IIT KHARAGPUR

NPTEL ONLINE CERTIFICATION COURSES

NPTEL

Irrigation and Drainage

Lecture No:01 Introduction

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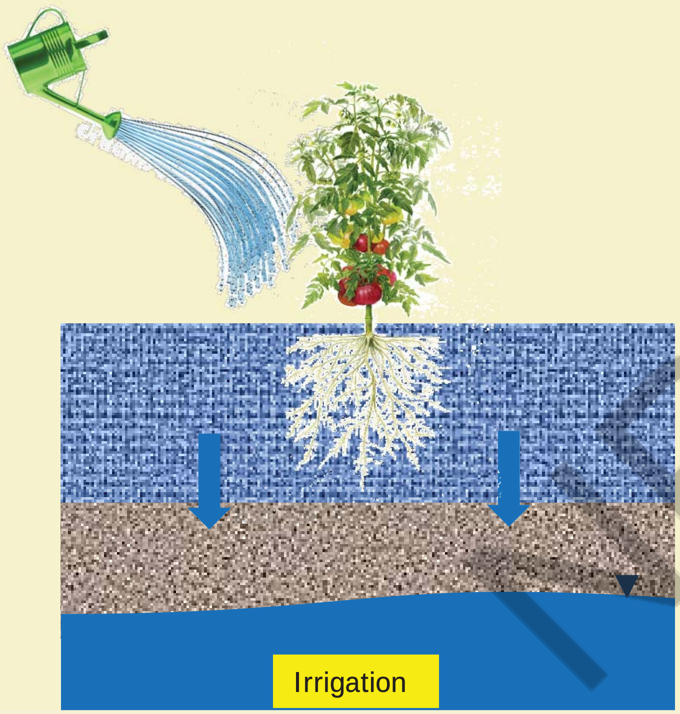
AGRICULTURAL AND FOOD ENGINEERING DEPARTMENT

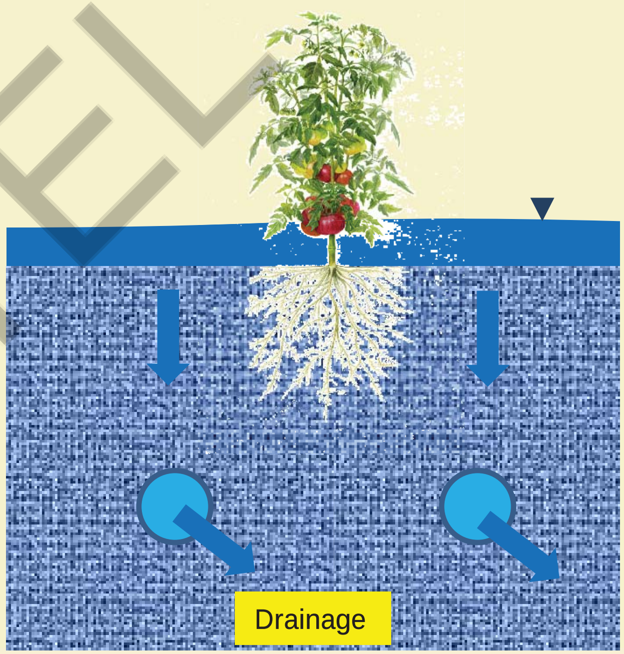
IIT KHARAGPUR

HIGHLIGHTS OF THE COURSE

- ✓ Two Modules
- ✓ 12 weeks
- ✓ 60 lectures of 30 min long
- ✓ Tutorials on GATE/ICAR-JRF problems
- ✓ Assignments
- ✓ Quizzes
- ✓ Online discussion
- ✓ 2-Technical Assistants

WHAT ARE IRRIGATION AND DRAINAGE?





LEARNING OUTCOME

- ✓ To understand irrigation and drainage principles
- ✓ To design gravity and pressurized irrigation systems
- ✓ To understand groundwater hydraulics
- ✓ To design surface and subsurface drainage systems
- ✓ To familiar with some irrigation and drainage models
- ✓ To know about water lifting devices and pumps

REFERENCE BOOKS

INTRODUCTION

- Sustainable development and efficient management of water is challenging in India
  - Declining groundwater table due to over-exploitation
  - Incomplete (many) major and medium irrigation projects
  - Very slow increase in gross irrigated area
  - Unsatisfactory quality of our rivers and lakes
  - Increasing water conflicts

WATER RESOURCES IN INDIA

With 2.4% of the world's total area, **India** has 16% of the world's population; but has only 4% of the total available fresh water

Item		Quantity (km^3)
Annual Precipitation Volume (Including snowfall)		4000
Average Annual Potential flow in Rivers		1869
Estimated Utilizable Water Resources		1122 (28%)
(i) Surface Water Resources	690 km^3	
(ii) Ground Water Resources	432 km^3	

PER CAPITA WATER AVAILABILITY IN INDIA

Sl. No.	Year	Population (in million)	Per-capita water availability, m^3
1	1951	361	5410
2	1955	395	4944
3	1991	846	2309
4	2001	1027	1902
5	2025 (Projected)	a. 1286 (Low growth) b. 1333 (High growth)	1519 1465
6	2050 (Projected)	a. 1346 (Low growth) b. 1581 (High growth)	1451 1235

GOI, Ministry of water Resources (2009)

- ✓ As per the international norms, if per-capita water availability is
  - ✓ < 1700 m^3 per year: the country is water stressed
  - ✓ < 1000 m^3 per year: the country is water scarce

IRRIGATION POTENTIAL OF WATER

✓ Total geographical area	: 329 mha
✓ Net sown area	: 141 mha (43% of 329 mha)
✓ Gross Irrigated area	: 87.23 mha
✓ Net Irrigated area	: 62.31 mha
✓ Productivity (irrigated)	: 2.5 ton/ha
✓ Productivity (rainfed)	: 0.5 ton/ha
✓ Food grain availability	: 523 g/capita/day

mha is the million hectares

PRODUCTIVITY OF CEREALS IN INDIA

Crops	Water applied (cm)	Yield (t/ha)	Productivity (kg/ha/mm)
Rice	120	4.9	3.8
Jowar(sorghum)	50	4.9	9.0
Bajra (pearl millet)	50	4.4	8.0
Maize	63	5.5	8.0
Wheat	40	5.5	12.5

IRRIGATION

- ✓ Irrigation is the artificial application of water to soil for meeting crop water requirement
- ✓ Irrigation water is applied to supplement water available from precipitation and ground water
- ✓ Main concerns of irrigation
  - ✓ How to apply?
  - ✓ How much to apply?
  - ✓ When to apply?

BENEFITS OF IRRIGATION

- ✓ Irrigation development has played a key role in
  - ✓ strenghtening economy
  - ✓ increasing employment opportunities
  - ✓ self sufficeincy in food production

BENEFITS OF IRRIGATION

- ✓ Raise a crop where nothing would grow otherwise
- ✓ Grow a more profitable crop
- ✓ Increase the yield and/or quality of a given crop
- ✓ Increase the aesthetic value of a landscape

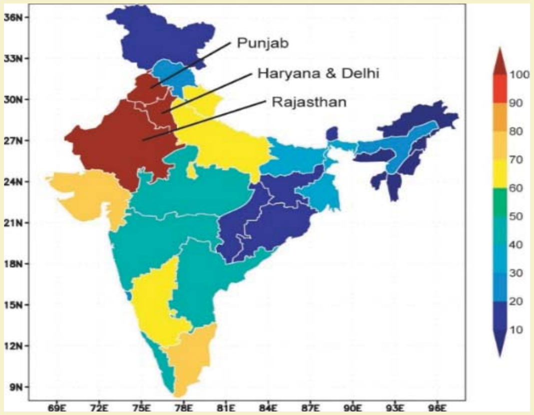
OTHER BENEFITS OF IRRIGATION

- ✓ Leaching of salts
- ✓ Wind erosion control
- ✓ Multiple cropping during an year
- ✓ Provides jobs
- ✓ Reduces risk of crop failures
- ✓ Improves socioeconomic conditions

DISADVANTAGES OF IRRIGATION

- ✓ Excessive irrigation
  - ✓ decrease in crop yield
  - ✓ leaching/transport of chemicals
- ✓ Yield reduction-deficit irrigation
- ✓ Water logging and salinity

Waterlogging at Lohgad village of Sarsa district in Haryana (Source: Narrain, 2005)



GW withdrawal as % of recharge

TYPES OF IRRIGATION PROJECTS

- ✓ **Major Irrigation Projects**
  - ✓ Irrigation potential >10000 ha and cost of project > Rs. 5 cr
- ✓ **Medium Irrigation Projects**
  - ✓ Irrigation potential: 2000-10000 ha; cost of project: Rs. 0.25-0.5 cr.
- ✓ **Minor Irrigation Projects**
  - ✓ Irrigation potential: <2000 ha; cost of project: < Rs. 0.25 cr.

SURFACE IRRIGATION SYSTEMS

- ✓ Water use for a gross irrigated area of 87 mha is 541 km^3
- ✓ India's gross water use (1.45 m) > the United States (0.9 m)
- ✓ Overall irrigation efficiency in the country is 38%
- ✓ Krishna, Godavari, Cauvery, and Mahanadi systems have a very low efficiency of around 27%
- ✓ Indus and Ganga systems are doing better with efficiencies in the range of 43-47% (rotational water supply-**Warabandi**)

PRESSURIZED IRRIGATION SYSTEMS

- ✓ Drip irrigation saves 25-60% water and increases yield up to 60%
- ✓ Sprinkler irrigation saves 25-33% of water
- ✓ Net irrigated area under drip is 0.5 mha and sprinkler is 0.7 mha
- ✓ Maharashtra has 46% of area under drip irrigation
- ✓ Our target is at least 10% of command area with microirrigation

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REASONS FOR LOW IRRIGATION EFFICIENCY

- ✓ Unlined canal systems with excessive seepage
- ✓ Lack of field channels
- ✓ Lack of canal communication network
- ✓ Lack of field drainage
- ✓ Improper field levelling
- ✓ No or low price for water

IRRIGATION TERMINOLOGY

- **Gross Command Area (GCA)**
  - The total area (includes roads/villages/farmstead etc.) lying between drainage boundaries, which can be irrigated by a canal system

    GCA = CCA + UCCA

- **Culturable command area (CCA)**
  - It is the GCA without UCCA such as unfertile barren land, alkaline soil, local ponds, villages and other areas as habitation

IRRIGATION TERMINOLOGY

- ✓ **Intensity of Irrigation (Ratio of irrigated to irrigable area)**
  - ✓ Actual area irrigated from an outlet in a year including different crop seasons.
- ✓ **Water Tanks:** These are dug areas of lands for storing excess rain water
- ✓ **Outlet:** It is a sort of head regulator for the field channel delivering water to the irrigation fields

IRRIGATION TERMINOLOGY

- ✓ **Water logged area:** An agricultural land is said to be waterlogged when its productivity or fertility is affected by high water table.

- ✓ **Field Capacity:** Water content held in the soil after excess water has drained and plants can extract sufficient water from soil for its growth.

- ✓ **Permanent wilting point:** or the wilting coefficient is that water content at which plants can no longer extract sufficient water from the soil for its growth.

IRRIGATION TERMINOLOGY

- ✓ **Crop ratio:** The ratio of cultivable areas under different crops (during different seasons) in a crop-year.
- ✓ **Crop period:** The number of days between sowing and harvesting of a crop.
- ✓ **Base period:** The number of days between first watering (at the time of sowing) to the last watering (before harvesting).

IRRIGATION TERMINOLOGY

- ✓ **Live storage (LS):** Water stored in a reservoir between full reservoir level and dead storage level.
- ✓ **Dead storage (DS):** Water stored in a reservoir between lowest supply level and deepest river bed level; 10% of GS
- ✓ **Gross storage (GS):** The storage capacity, between full reservoir level and deepest reservoir level

GS =LS+DS;   =LS+0.1*GS;   =LS/0.9

IRRIGATION TERMINOLOGY

- ✓ **Delta(Δ):**
- ✓ Total depth of irrigation water required by a crop during the cropping period
- ✓ If a crop requires about 12 irrigations of 10 cm depth each at an interval of 10 days, the delta for that crop would be 120 cm or 1.2m
- ✓ If the area under the crop is A ha, the total water required would be 1.2 *A (ha-m) over a period of 120 days

IRRIGATION TERMINOLOGY

- ✓ **Duty (ha/cumec):**
- ✓ It is the ratio between the irrigated crop area and the quantity of irrigation water required during the base period.

- ✓ If 3 cumec of irrigation water is required for a crop sown over an area of 5100 ha, the **Duty** of irrigation water would be 5100/3 = 1700 ha/cumec, and 3 cumec discharge would be required throughout the *base period*.

IRRIGATION TERMINOLOGY

- ✓ The value of **Duty** would be different at the head of the watercourse (channel bringing water to the field) or at the head of the distributary
- ✓ Relationship between Duty and Delta

$$\mathbf{\Delta = 8.64\ B/D}$$

Where, Δ = delta, meters; B = base period, days; D = Duty, hectares/cumec

EXAMPLE 1.1

An irrigation canal has a GCA of 80000 ha out of which 85% is culturable area. The intensity of irrigation for Kharif season is 30% and for Rabi season 60%. Find the discharge required at the head of the canal if the Duty at its head is 800 ha/cumec for Kharif season and 1700 ha/cumec for Rabi season.

Solution:

Culturable Irrigable area = 80000 × 0.85 = 68000 ha

Area under Kharif season = 68000 × 0.30 = 20400 ha (Irrigated)

Area under Rabi season = 68000 × 0.60 = 40800 ha (Irrigated)

Water required at the head of canal to irrigate during

Kharif is 20400/800 cumec = 25.5 cumec and

Rabi is 40800/1700 cumec = 24 cumec

Since the water requirement in Kharif season is higher than Rabi season, canal must be designed to carry an average discharge of 25.5 cumec. (higher of two)

EXAMPLE 2.1

A watercourse has a culturable command area of 2600 ha, out of which the intensities of irrigation for perennial sugarcane and rice crops are 20% and 40%, respectively. The Duty for these crops at the head of the watercourse is 750 ha/cumec and 1800 ha/cumec, respectively. Find the discharge required at the head of watercourse if the peak demand is 20% higher than the average requirement.

Solution:

Area under sugarcane = 2600 × 0.2 = 520 ha

Area under rice = 2600 × 0.4 =1040 ha

Water required for sugarcane = 520/750 = 0.694 cumec

Water requirement for rice = 1040/1800 = 0.577 cumec

Since sugarcane is perennial crop, it will require water throughout the year. hence watercourse should carry total discharge of (0.694 + 0.577) = 1.271 cumec.

Hence, peak design discharge = 1.271 × 1.2 = 1.52 cumec

Thank You!!

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Lecture No:02 Soil Properties-1

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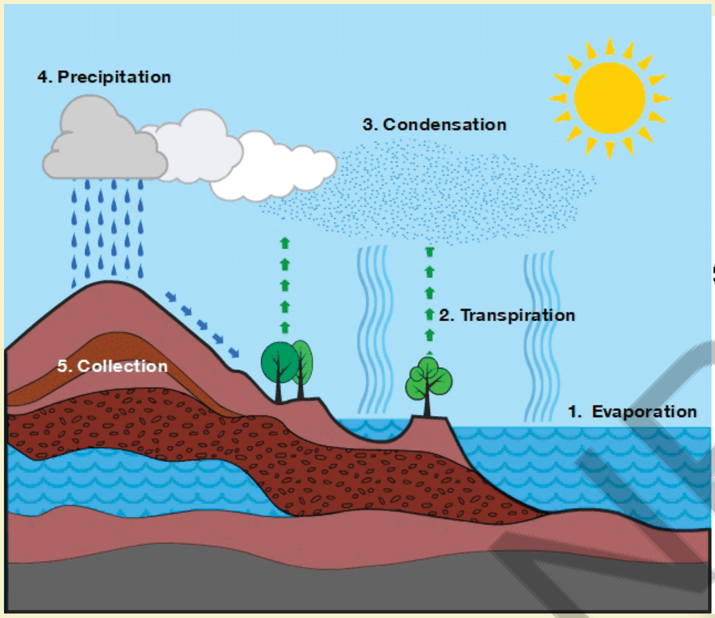
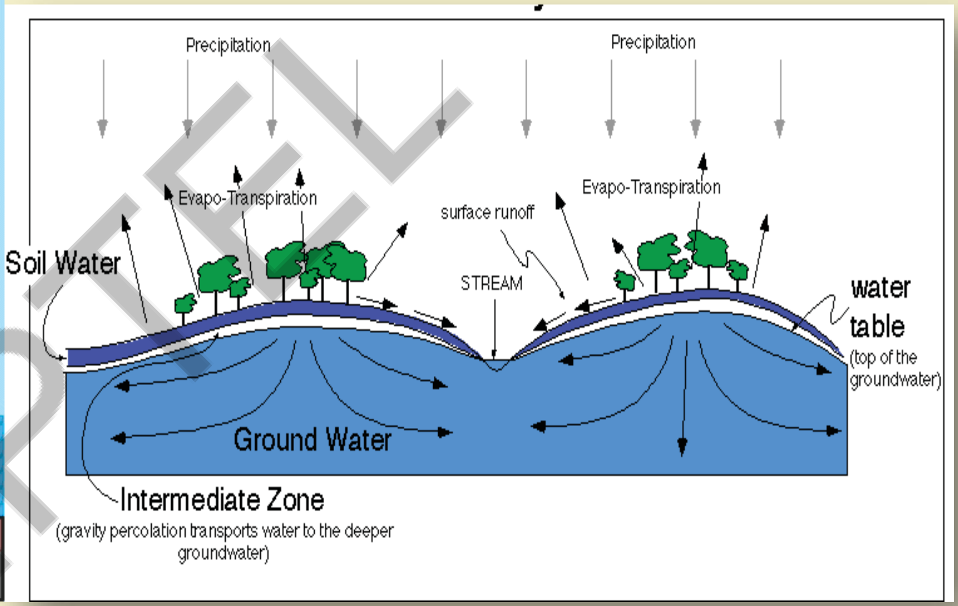
SOIL-WATER-PLANT- ATMOSPHERE



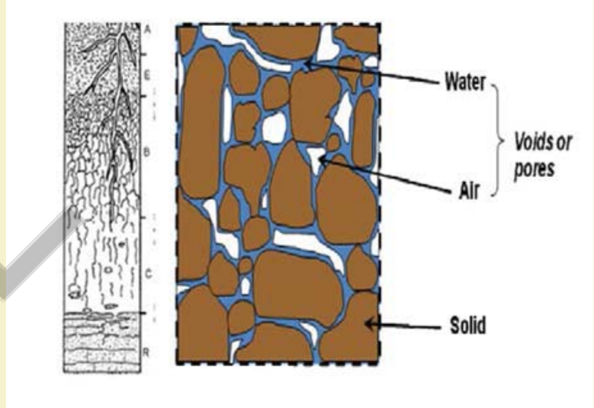


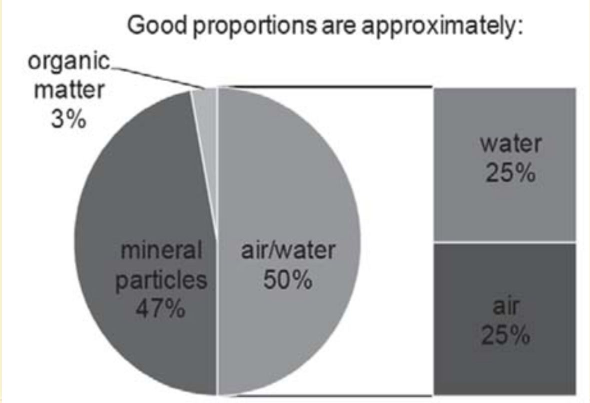
http://www.kesab.asn.au/apyl/water/educators/using-water-wisely/water-cycle/

Hydrologic Cycle

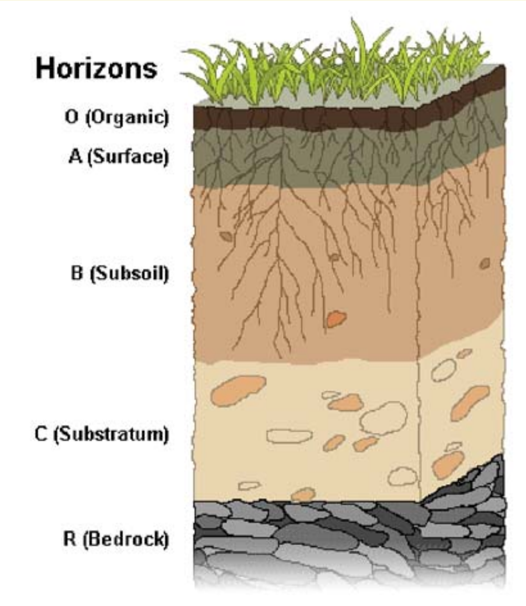
SOIL

- ✓ Three phase system
  - ✓ Solid phase: mineral, organic matter and various chemical compounds
  - ✓ Liquid phase: Soil moisture
  - ✓ Gaseous phase: Soil air





A TYPICAL SOIL PROFILE



Distinct layers called horizons

O - Primarily composed of organic matter

A – OM mixes with inorganic products of weathering

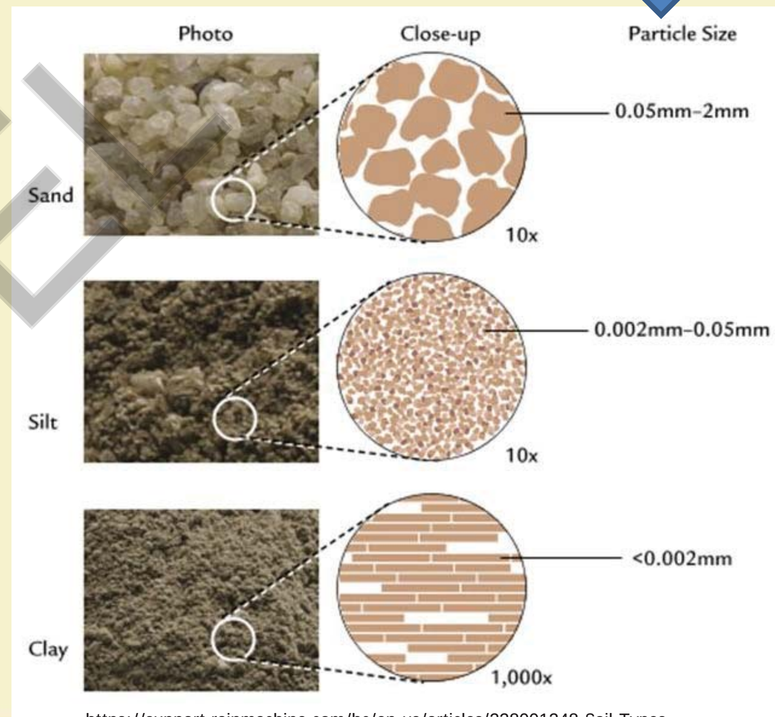
B – Fine material accumulated and enriched with calcium carbonate

C – Represents soils parent material

SOIL PROPERTIES

- ✓ **Texture**
  - ✓ Relative proportions of various sizes of individual soil particles
  - ✓ Texture may be modified by organic matter content, clay minerals and their associated ions

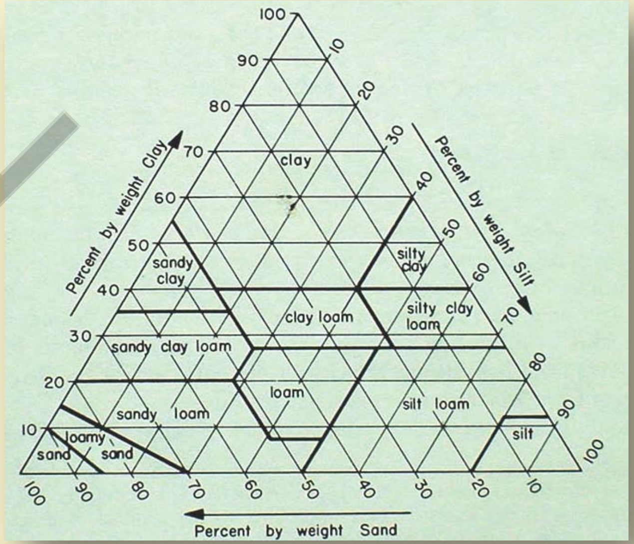
USDA Classification



https://support.rainmachine.com/hc/en-us/articles/228001248-Soil-Types

SOIL PROPERTIES

- ✓ **Texture**
  - ✓ Textural triangle: USDA Textural Classes
    - ✓ Coarse vs. Fine, Light vs. Heavy
  - ✓ Affects water movement and storage

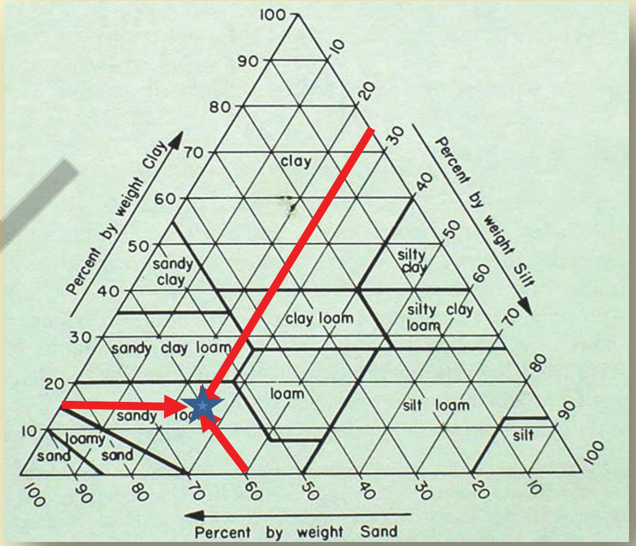


SOIL PROPERTIES

Example 2.1

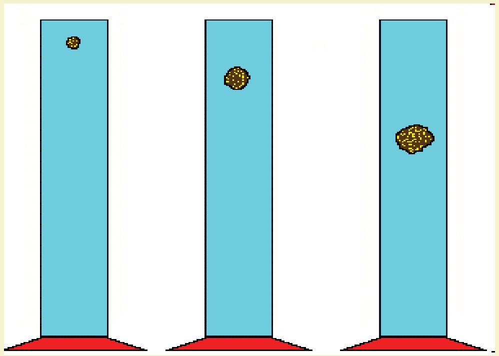
- ✓ If a soil containing
  - ✓ Sand: 60%
  - ✓ Silt: 25%
  - ✓ Clay: 15%

  What is its textural class?



SOIL PROPERTIES

- ✓ **Textural Analysis**
  - ✓Sieve method (> 0.05 mm size)
  - ✓Sedimentation method (< 0.05 mm size)
    - ✓Pipette
    - ✓Hydrometer



http://www.soils.umn.edu/academics/classes/soil2125/doc/s2chp1.htm

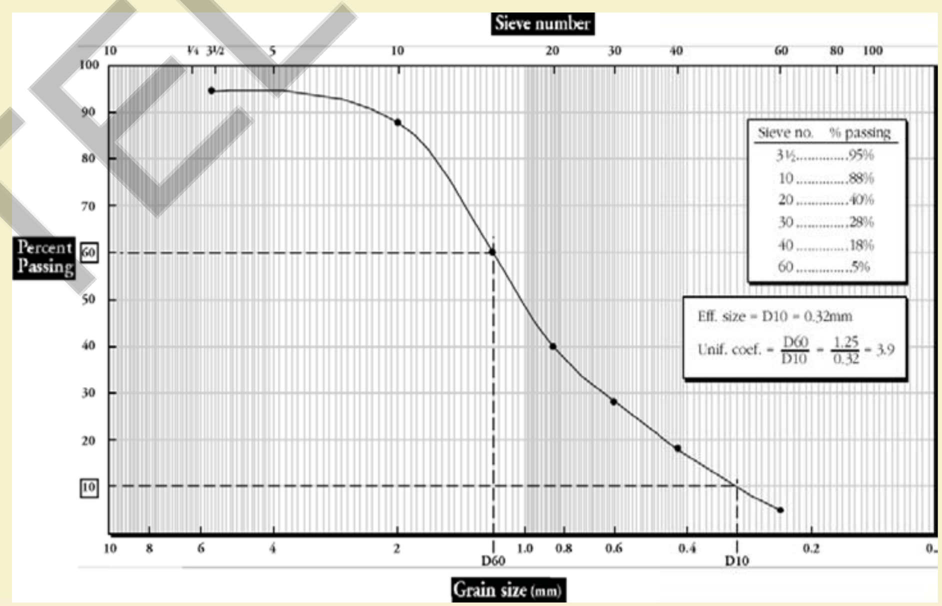
SOIL PROPERTIES

✓ **Textural Analysis by Sieve method**

SOIL PROPERTIES

✓ **Textural Analysis by sieve method**

Sieve No.	Sieve Size	Wt. Retained (g)	% Retained	Cumulative Retained %	Com. % Passing
inch	mm		(wt. ret./ Total) 100%	Sum % Retained	100 - Com. Ret.
1"	25	10	0.5	0.5	99.5
3/4"	19	50	2.5	3	97
1/2"	12.5	140	7	10	90
3/8"	9.5	250	12.5	22.5	77.5
# 4	4.75	340	17	39.5	60.5
# 8	2.36	50	2.5	42	58
# 16	1.18	450	22.5	64.5	35.5
# 30	0.6	200	10	74.5	25.5
# 50	0.3	175	8.75	83.25	16.75
# 100	0.15	225	11.25	94.5	5.5
# 200	0.075	100	5	99.5	0.5
Pan	Pan	10	0.5	100	0
	Total	2000	100		



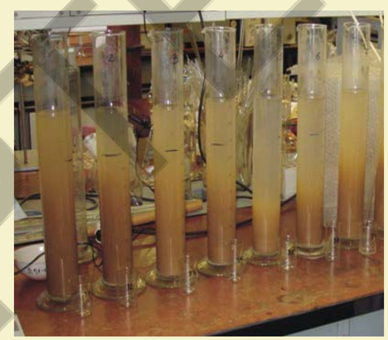
SOIL PROPERTIES

- ✓ **Textural Analysis by Pipette Method**
  - ✓ works on Stokes' law

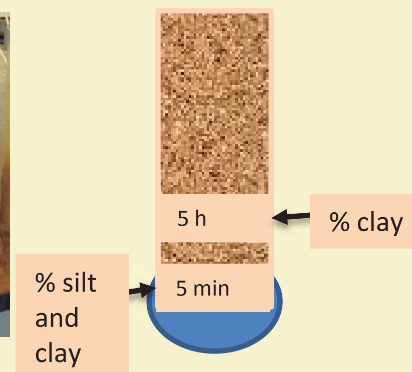
Measure 20 g of soil sample

Added 5 ml Of (NaPO3)6

Add some DI water and blend for 5 min



Make a volume of 1000 ml



Pipetteout 0.25mL at 5 min and 5 h

SOIL PROPERTIES

Textural analysis by Pipette method

Soil Specimen weight	Weight of dry sample at 5 min (g)	Weight of dry sample at 5 h (g)	% of (silt+ clay) particles	% Clay particles	% Silt particles	% Sand particles	Soil texture
A	0.16	0.09	32	17.55	14.45	68.00	
B	0.14	0.09	28	17.55	10.45	72.00	
C	0.14	0.09	28	17.55	10.45	72.00	Sandy loam

$$Silt + clay\ (\%) = \frac{\text{Weight of dry sample at 5 min}}{weight\ of\ soil\ \times volume\ of\ soil\ sample\ taken} \times Total\ volume$$

$$\%\ clay = \frac{\text{Weight of dry sample at 5 h}}{weight\ of\ soil\ \times volume\ of\ soil\ sample\ taken} \times Total\ volume$$

$$\%\ Sand = 100 - (\%\ Silt + \%\ Clay)$$

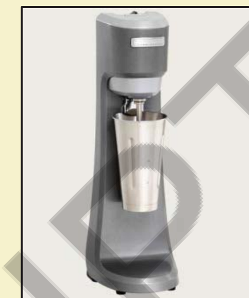
SOIL PROPERTIES

- ✓ **Textural Analysis by Hydrometer method**
  - ✓ Rapid and simpler than pipette method

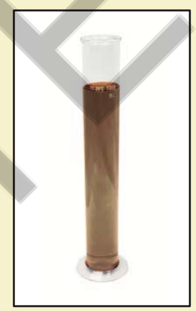
Hydrometer

Weigh 50 g of sieved soil (<2 mm size)

Add soil, DI water, and dispersing agent {$(NaPO_3)_6$, calgon etc.} to a blender cup

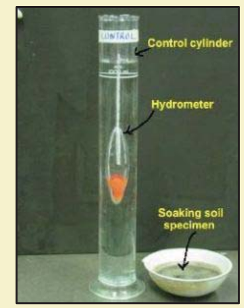


Blend for about 5 mins



Transfer sample to a 1000 ml measuring cylinder and bring volume to 1000 ml

Hydrometer reading is recorded at 40 sec and 20 mins after the cylinder was set down record the



Calibration of hydrometer

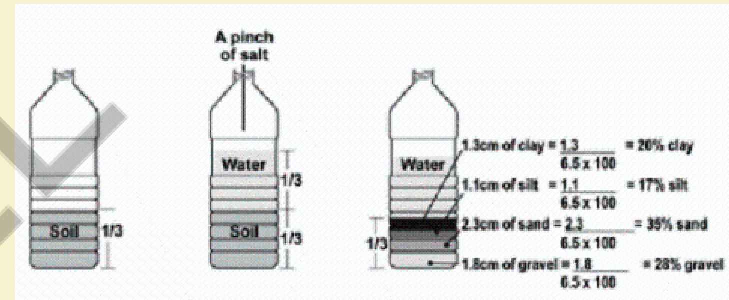
SOIL PROPERTIES

Soil textural analysis by Hygrometer method

Item	Example calculation
Initial mass of soil sample, $\mathbf{M_1}$	50 g/l
40 second hydrometer reading [grams per liter of silt + clay still in suspension] $\mathbf{M_2}$	30 g/l {which means you have 30 grams of silt + clay still in suspension}
20 minute hydrometer reading [grams per liter of clay still in suspension] $\mathbf{M_3}$	10 g/l {which means you have 10 grams of clay still in suspension}
grams sand = **[$\mathbf{M_1}$- $\mathbf{M_2}$]**	50 -30 = **20** g/l
grams clay = [20 minute hour reading]	**10 g/l**
grams silt = [50 grams - (g sand + g clay)]	50 - (20+10)= **20** g/l
% sand [= (g sand / 50 g soil) X 100]	20/50 × 100=40%
% clay [= (g clay / 50 g soil) X 100]	100/50 × 100=20%
% silt [= (g silt / 50 g soil) X 100]	20/50 × 100=40%

SOIL PROPERTIES

- ✓ **Texture**
  - ✓ **Simple plastic bottle method (RELMA 2005)**
  - ✓ Add soil upto 1/3rd full of bottle
  - ✓ Add water upto 2/3rd full
  - ✓ Add a pinch of salt and shake the bottle for about one minute, leave it for one hour
  - ✓ Shake it again, leave it for four hours
  - ✓ Measure the thickness of the soil layers
  - ✓ Calculate the percentage of each soil fraction



RELMA. Regional Land Management Unit / World Agroforestry Centre (2005). Water from ponds, pans and dams: a manual of planning, design, construction and maintenance. Technical handbook No.32. ISBN 9966-896-67-8

SOIL PROPERTIES

- ✓ **Soil Textural Classification**
- ✓ Classified by the United States Department of Agriculture (**USDA**) and by the International Soil Science Society (**ISSS**):

Soil fraction	Particle diameter (mm)	
	USAD	ISSS
Gravel	>2	>2
Very coarse sand	1-2	-
Coarse sand	0.5-1	0.2-2
Medium sand	0.25-0.5	-
Fine sand	0.1-0.25	0.02-0.2
Very fine sand	0.05-0.1	-
Silt	0.002-0.05	0.002-0.02
Clay	<0.002	<0.002

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Lecture No:03 Soil Properties-2

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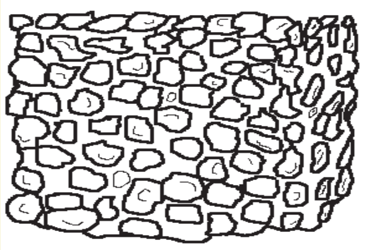
SOIL PROPERTIES

- **Structure**
  - The arrangement of soil particles in a soil
  - Affects root penetration and water intake and movement
  - Soil structure together with soil texture affect pore size and pore distribution, and thus the porosity of soil
    - Micropores - helpful in retention of water and solute
    - Macropores - helpful in infiltration, drainage and aeration

SOIL PROPERTIES

Granular Structure



http://soil.gsfc.nasa.gov/pvg/granular.gif

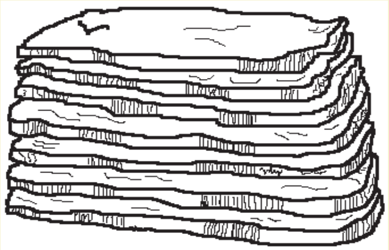
Blocky Structure

http://soil.gsfc.nasa.gov/pvg/blocky.gif

Prismatic Structure

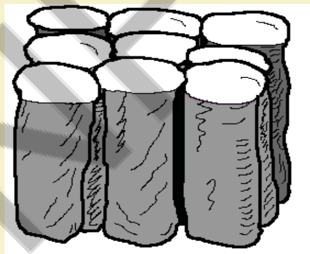
http://soil.gsfc.nasa.gov/pvg/prismatic.gif

Platy Structure



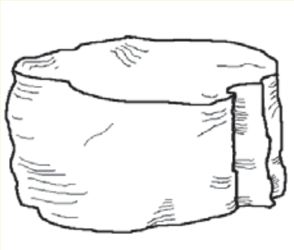
http://soil.gsfc.nasa.gov/pvg/platy.gif

Columnar Structure



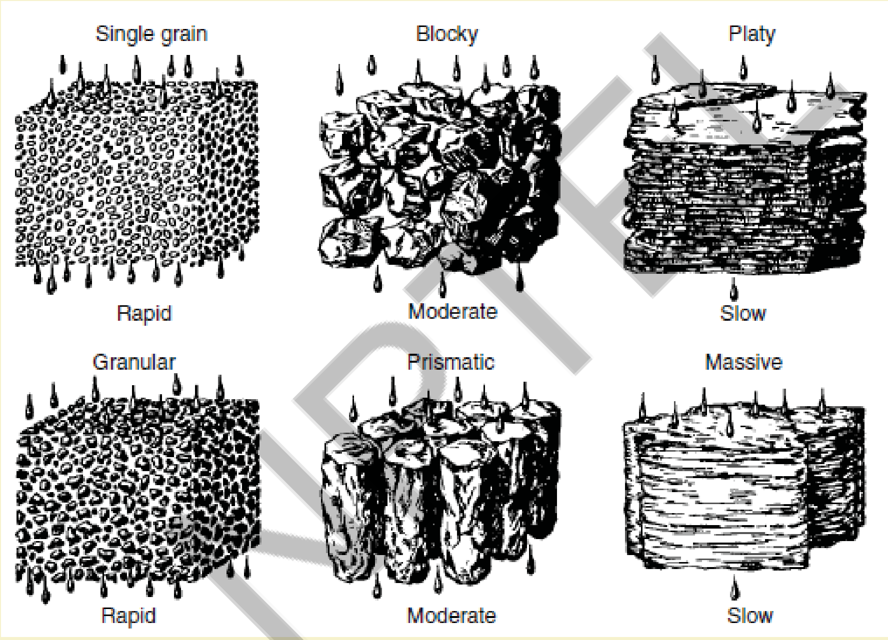
http://soil.gsfc.nasa.gov/pvg/columnar.gif

Massive Structure



http://soil.gsfc.nasa.gov/pvg/massive.gif

SOIL STRUCTURE IN RELATION TO WATER MOVEMENT



Source: courses.**soil**.ncsu.edu/ssc012/Labs/4.ppt

SOIL PROPERTIES

✓ **Bulk density by gravimetric method**






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

- ✓ ρ_b = soil particle density, g/cm^3
- ✓ M_s = mass of dry soil, g
- ✓ V_s = volume of solids, cm^3

https://www.ams-samplers.com/

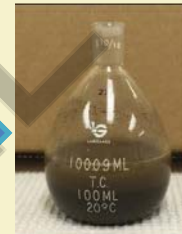
SOIL PROPERTIES

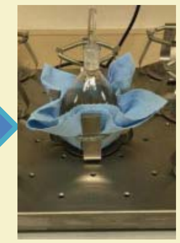
✓ **Particle density by Gay-Lussac specific-gravity bottles/pycnometer**

Density bottle no.	1
Mass of bottle +Stopper	M_1
Mass of bottle +Stopper+ Dry soil	M_2
Mass of bottle +Stopper+ Dry soil + Water	M_3
Mass of bottle +Stopper + full of Water	M_4
Mass of dry soil used	$M_2 - M_1$
Mass of water used	$M_3 - M_2$
Mass of water to fill bottle	$M_4 - M_1$
Particle density, ρ_s (g/cm³)	$\rho_s = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)} \times \rho_w$

M_1

M_2



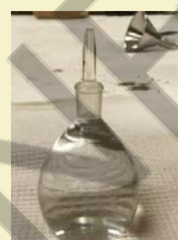


Entrapped air removed by Stirring and vacuuming.

M_3

PARTICLE DENSITY

$$\rho_s = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)} \times \rho_w$$



M_4

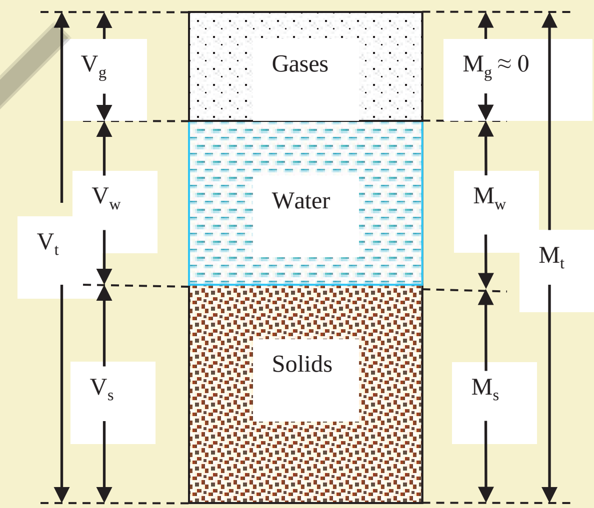
BASIC SOIL WATER RELATIONSHIPS

- A bulk undisturbed volume (V_t) of soil,

$$V_t = V_s + V_w + V_g$$
$$M_t = M_s + M_w$$

- Seven measurable quantities (V_g, V_w, V_s, V_t, M_w, M_s, and M_t)

- Commonly used relationships are derived from these quantities



BASIC SOIL WATER RELATIONSHIPS

Density of solids (Particle density)

$$\rho_s = \frac{M_s}{V_s} \quad (1)$$

ρ_s = soil particle density, g/cm^3
M_s = mass of dry soil, g
V_s = volume of solids, cm^3
Typical values: 2.6 - 2.7 g/cm^3

Dry bulk density

$$\rho_b = \frac{M_s}{V_t} \qquad V_t = V_s + V_g + V_w \quad (2)$$

ρ_b = soil bulk density, g/cm^3
M_s = mass of dry soil, g
V_t = total volume of soil, cm^3
Typical values: 1.1 - 1.6 g/cm^3

BASIC SOIL WATER RELATIONSHIPS

Total (wet) bulk density

$$\rho_t = \frac{M_t}{V_t} = \frac{M_s + M_w}{V_s + V_g + V_w} \quad (3)$$

Porosity

$$n = \frac{V_v}{V_t} = \frac{V_g + V_w}{V_s + V_g + V_w} \quad (4)$$

Typical values 30-60%

Void ratio

$$e = \frac{V_v}{V_s} = \frac{V_g + V_w}{V_s} \quad (5)$$

Specific gravity of solids

– **Ratio of the density of solids to the density of water**

$$G_s = \frac{\rho_b}{\rho_w} \quad (6)$$

WATER IN THE SOIL

Soil water content (dry basis)

$$\theta_{dm} = \frac{M_w}{M_s} \quad (7a)$$

Soil water content (wet basis)

$$\theta_{wm} = \frac{M_w}{M_s + M_w} \quad (7b)$$

- θ_{dm} = mass water content dry basis (fraction)
- θ_{wm} = mass water content wet basis (fraction)
- M_w = mass of water evaporated, g (≥24 hours @ 105^{o}C)
- M_s = mass of dry soil, g

WATER IN THE SOIL

Volumetric water content (θ_v)

$$\theta_v = \frac{V_w}{V_t} \qquad (8)$$

θ_V = volumetric water content (fraction)

- At saturation, $\theta_V = n$
- $\theta_V = A_s \, \theta_{dm}$

– A_s = apparent soil specific gravity = ρ_b/ρ_w
(ρ_w = density of water = 1 g/cm^3)

– $A_s = \rho_b$ numerically when units of g/cm^3 are used

WATER IN THE SOIL

Equivalent depth of water (d)

d = volume of water per unit land area = (θ_v A L) / A = θ_v L

d = equivalent depth of water in a soil layer

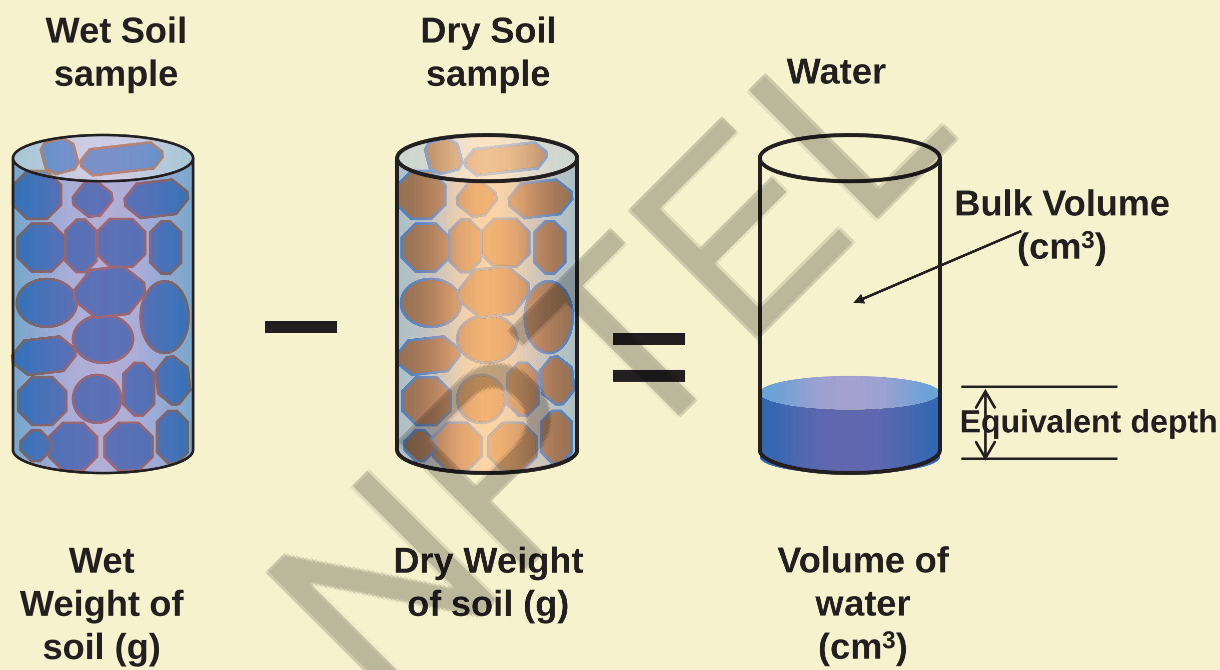
L = depth (thickness) of the soil layer

Degree of saturation

Volume of water present in the total pore volume

$$\text{Degree of saturation} = \frac{V_w}{V_v} = \frac{V_w}{V_g + V_w} \quad (9)$$

WATER CONTENT & EQUIVALENT DEPTH



INTER-RELATIONSHIPS

$\theta_v = \theta_{dm} \rho_b/\rho_w$

$\theta_{dm} = \theta_{wm}/(1 - \theta_{wm})$

$\theta_{wm} = \theta_{dm}/(1 + \theta_{dm})$

$f = 1 - (\rho_b/\rho_s)$

$\rho_b = \rho_t/(1 + \theta_{dm})$

$\rho_b = \rho_s/(1 + e)$

$e = f/(1 - f)$

$f = e/(1 + e)$

Thank You!!

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NPTEL ONLINE CERTIFICATION COURSES

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Irrigation and Drainage

Lecture No:04 Soil Water

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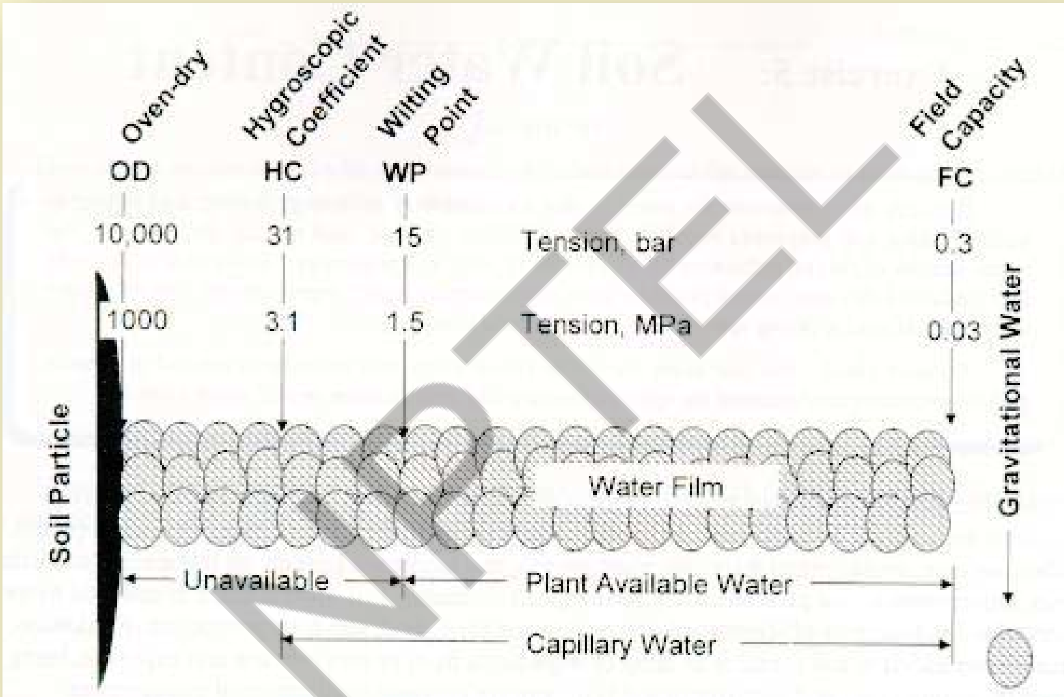
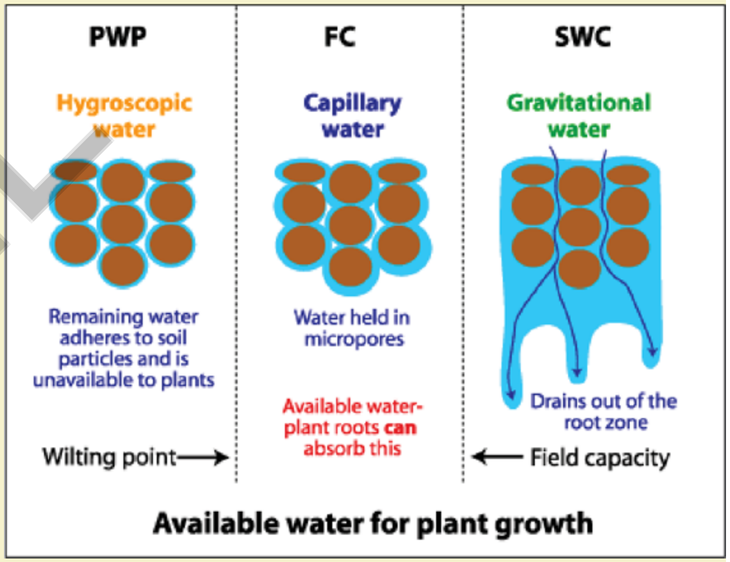
Soil Water



Oven-dry
Hygroscopic Coefficient
Wilting Point
Field Capacity
OD
HC
WP
FC
10,000
31
15
Tension, bar
0.3
1000
3.1
1.5
Tension, MPa
0.03
Soil Particle
Water Film
Gravitational Water
Unavailable
Plant Available Water
Capillary Water

Soil Water

- **Gravitational Water**
  - Soil water between saturation (**0 bar**) and field capacity (**1/3 bar**).
  - Held in the macro pores and drains out easily due to gravitational forces
  - Not available for plant growth.
- **Capillary Water**
  - Soil water held between field capacity (**1/3 bar** suction) and hygroscopic coefficient (**31 bar** suction).
  - Grouped into two groups
    - Water available to plants (**1/3 to 15 bar** suction),
    - water not available for plants (**15 to 31 bar** suction).
  - Moves easily in soil system, but it does not drain freely from soil profile.
- **Hygroscopic Water**
  - Soil water above the hygroscopic coefficient (at **suction > 31 bar**).
  - Not available to the plants.
  - Mostly held in soil colloids and moves at extremely slow rates in the vapor state.



http://www.jsw.org.au

Soil Water Availability to Plant

- ✓ **Field Capacity (FC or θ_{fc})**
  - ✓ *Field capacity* is defined as the water content of a thoroughly wet soil, at surface by irrigation or rain, allowed to drain into a drier soil until the internal drainage of water through the soil profile due to gravity becomes negligible as compared to plant root uptake.
  - ✓ This condition may reach within a few hours to a few days depending upon soil texture, structure and layering.
    - ✓ The upper limit of soil water available to plant
    - ✓ 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**

Field Capacity

- **Field Capacity (FC or θ_{fc})**
- ✓ Field capacity is affected by several factors
  - o Soil texture, soil layering, organic matter content of the soil, depth of wetting and evapotarnspiration. However, it is assumed as constant over the growing season.
- ✓ It is an idealized concept because soils do not drain to a given water content and cease to drain further
- ✓ The concept is invalid in the presence of impermeable layer or water table
- ✓ The FC concept may not be applicable to soils with swelling and shrinkage problems

Permanent Wilting Point (WP or θ_{wp})

- ✓ It is defined as the amount of water left in the soil when the plants are unable to extract any more water to meet their demand

- ✓ The lower limit of soil water available to plant
- ✓ Still some water in the soil but not enough to be of use to plants
  - ✓ Water is held by adsorptive force
  - ✓ *Hygroscopic water*
- ✓ Traditionally defined as the water content corresponding to **-15 bars of SWP**

Available Water (AW)

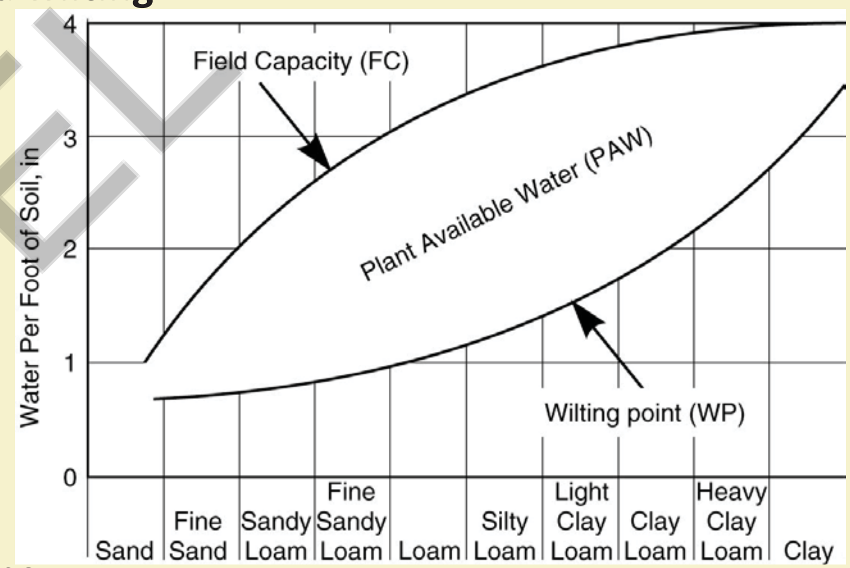
- ✓ Water held in the soil between **field capacity** and **wilting point**
- ✓ "Available" for plant use
- ✓ $AW = D_{rz}(\theta_{fc} - \theta_{wp})/100$

  AW = available water (m, in)

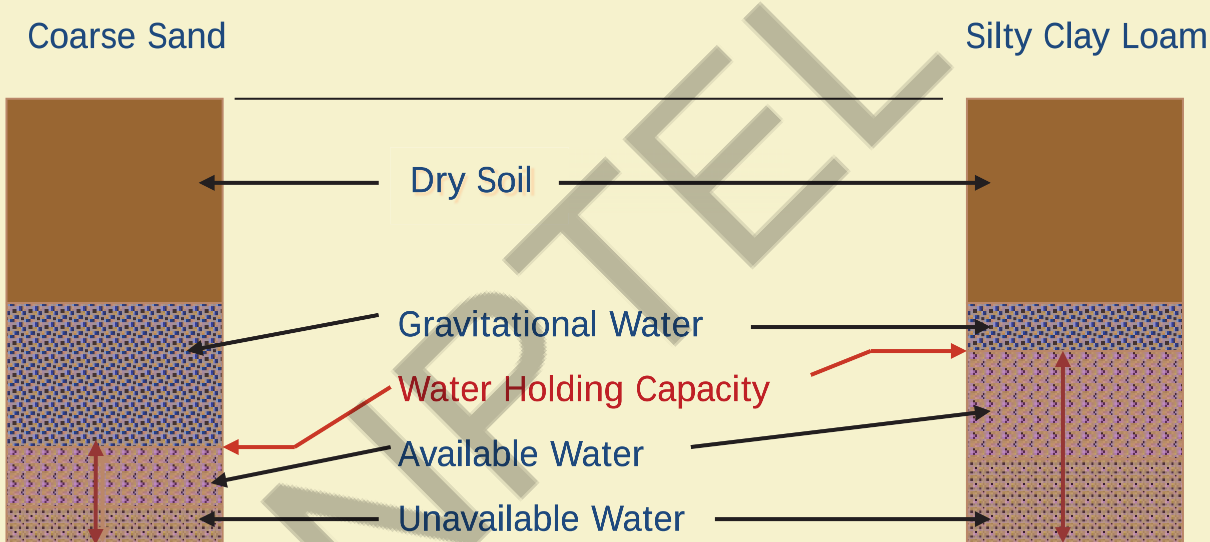
  D_{rz} = depth of the root zone (cm)

  θ_{fc} = field capacity in percent by volume

  θ_{wp} = permanent wilting point in percent by volume



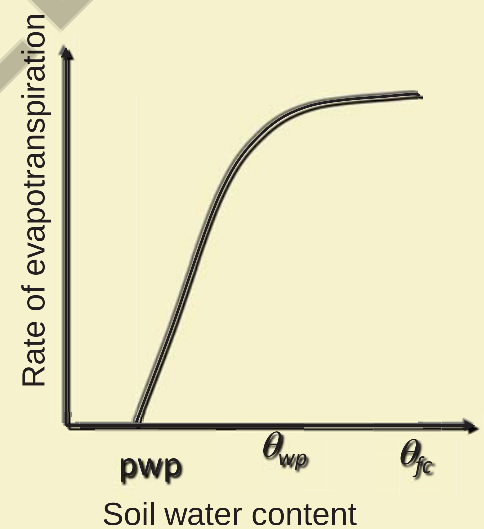
Water-Holding Capacity of Soil Effect of Soil Texture



Readily available water (RAW)

- ✓ Relatively small declines in actual transpiration associated with soil water content reduction between θ_{fc} and θ_{wp} indicate that the water is more readily available and that higher crop yield should be expected.
- ✓ Irrigations are normally scheduled above θ_{wp}.

$$RAW = \frac{D_{rz}\left(\theta_{fc} - \theta_{wp}\right)}{100}$$



Maximum Allowable Deficiency (MAD)

- ✓ Used to estimate the amount water that can be used without adversely affecting the plant
  - ✓ (for most crops it is 0.65)

$$MAD = \frac{RAW}{AW}$$

- ✓ Deficit irrigation
  - ✓ Sacrificing crop revenues to achieve reduction in water and/or energy costs that exceed the sacrificed crop revenue

Soil Water Potential

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

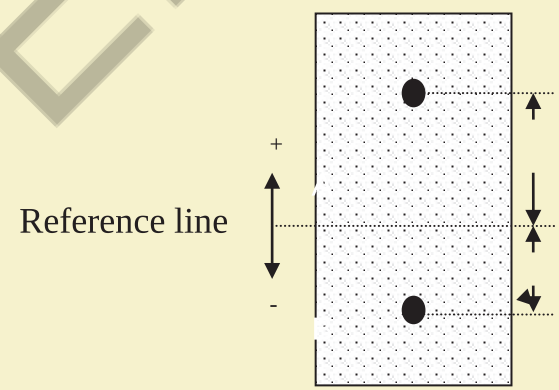
- ✓ ψ_t = total soil water potential
- ✓ ψ_g = gravitational potential (force of gravity pulling on the water)
- ✓ ψ_m = matric potential (force placed on the water by the soil matrix – soil water "tension")
- ✓ ψ_o = osmotic potential (due to the difference in salt concentration across a semi-permeable membrane, such as a plant root)

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

Gravitational Potential (ψ_g)

- ✓ Component of total potential which is due to position of a point relative to some reference or specified elevation

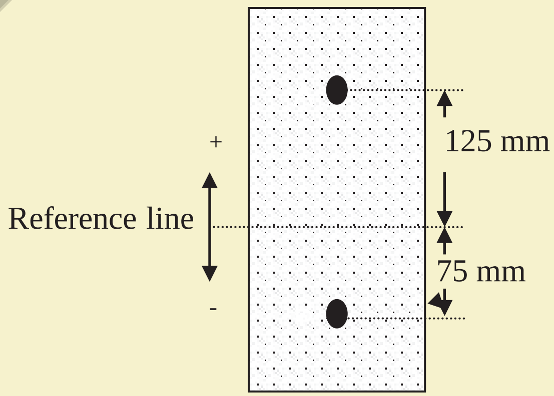
- ✓ Gravitational potential
  - ✓ At reference point: zero
  - ✓ Above reference point: +ve
  - ✓ Below reference point: - ve



Gravitational Potential

Example 4.1:

Find out the gravitational potential of points A and B located at a distance of 125 mm above and 75 mm below an arbitrary reference line. Also determine change in gravitational potential between point A and B.



Solution

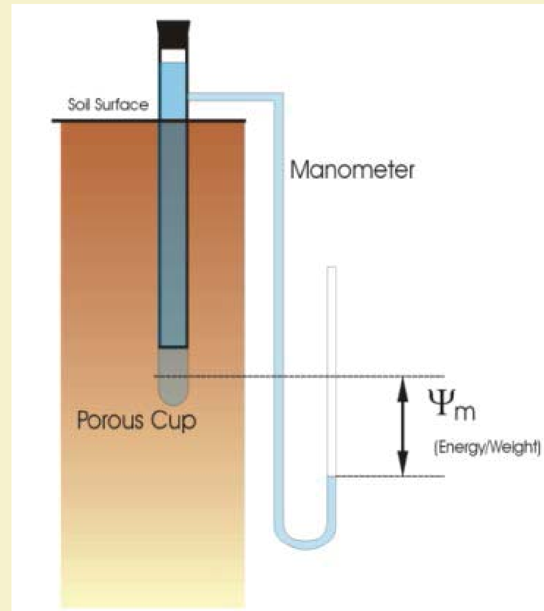
ψ_{gA} = 125 mm, and ψ_{gB} = -75 mm

$$\Delta\psi_g = \psi_{gA} - \psi_{gB}$$

= 125 - (-75) = 200 mm

Matric Potential (ψ_m)

- ✓ Application of pressure or suction to the soil water causes change in water potential. This change of water potential is called the **Pressure Potential**
- ✓ Pressure potential: +ve or -ve
  - ✓ Depends on increase or decrease in potential energy with respect to free water (atmosphere).
- ✓ Under unsaturated conditions
  - ✓ soil water pressure is negative
  - ✓ -ve pressure potential is also known as **capillary pressure**, or **matric potential**, suction or tension.

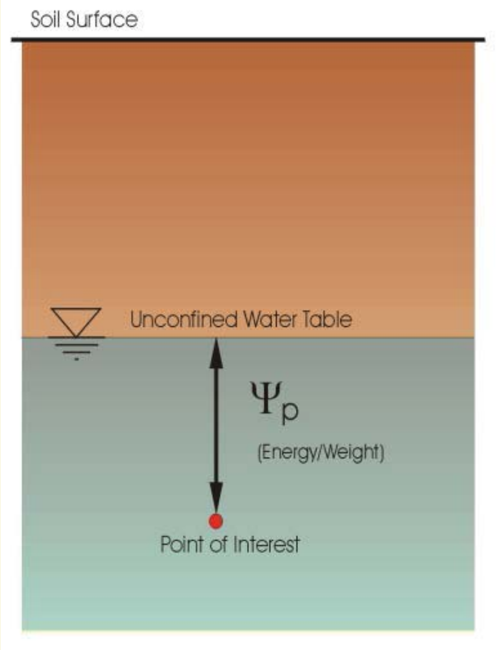


Matric Potential (ψ_m)

- ✓ Water table is the locus of atmospheric pressure in the soil water system
- ✓ Below water table, soil water pressure is positive
- ✓ Representing total energy in terms of head (energy per unit of weight) with the assumption that the osmotic head is everywhere same or negligible,

  H = h + z

  H = hydraulic head (m), h = pressure head (m) and z = elevation head (m).



Example 4.2:

In a 1000 mm soil profile, soil water is in equilibrium with at water table at -600 mm. Estimate pressure, gravitational and hydraulic (total) heads throughout the profile at an interval of 100 mm assuming that solute concentration is negligible.

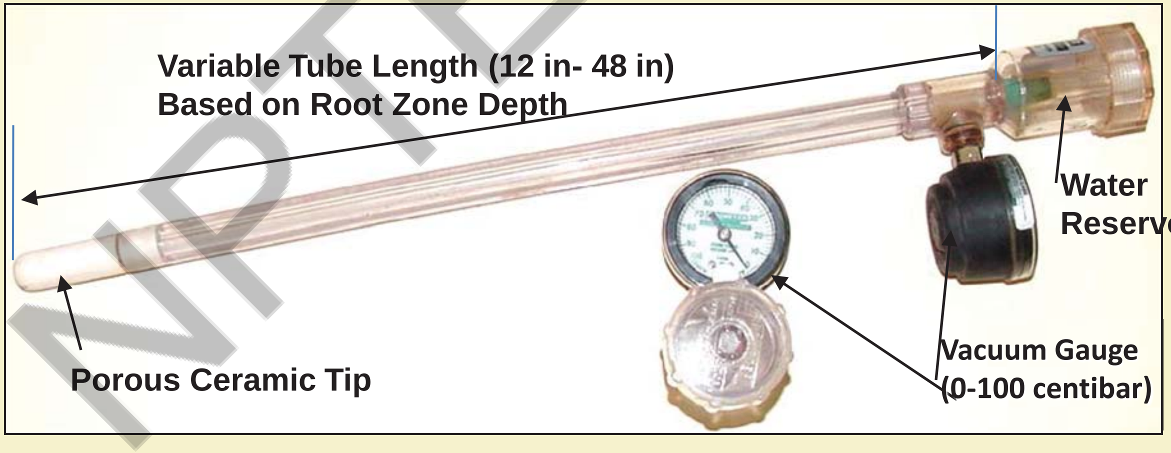
Solution:

Considering water table as reference, values of pressure, gravitational and total heads are determined and given below.

Depth, mm	h, mm	z, mm	H, mm
0	-600	600	0
100	-500	500	0
200	-400	400	0
300	-300	300	0
400	-200	200	0
500	-100	100	0
600	0	0	0
700	100	-100	0
800	200	-200	0
900	300	-300	0
1000	400	-400	0

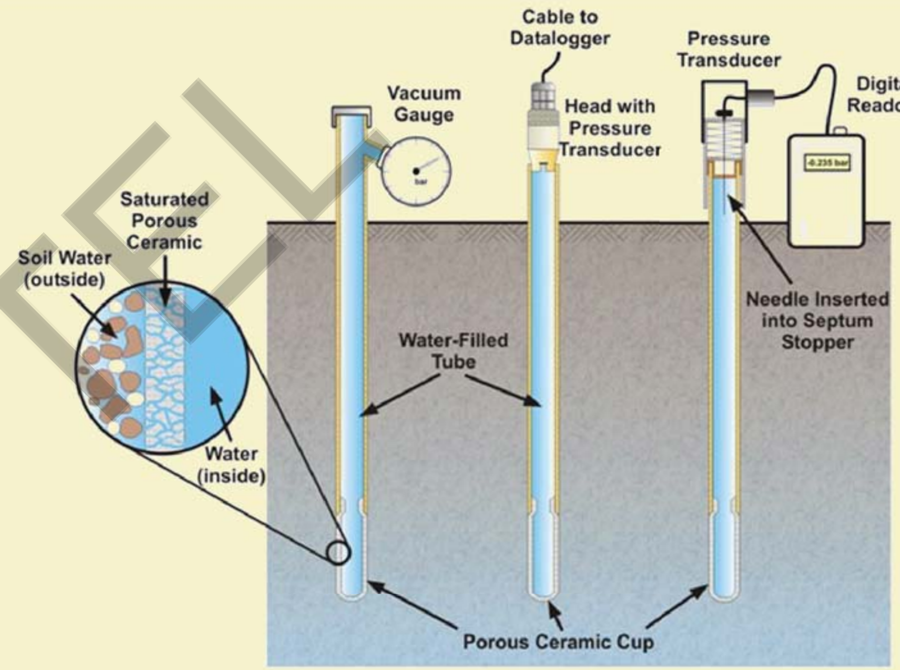
Soil Water Potential Measurement

- **Tensiometer**
  - Measures soil water potential (tension)
  - Indirect method for soil moisture measurement because soil water is related with soil water pressure potential.
  - Practical operating range is about **0 to 0.75 bar** of tension (this can be a limitation on medium- and fine-textured soils)



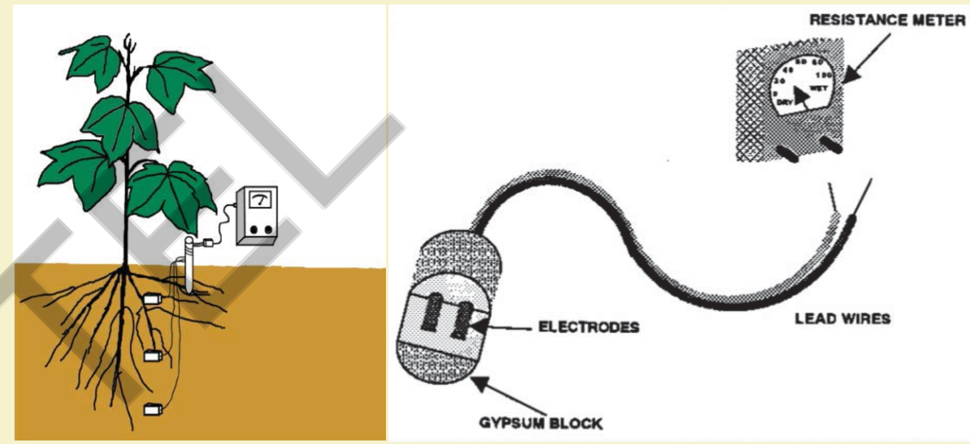
Tensiometer

- ✓ Generally effective only at less than 85 centibars of tension
  - ✓ Because the gauge will malfunction when air enters the ceramic tip or the water in the tube separates.
- ✓ The usable range from **0 to 85 centibars**
  - o Most important range for irrigation management
- ✓ Do not directly give readings of soil water content
  - ✓ To obtain soil water content, **a moisture release curve** (water content versus soil tension) is needed.



Electrical resistance blocks

- ✓ Measure soil water potential (tension)
- ✓ Tend to work better at higher tensions
  - ✓ (lower water contents)



- ✓ Meter resistance readings change as moisture in the block changes
  - ✓ The manufacturer usually provides **calibration** to convert meter readings to soil tension
- ✓ The blocks tend to deteriorate over time, and it may be best to use them for only one season
- ✓ Problems may occur with highly acid or highly saline soils.

Soil Water Release Curve (Pressure Plate Apparatus)

Pressure plate with sample ring

Saturated soil sample filled inside the ring

Completely filled saturated soil sample

Setting the pressure

Running the instrument

Ring removed from the plate

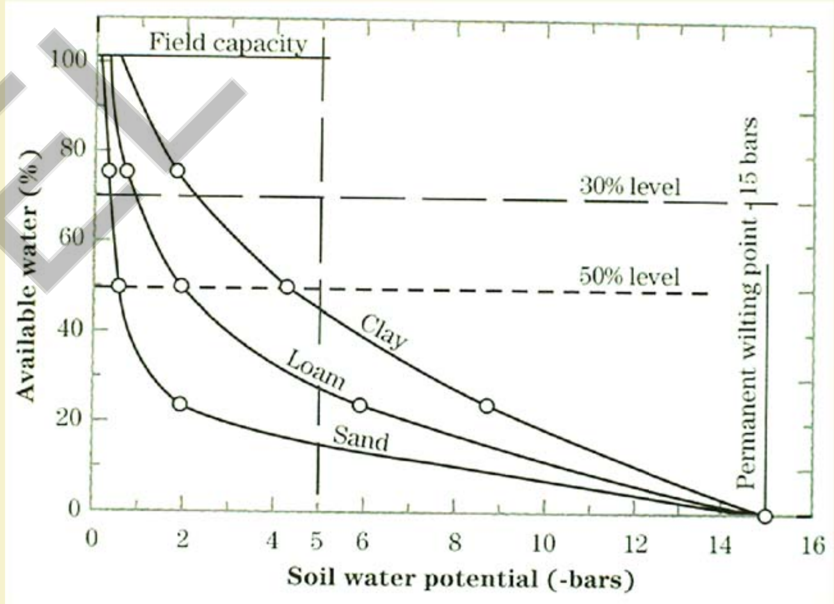
Collection of the soil sample from the plate

Soil sample in the hot air oven for drying

(Surendar et al. 2013: http://biopublisher.ca/index.php/ijh/article/html/748/)

Soil Water Release Curve

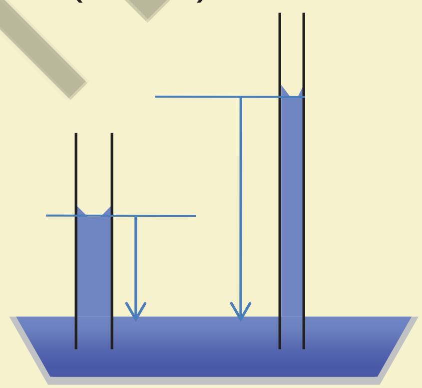
- ✓ Curve of matric potential (tension) vs. water content
  - ✓ Less water → more tension
- ✓ At a given tension
  - ✓ finer-textured soils retain more water (larger number of small pores)



Matric Potential and Soil Texture

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

Height of capillary rise inversely related to tube diameter



Thank You!!

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Irrigation and Drainage

Lecture No:05 Tutorial W1

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Exercise W1.1:

Show that the water content (W), specific gravity (G), degree of saturation (S_r) and void ratio (e) are related as **WG = S_r e** (GATE-2001)

Solution:

Water content (W) = $\frac{w_w}{w_d}$

Void ratio (e) = $\frac{V_v}{V_s}$

Degree of saturation (Sr) = $\frac{V_w}{V_v}$

Unit weight (γ) = $\frac{w}{V}$

Specific gravity (G) = $\frac{\gamma_s}{\gamma_w}$

$$\gamma_s = G\,\gamma_w$$

$$\frac{w_s}{V_s} = G\,\gamma_w$$

Cont....

$$\frac{w_s}{V_s} \times \frac{w_w}{w_w} = G\ \gamma_w$$

$$\frac{w_w}{V_s} \times \frac{w_s}{w_w} = G\ \gamma_w$$

$$\frac{w_w}{V_s} \times \frac{1}{\frac{w_w}{w_s}} = G\ \gamma_w$$

$$\frac{\gamma_w\ v_w}{V_s} \times \frac{1}{W} = G\ \gamma_w$$

$$\frac{v_w}{V_s} = GW$$

$$\frac{v_w}{V_s} \times \frac{v_v}{V_v} = GW$$

$$\frac{v_w}{V_v} \times \frac{v_v}{V_s} = GW$$

$S_r\, e = WG$

Exercise 2.

Show the relationship between unit weight (γ), specific gravity (G), void ratio (e), Degree of saturation (S_r) and Unit weight of water (γ_w)

$$\gamma = \frac{(G + e \times S_r) \times \gamma_w}{1 + e}$$

Solution: Unit weight (γ) = $\frac{w}{V}$

Void ratio (e) = $\frac{V_v}{V_s}$

Degree of saturation (Sr) = $\frac{V_w}{V_v}$

$$\gamma = \frac{w_w + w_s}{v_v + v_s}$$

$$\gamma = \frac{\gamma_w\, v_w + \gamma_s\, v_s}{v_v + v_s}$$

$$\gamma = \frac{\gamma_w\, v_w + G\, \gamma_w v_s}{v_v + v_s}$$

Cont....

$$\gamma = \frac{(v_w + G\, v_s)\gamma_w}{v_v + v_s}$$

$$\gamma = \frac{(S_r v_v + G\, v_s)\gamma_w}{v_v + v_s}$$

$$\gamma = \frac{(S_r \frac{v_v}{v_s} + G\, \frac{v_s}{v_s})\gamma_w}{\frac{v_v}{v_s} + \frac{v_s}{v_s}}$$

$$\gamma = \frac{(S_r \times e + G)\gamma_w}{1 + e}$$

Exercise 3.

A tensiometer, attached with mercury manometer, is installed 0.4 m below the soil surface the height of mercury in the cup 0.2 m for saturated soil. The density of mercury is 13600 kg/m^3. the rise of mercury in manometer at 0.6 atmosphere tension is (GATE-2004)

Solution:

Tensiometer depth = 0.4 m

Height of mercury in the cup = 0.2 m

Density of mercury = 13600 kg/m^3

$$h = \frac{0.6 \times 1.013 \times 10^5}{13600 \times 9.81}$$

h = 0.456 m

Exercise W1.4:

A wheat field needs to be irrigated with the depth of irrigation of 50 cm, the duration of the crop season is 125 days. A stream size of 15 lps flowing for 15 hours a day can irrigate an area of

(GATE 2005)

Solution:

Depth of irrigation = 50 cm

Duration of the crop =125 days

For 15 hours = $15 \times 10^{-3} \times 15 \times 3600 \times 125$

$= 101250 \text{ m}^3$

Area= 101250/0.5

$= 202500 \text{ m}^2$

= 20.25 ha

Exercise W1.5:

The root zone depth of crop is 90 cm and its availability water holding capacity is 15 cm/meter. Irrigation to be applied when 40% available water in the root zone is depleted. If daily consumption use is 3 mm, the irrigation period is (GATE-2005)

Solution:

Water holding capacity = 15 cm/meter

Root zone depth of crop = 90 cm

= 0.9 m

Daily consumption use = 3 mm

Water depth = $15 \times 0.9 = 13.5$ cm

Irrigation to be applied when 40% available water in the root zone is depleted

Irrigation required = $40/100 \times 13.5$

= 5.4 cm

= 54 mm

Irrigation period = 54/3

= 18 days

Exercise W1.6:

A crop has effective root zone depth of 1200 mm and monthly (30 days) crop evapotranspiration of 260 mm. The effective rainfall during 30 days period is 20 mm. The field capacity and permissible soil moisture depletion (volume basis) are 16% and 8%, respectively. The irrigation interval in days for the crop will be (GATE-2014)

Solution:

Effective root zone depth = 1200 mm

Crop evapotranspiration (ET) =260 mm

Period = 30 days

Daily consumption use = 260 mm /30 days

Effective rainfall =20 mm

Feld capacity and permissible soil moisture depletion =16% and 8%

Cont....

Net depth of irrigation $= \frac{(16-8)}{100} \times 1200 = 96$ mm

$$\text{Irrigation interval} = \frac{\text{Net depth of irrigation} + \text{Rainfall}}{\text{Daily consumption use}}$$

$$= \frac{96 + 20}{\frac{260}{30}}$$

$$= \frac{116}{8.67}$$

= 13.37

~13 days

Thank You!!