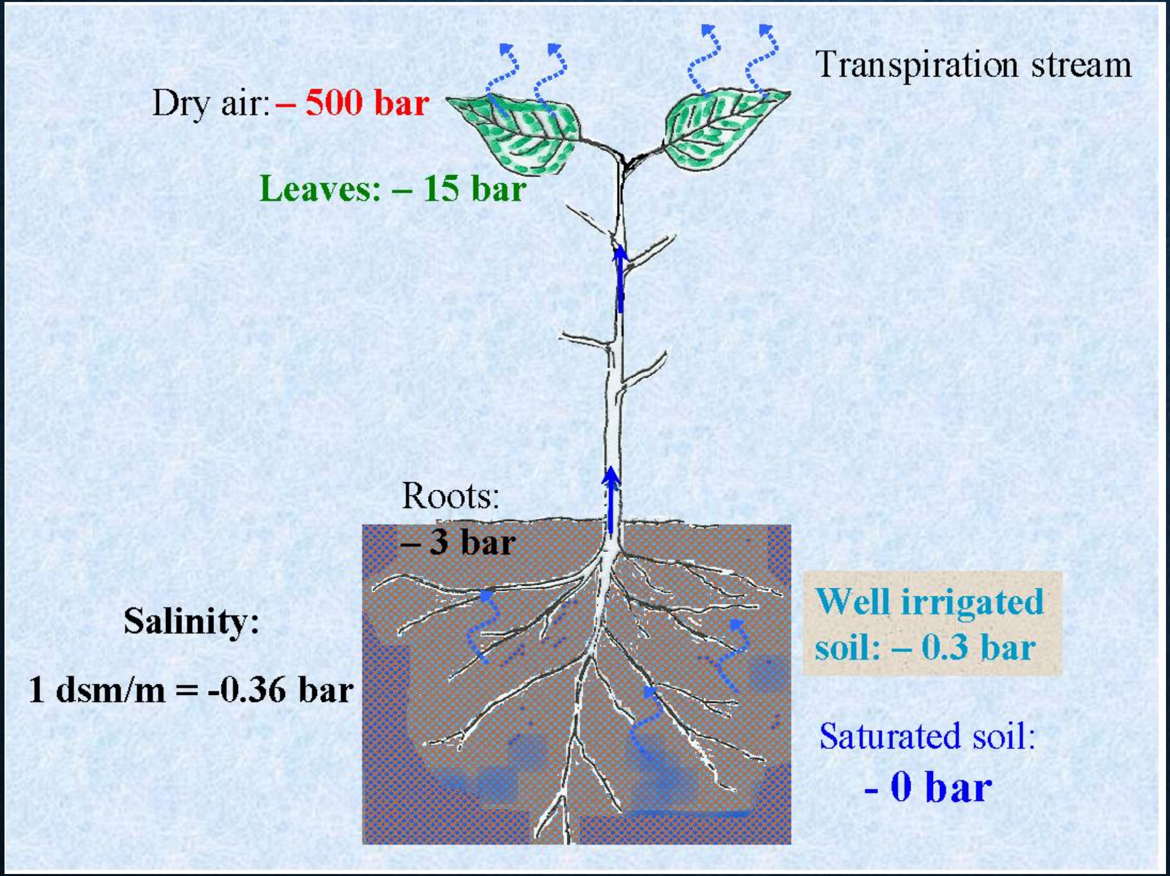
Water movement both downward and outward from furrow

- น้ำซึมทั้งทางดิ่งและทางราบ


Sandy loam
0
30
60
90
120
150
180
Depth - cm from bottom of furrow
15 min
40 min
1 hour
24 hours
30
15
0
15
30


Clay loam
4 hours
24 hours
48 hours
75
60
45
30
15
0
15
30
40
60
75

Water Flow in Plant

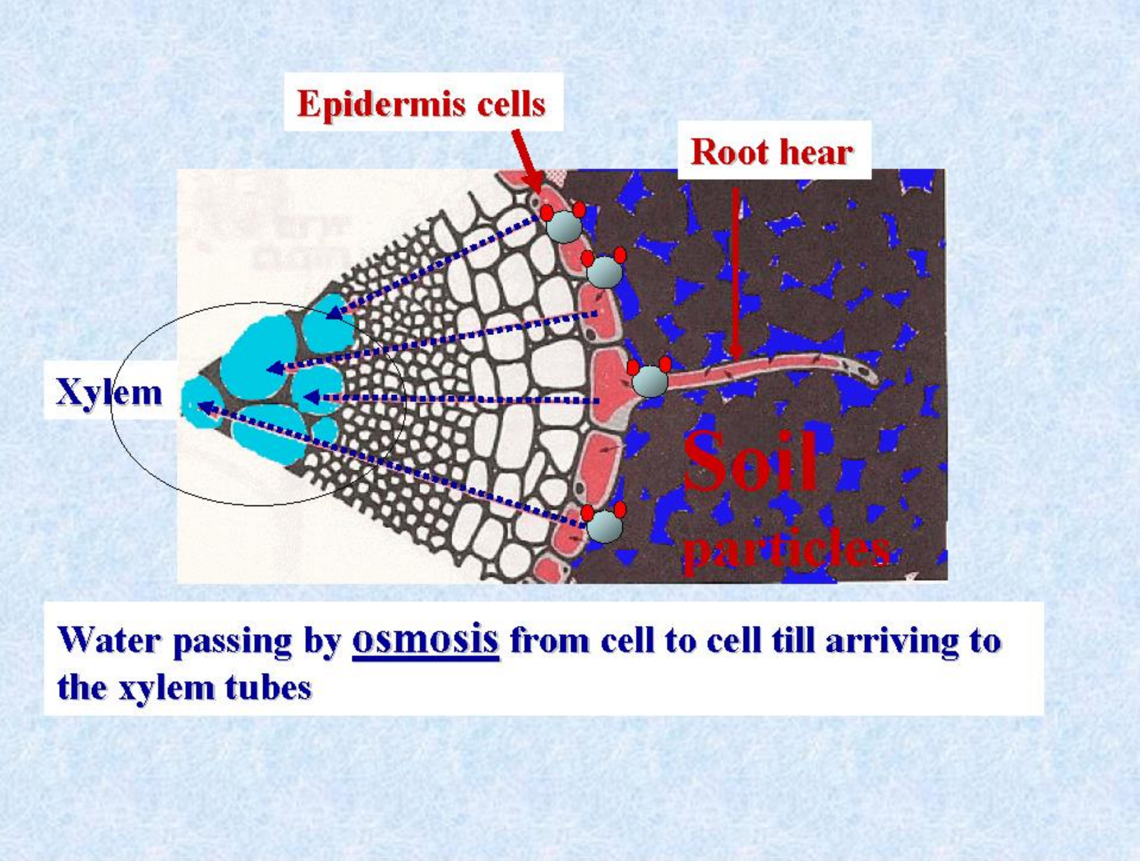


Source:

Shlomo Kramer

Irrigation & Fertilization Consultant

Tel: 972 50 6241483 Shlomo@arava.co.il



Water passing by osmosis from cell to cell till arriving to the xylem tubes

Source:

Shlomo Kramer

Irrigation & Fertilization Consultant

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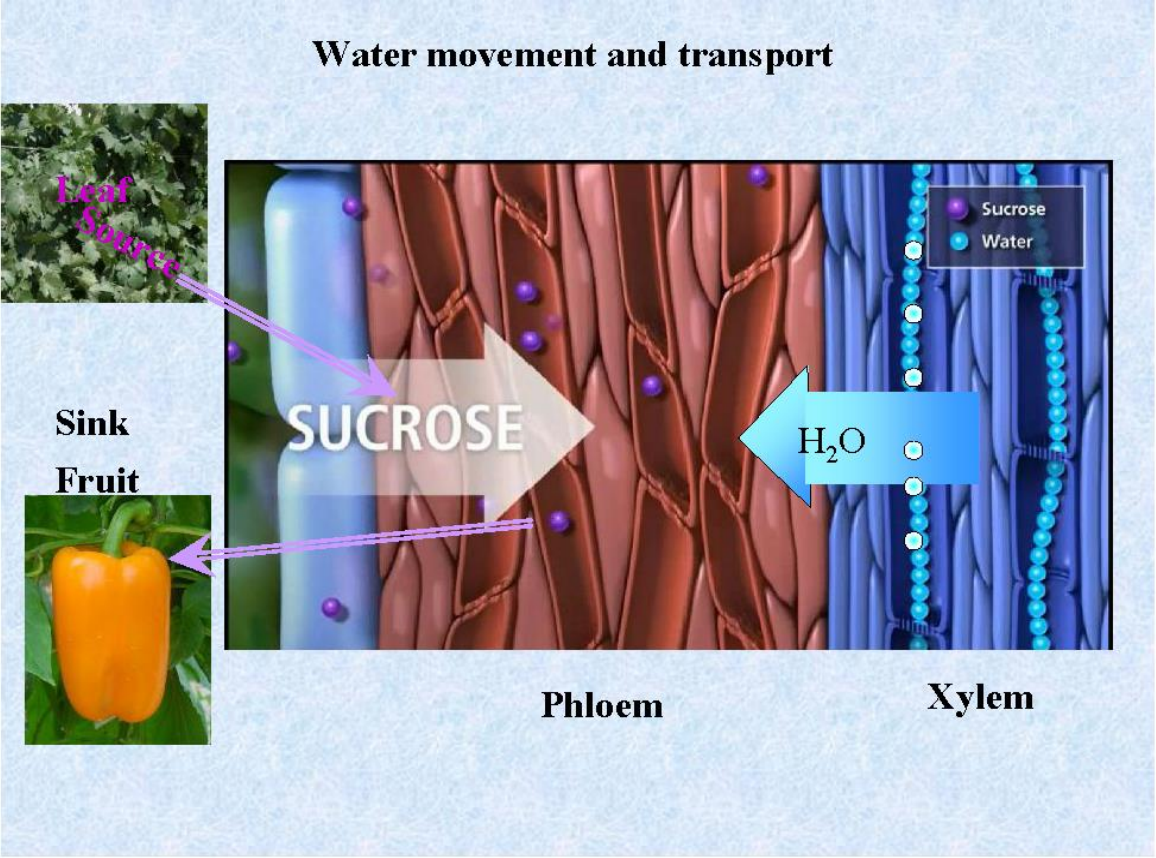

Water movement and transport

Source:

Shlomo Kramer

Irrigation & Fertilization Consultant

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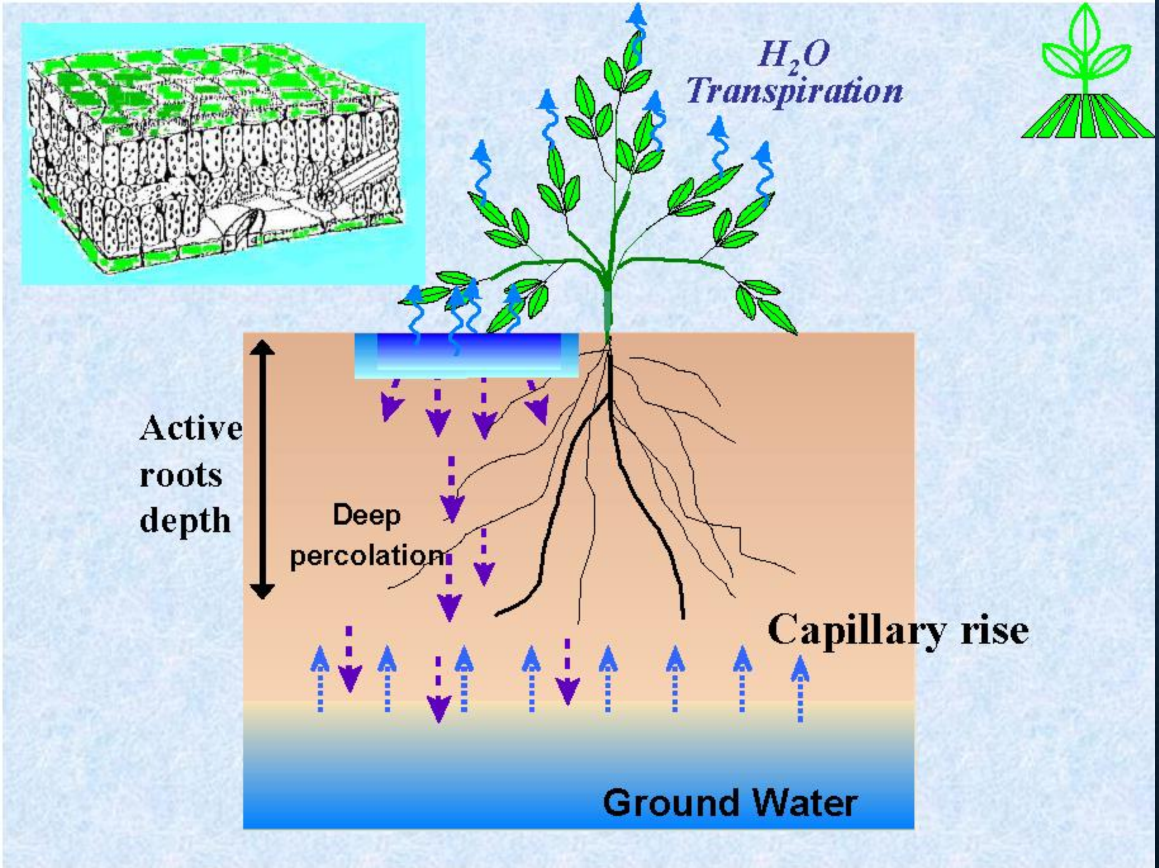

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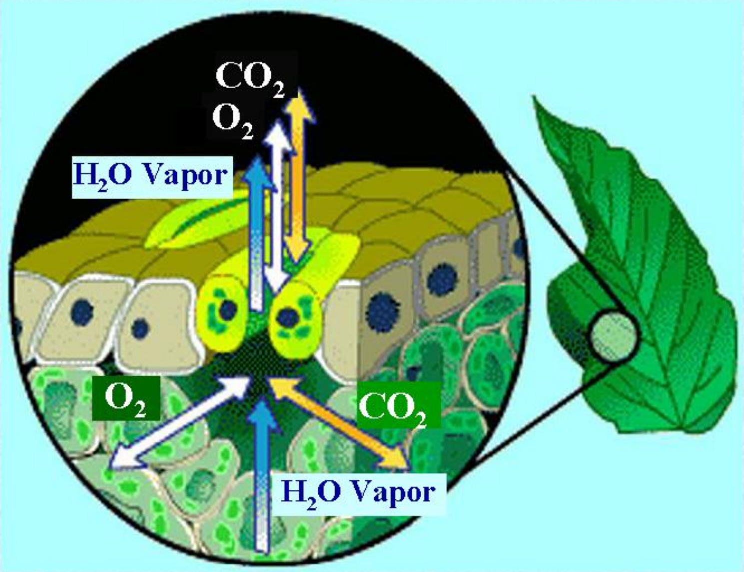
Gas exchange through the Stomata opening



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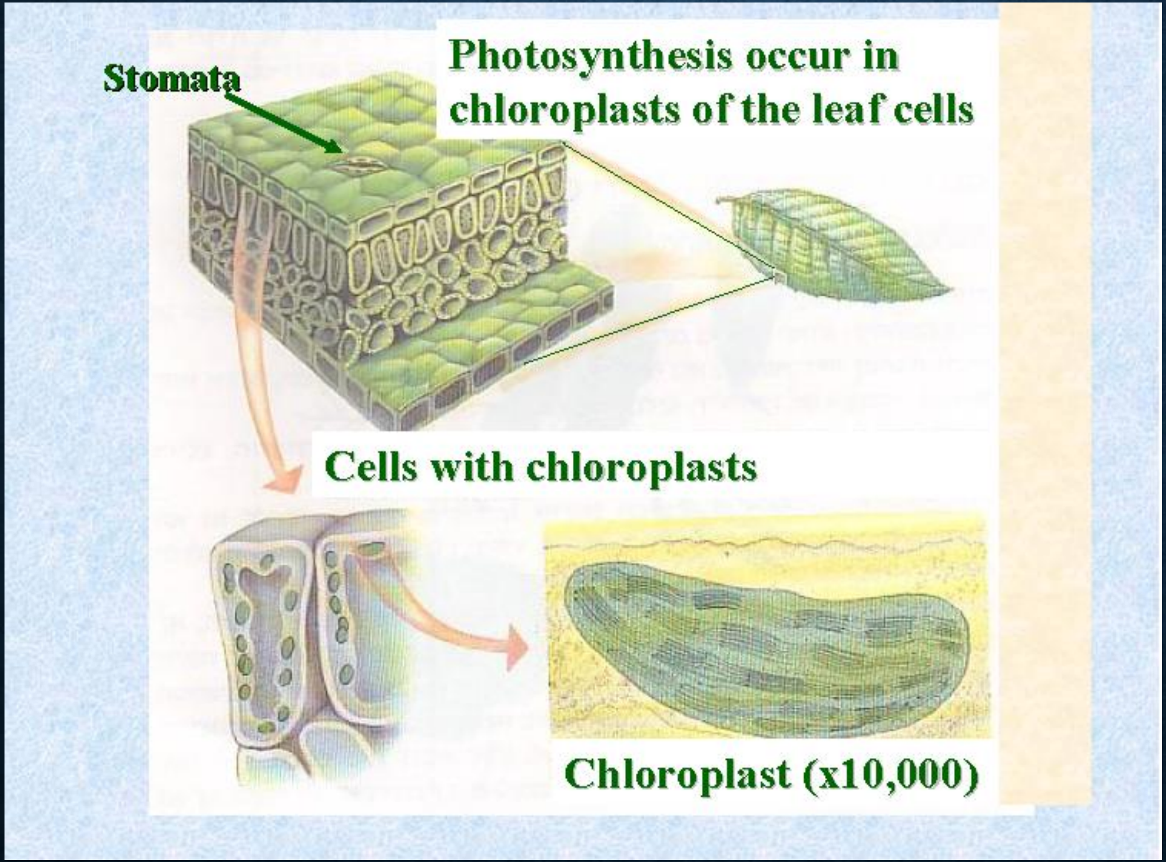

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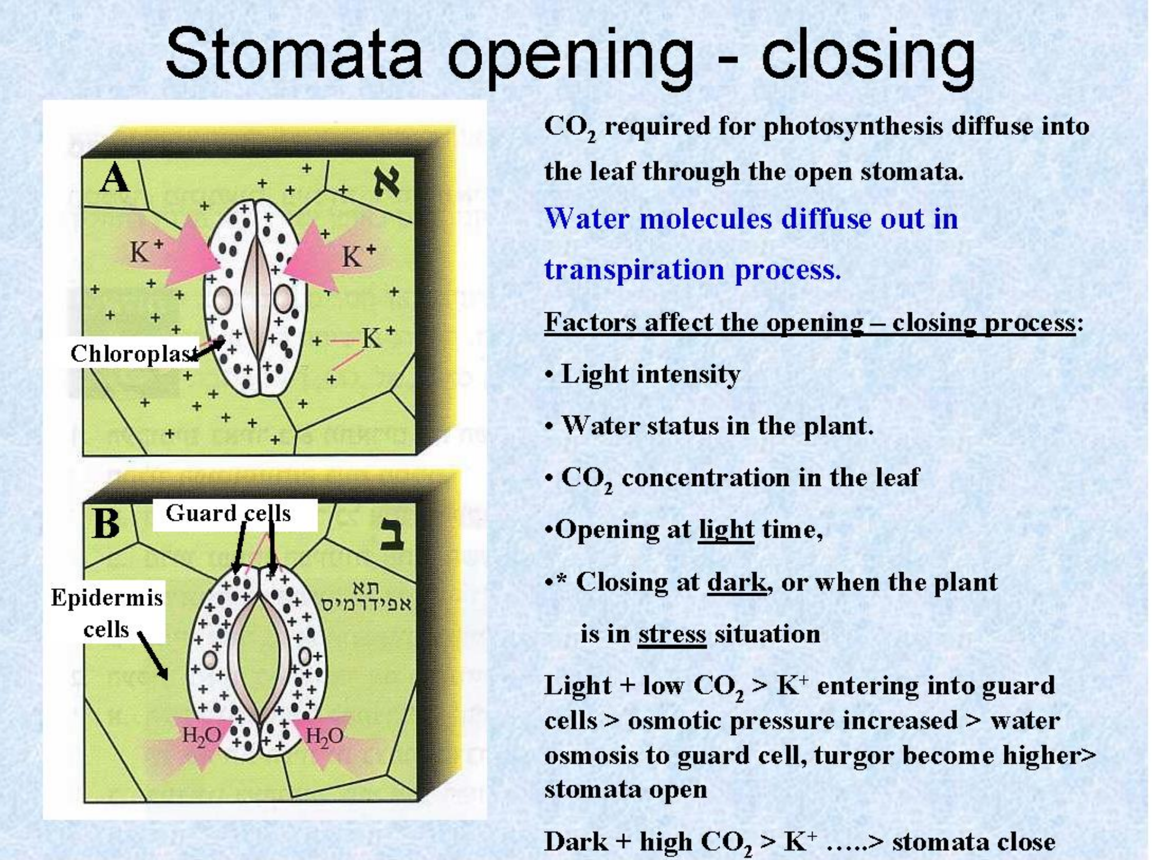

Stomata opening - closing

CO_2 required for photosynthesis diffuse into the leaf through the open stomata.

Water molecules diffuse out in transpiration process.

<u>Factors affect the opening – closing process</u>:

- **Light intensity**
- **Water status in the plant.**
- **CO_2 concentration in the leaf**
- **Opening at <u>light</u> time,**
- *** Closing at <u>dark</u>, or when the plant is in <u>stress</u> situation**

Light + low CO_2 > K^+ entering into guard cells > osmotic pressure increased > water osmosis to guard cell, turgor become higher> stomata open

Dark + high CO_2 > K^+ …..> stomata close

Source:

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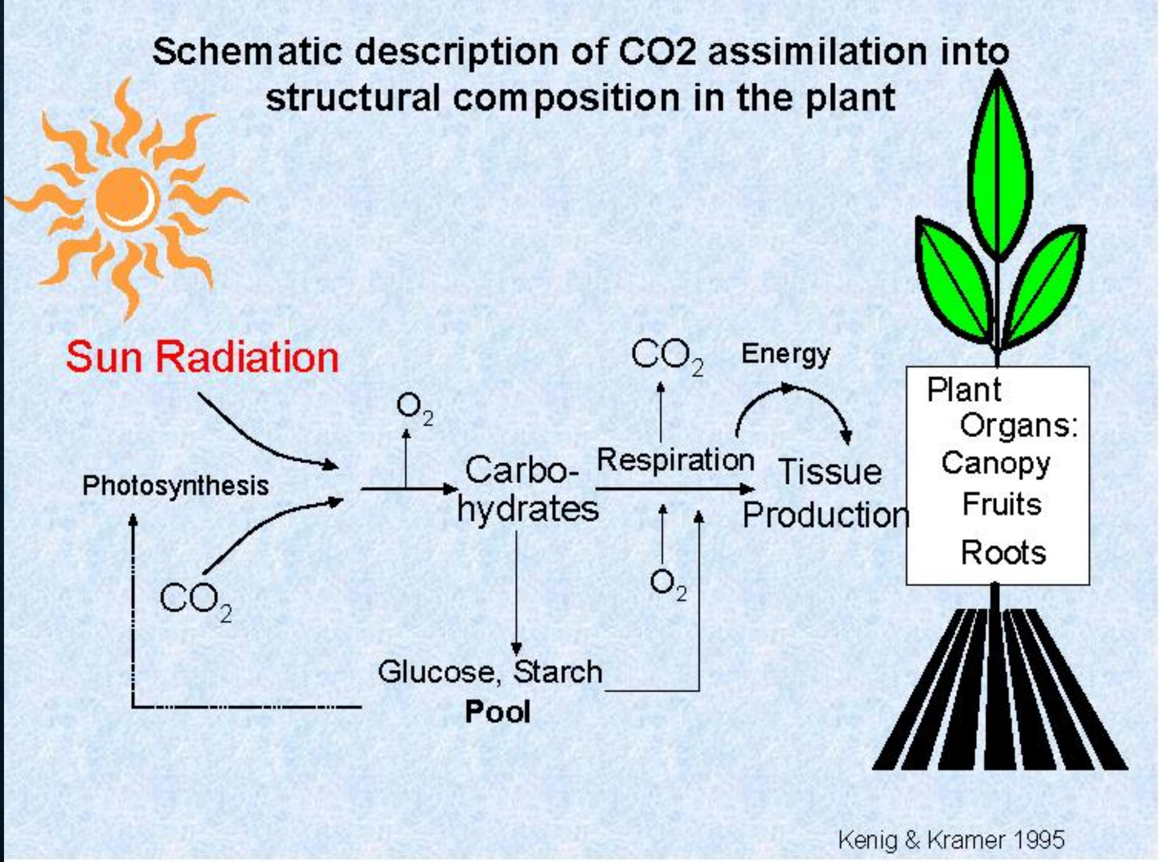

Schematic description of CO2 assimilation into structural composition in the plant

Kenig & Kramer 1995

Source:

Shlomo Kramer

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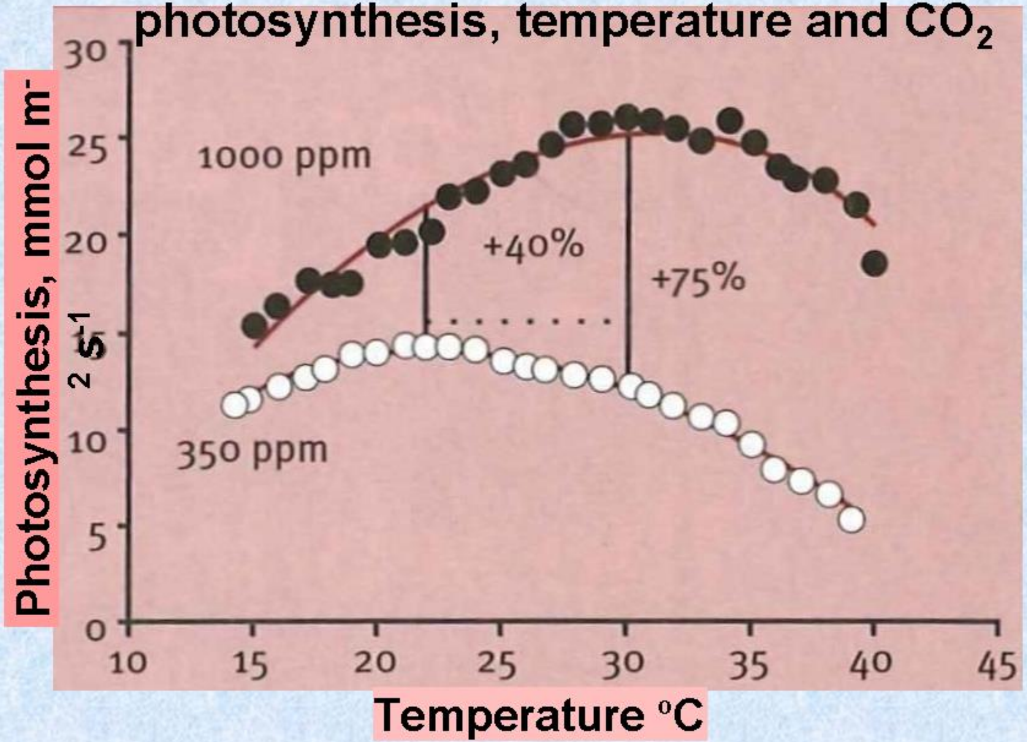
The relationship between photosynthesis, temperature and CO_2



After: Peter van Weel, PPO greenhouse horticulture, Wageningen, the Netherlands

Source:

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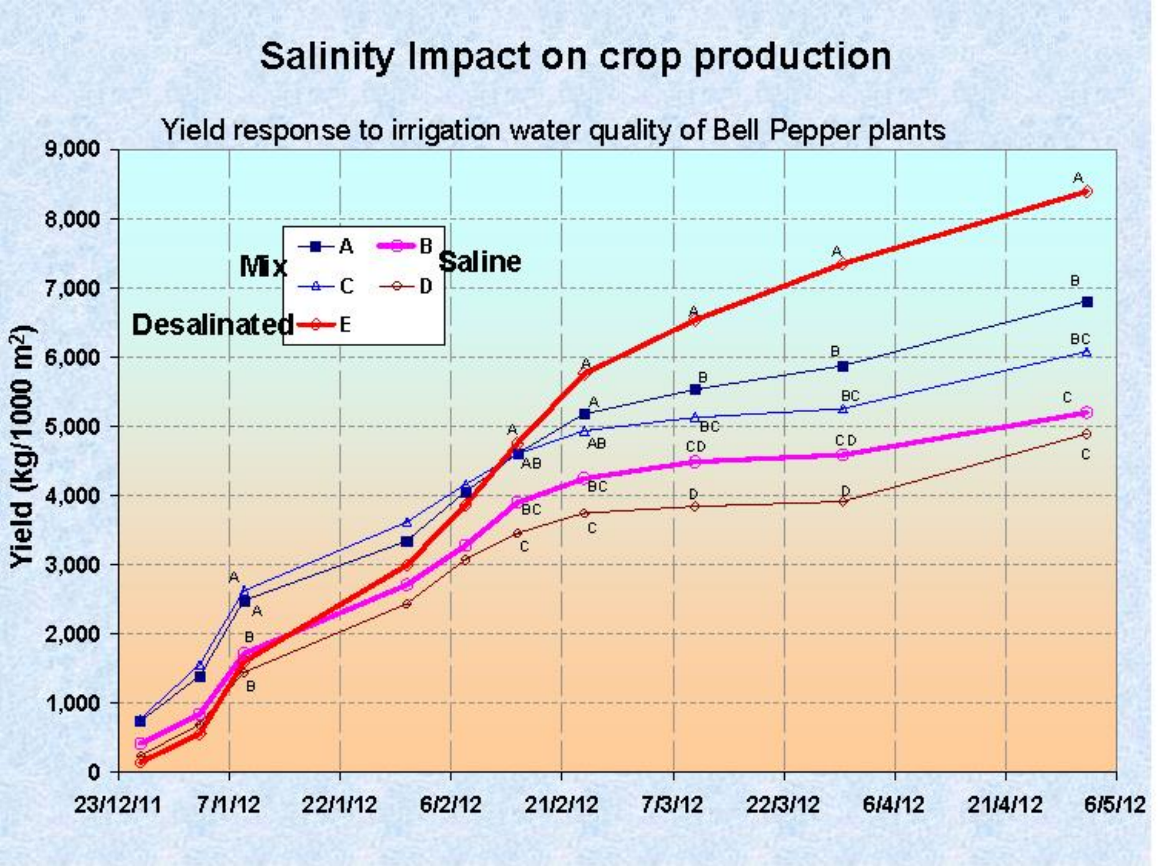

Source:

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Thank you