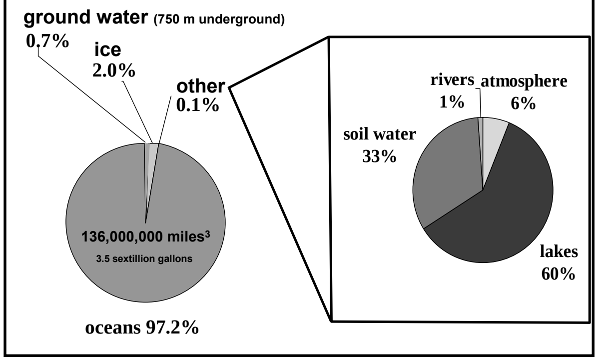
Chapter 5

Soil Water

Ch. 5 Learning Objectives

- Define water content and water potential
- Identify the terms commonly used to qualitatively describe soil wetness
- Discuss how water moves in the soil and define the forces that act on soil water
- Identify the factors affecting the amount of plant-available soil water
- Describe the linkage between soil water and water quality

Soil as a freshwater reservoir



Importance of soil in the global hydrological cycle

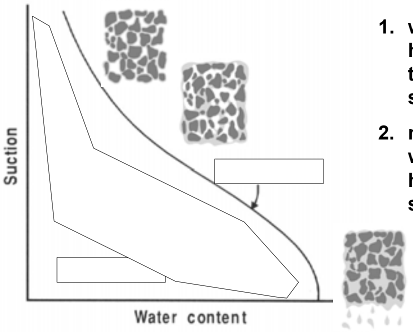
- Soil transforms non-continuous rainfall or snow into a continuous supply of water for plant growth.
- Soil transforms discontinuous precipitation into continuous discharges, i.e., streams and rivers
- without soil: FLOODS!

Amount of water stored in soil is a function of…

See p. 146 of text for nice summary

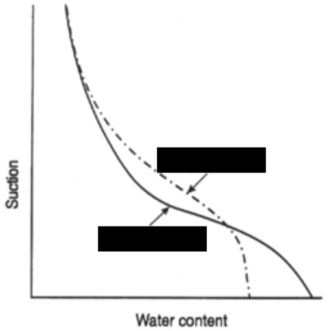
- Water inputs (rainfall type, frequency)
  infrequent, intense storms cause runoff
- Soil texture clayey soil holds more water
- Soil structure aggregated soil holds more water
- Soil depth deeper soil holds more water
- Presence of impeding layers If yes, then runoff
- Organic matter content (surface only)
  More OM means more available water

Effect of texture on soil water retention



1. **water not held as tightly in sandy soils**
2. **not as much water can be held in sandy soils**

Effect of structure on soil water retention



Measuring soil water

- Mass-based (gravimetric): simple, cheap: (wet wt. – dry wt)/dry wt.
- Volume-based (volumetric):
  - allows you to convert a measurement on a sample to information about a field site (e.g., how much irrigation water to apply)

<u>Gravimetric Moisture Content:</u> **Mass wetness**

The amount (by wt.) of water contained in a soil sample at a given time. **Mass of water relative to the mass of the dry soil**

- Calculated on an **OVEN-DRY BASIS**:

θ_m = 100*((wet weight – dry weight) / dry weight)

- Expressed as a ratio or percentage
- Example:

  wet weight 150g, dry weight = 102g:
  [(150-102)/102]*100 = 47%

  or [(150-102)/102] = 0.47

<u>Volumetric Moisture Content:</u> **Volume wetness**

Percentage of the total volume of the soil. At saturation, θ = porosity

The amount (by volume) of water contained in a soil sample at a given time.

Volumetric (θ_v) = Gravimetric (θ_m) * bulk density (D_b)

<u>Example</u>:
If gravimetric is 47% and D_b is 1.3 g/cm^3,
0.47 * 1.3 = 0.61g H_2O/cm^3 soil (or 61%)

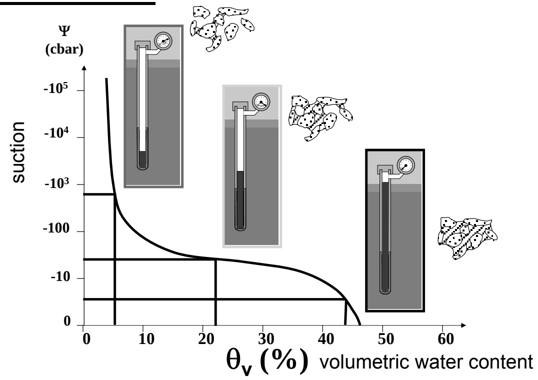
Methods of measuring soil water

- Gravimetric (lab) – weigh, dry, weigh
- Buried porous block (field) –
  measures electrical conductance as block absorbs water
- Time domain reflectometry (TDR; field) –
  measure propagation velocity of electromagnetic pulse
- Neutron probe (field) –
  probe emits fast neutrons, which slow upon collision with water and bounce back to sensor
- Tensiometer – (field) tension gauge & cermaic cup

Measuring water content

Method	Advantages	Disadvantages
Gravimetric	Inexpensive	Destructive, tedious
Buried block	Continuous	Low accuracy
TDR	Fast, accurate, nondestructive, continuous	Expensive
Neutron probe	Same as TDR	Expensive, health hazard
Tensiometer	Inexpensive	Must meas. moist curve for each soil; hysteresis errors

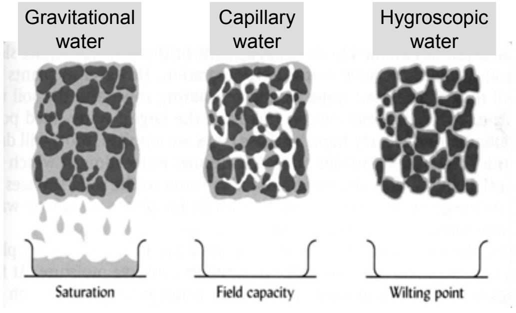
Using a Moisture Characteristic Curve & Tension Data



Categories of soil water

1. **Gravitational water**:
   "excess" water that drains away under the force of gravity
2. **Capillary water**:
   readily available for plant growth; retained by forces of cohesion and adhesion after gravitational water is gone
3. **Hygroscopic water**:
   Bound to the mineral surface, unavailable for plant growth; moves only as a vapor

Visual for water terminology



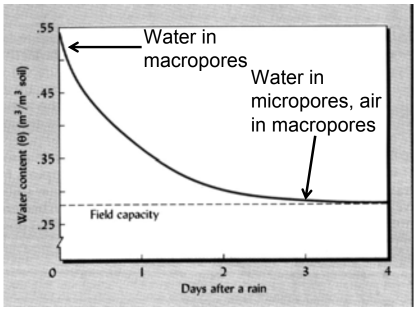
More terms to know

- Field capacity:

  when water has drained from the macropores (2-4 days after saturation event)
- Wilting point:

  water is there, but held too tightly for the plants to access it

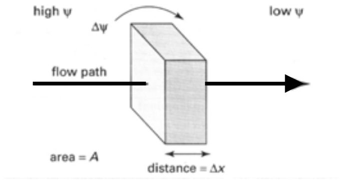
Field capacity: the ideal state


Water in macropores

Water in micropores, air in macropores

Soil water potential

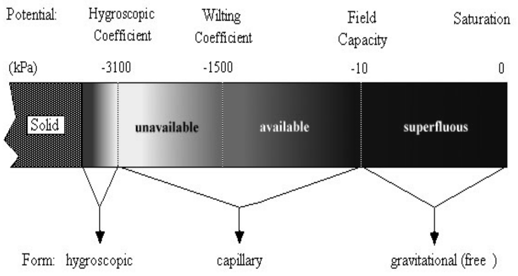
Water (like everything) moves from **HIGH to LOW energy**



Categories of potential energy

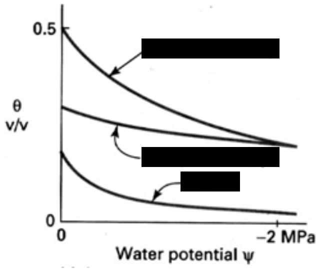
- Gravitational Key in saturated soils
- Osmotic Due to solutes (salts) – soils of arid areas
- Matric Due to attraction of water for soil particle surfaces KEY in <u>un</u>saturated soils

Relationship between water categories and potential energy



Source: Crown and Palylyk, 1996

Relationship between water content and water potential for soils of different texture



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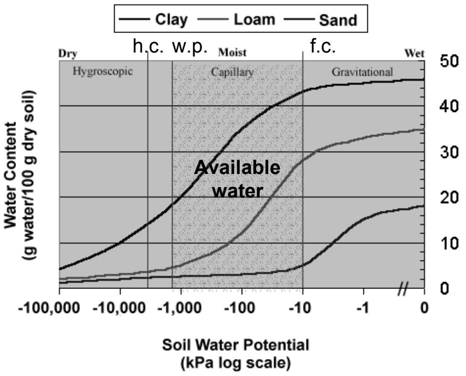
Water held loosely

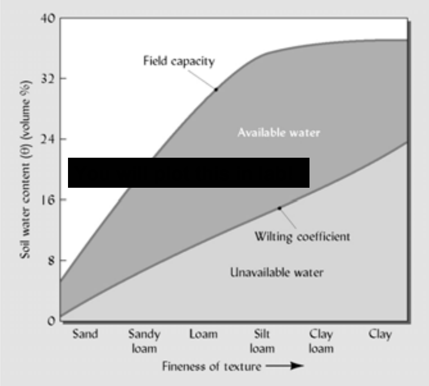
Water held tightly

Relationship between water content and water potential



Juma & Nickel

Available water **(we'll come back to this)**



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Water moves in part because water is a polar molecule

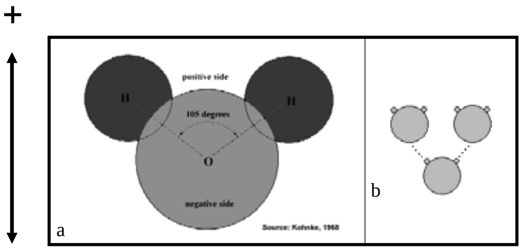
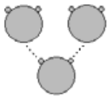


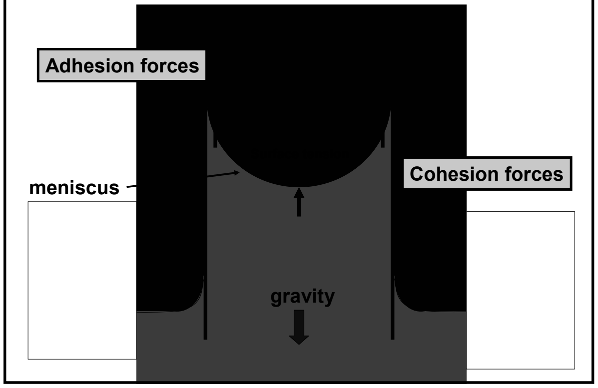
Fig. 8.2. (a) Structure of water molecule and (b) hydrogen bonding between water molecules.

Two terms arise from this polarity: adhesion & cohesion

- **Adhesion**: the attraction of water molecules for solid surfaces
- **Cohesion**: the attraction of water molecules for each other



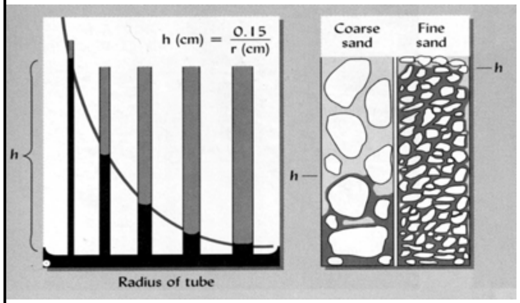
Capillarity: the sum of adhesion and cohesion



Capillarity and Water Movement

- Soil water exists in small spaces as a film around soil particles
- Small soil pores <u>act as small capillary tubes</u>
- Capillary action holds water in the small pores against the force of gravity
- The smaller the pores, the greater the force of capillarity relative to other forces (i.e. gravity)

Relationship between pore size and **capillary rise**



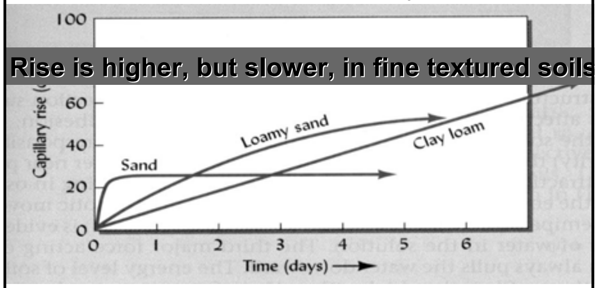
Height of rise is greater in finer textured soils

Effect of Soil Texture on Capillary Rise

Radius of soil pore (cm)	Capillary rise (cm)
0.015 (sand)	10
0.0015 (clay)	100

- **Capillary rise greatest in fine-textured soils**

Relationship between pore size and RATE of capillary rise



Rise is higher, but slower, in fine textured soils

Categories of water movement

- **Saturated flow**: The movement of water through a soil that is temporarily saturated. Most of the water moves downwards, though slow lateral movement occurs too.
- **Unsaturated flow**: The movement of water in soil in which the pores are not filled to capacity with water.
- **Vapor movement**: hygroscopic water

Saturated Flow Through Soils

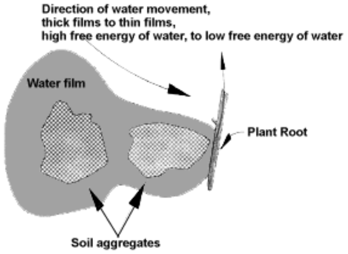
- Saturated flow is the mostly vertical movement of water due to the force of gravity in a soil in which all the pores are completely filled (saturated) with water
- Under these conditions, ψ (suction) is zero

Unsaturated flow in soils

- Occurs when some pores are air-filled
- Driven by differences in matric potential
  - wet →dry or dry → wet fast
  - moist → slightly less (or more) moist slow
  - water flows from thick films to thinner films (more ψ (suction) in thin films)

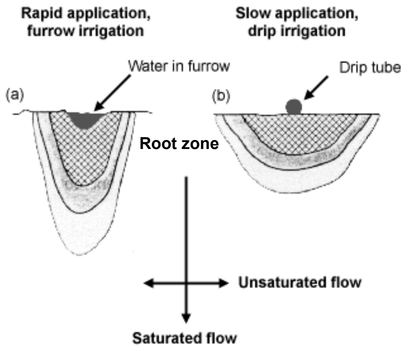
Unsaturated Flow Through Soils

- Thick films to thinner films



Source: Hassett and Banwart,

Effect of application rate on water movement



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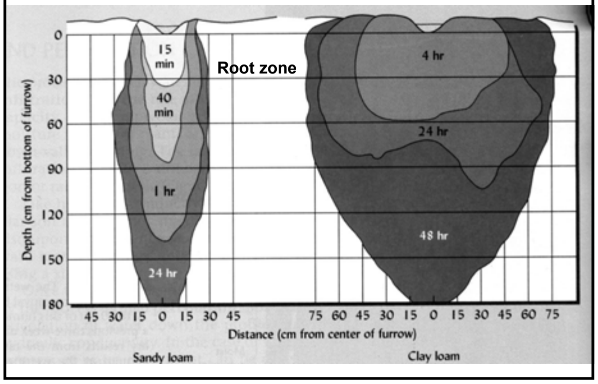
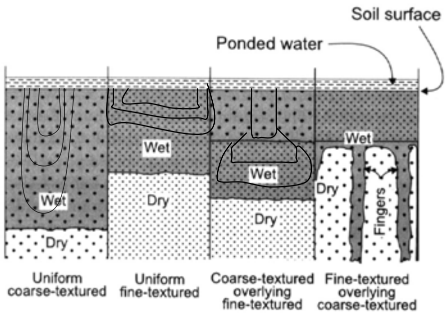
Effect of texture on water movement



Movement of water in layered soils



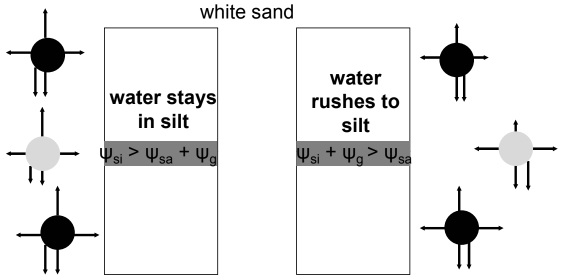
Unsaturated water movement in stratified soils

- Sand over silt: quick flow of water through sand
  - Why?

    Micropores of silt attract water, but the flow then slows . . .
- Silt over sand: flow is slow!
  - Why? 'cuz sand has less adhesive force, doesn't draw water in

Sand over silt vs. silt over sand

Turquoise gravity,
yellow silt,
white sand



water stays in silt

$\Psi_{si} > \Psi_{sa} + \Psi_{g}$

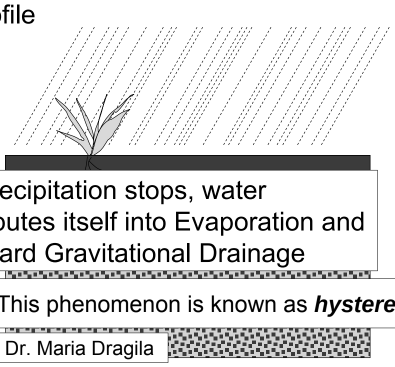
water rushes to silt

$\Psi_{si} + \Psi_{g} > \Psi_{sa}$

Depth of Wetting:

When water is added to a dry soil, it will wet each layer from its present water content to field capacity and then the excess (gravitational water) will leach and wet lower layers.

During precipitation, water infiltrates into the soil profile



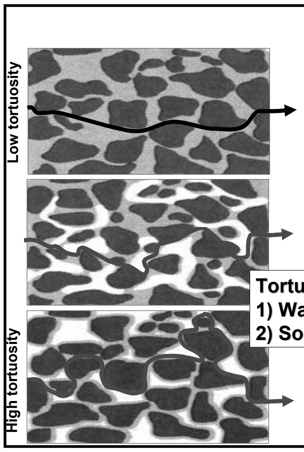
After precipitation stops, water redistributes itself into Evaporation and Downward Gravitational Drainage

This phenomenon is known as ***hysteresis***

Thanks to Dr. Maria Dragila

Hydraulic conductivity (K) = rate of water movement in soil

- The greater number of pores filled with water, the more pathways there are for water to flow ∴ **K is high**
- **K** affected by total porosity AND pore size distribution
  - Larger pores drain first
  - Smaller pores drain more slowly
  - The more convoluted the route (↑ tortuosity), the slower the flow



Hydraulic conductivity as a function of tortuosity

Tortuosity influenced by both:
1) Water content (water potential)
2) Soil structure & particle packing

Relationship among **texture, bulk density, porosity and saturated hydraulic conductivity (K_{sat}) of soils**

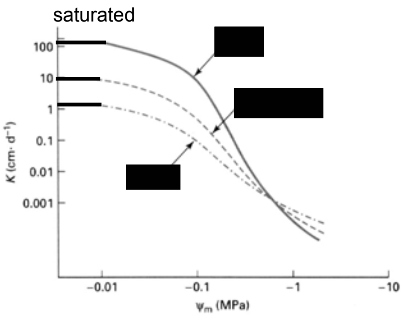
Textural Class	Bulk Density (Mg/m^3)	Porosity (%)	Hydraulic Conductivity (K_{sat})
Sand	**1.55**	**42**	**7.2 - 1.2 cm/min**
Loam	**1.22**	**55**	**1 - .006 mm/h**
Clay	**1.05**	**60**	**0.02 - 9 x 10^{-4} mm/24hr**

After Hanks and Ashcroft, 1980

Hydraulic conductivity and water content

- When soil is saturated, hydraulic conductivity **(K_{sat})** is constant
- When soil is not saturated, hydraulic conductivity **(K)** varies as a function of water content (more water = faster flow)

Effect of water content on hydraulic conductivity



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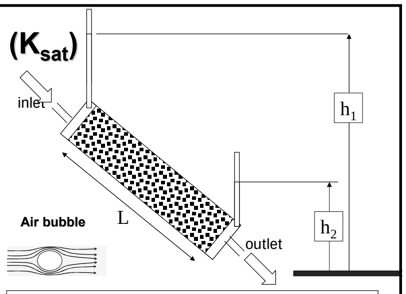
Darcy's law **(K_{sat})**

- The flow of water through saturated media is a function of the pressure head across the media

  the length of the media and the texture of the media, i.e., coarse or fine



$$V/t = AK_{sat}\triangle H/L$$

V/t = quantity of water per unit time
A = cross sectional area (r^2)
K_{sat} = saturated hydraulic conductivity
$\triangle H = h_1 - h_2$ (head change)

Review: water movement in soils

- Water moves from high to low energy (also from thick films to thin films)
- Saturated soils drain by gravity, unsaturated flow mediated mostly by adhesion forces
- Large pores drain first and are air-filled at field capacity
- The finer the texture, the lower K is
- The more convoluted a route, the slower the flow (tortuosity)

Infiltration rate

- The rate at which water enters soil surface (distance/time: e.g., cm/sec)
- Dry soils
  - rate is variable
  - flow <u>fast</u> at first **(matric forces dominate)**
  - <u>then slows</u> to saturated flow rates **(K_{sat}) (gravitational force dominates).**
- Saturated soils
  - rate is constant **(K_{sat}) (gravitational force dominates)**

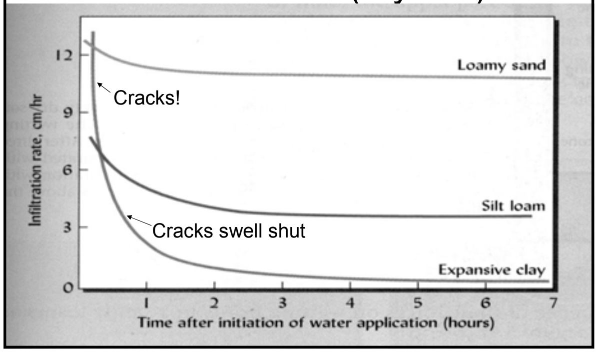
Infiltration rate

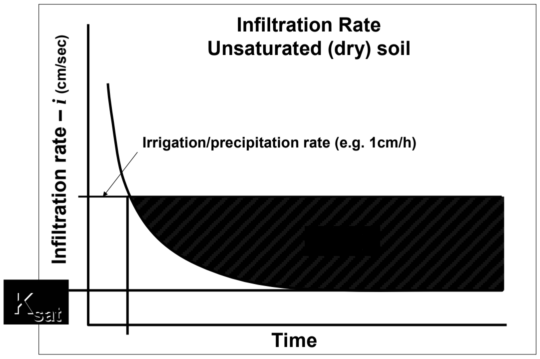
- Rate at which water enters the soil. Affected by:
  - Surface texture, bulk density, O.M. content
  - Subsurface structure (good structure promotes higher permeability)
  - Initial water content (highest when soils already moist)

Infilitration rate (cont.)

- Presence of forest litter layer (high WHC, breaks impact of raindrops)
- Canopy structure (breaks impact)
- Presence of stones and cobbles (promotes formation of cracks –- 'cuz of differential expansion)
- Microrelief (slows overland flow)

Effect of texture on rate of infiltration rate (dry soil)



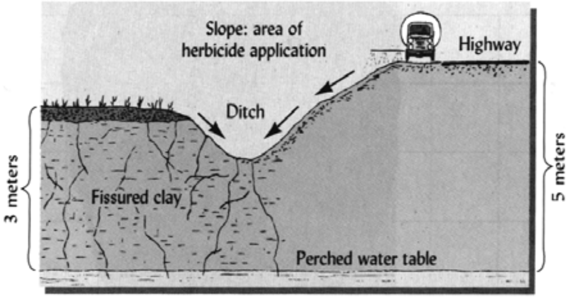


Effects of vegetation and texture on infiltration

Texture	Vegetated (mm/hr)	Bare soil (mm/hr)
Loamy sand	50	25
Loam	25	13
Clay loam	5	3

infiltration ~ half as fast in bare soil!!

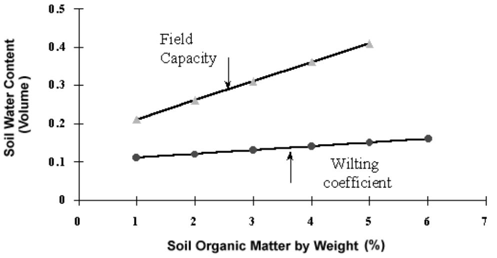
Implications: groundwater quality



Controls on plant-available water

- How much water is in the soil
- How tightly that water is held
- Soil organic matter content

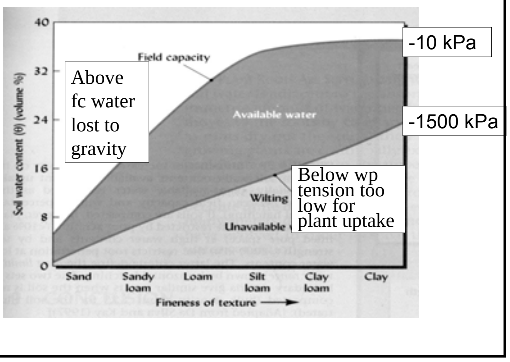
Impact of soil organic matter content on soil water content



Volumetric water content at field capacity and its availability

Soil	Volume %	Volume % (θ_v)	
	Field capacity (-10 kPa)	Wilting point (-1500 kPa)	Available water (col1-col2)
Sandy loam	12	3	9
Silt loam	30	10	20
Clay	35	18	17

Plant available water



-10 kPa

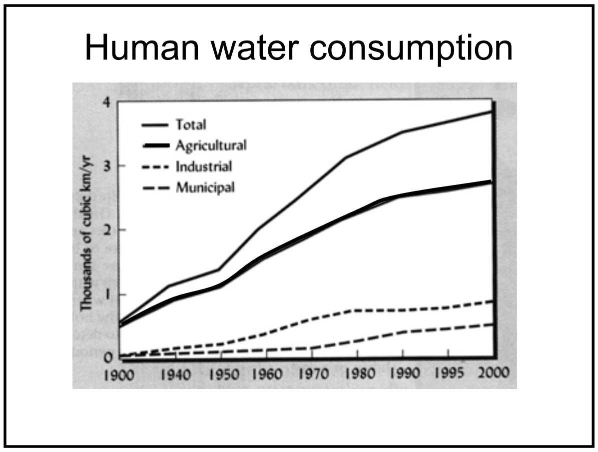
Above fc water lost to gravity

-1500 kPa

Below wp tension too low for plant uptake

Take home message

- Clay soils have a higher water-holding capacity than sandy soils
- Water in coarse textured soils is easier for plants to remove than in fine textured soils
- Much of the water in high-clay soils is unavailable to plants, while most water in sandy soils is available



Human water consumption