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Irrigation and Drainage

Lecture No: 36 Management of salt affected soils

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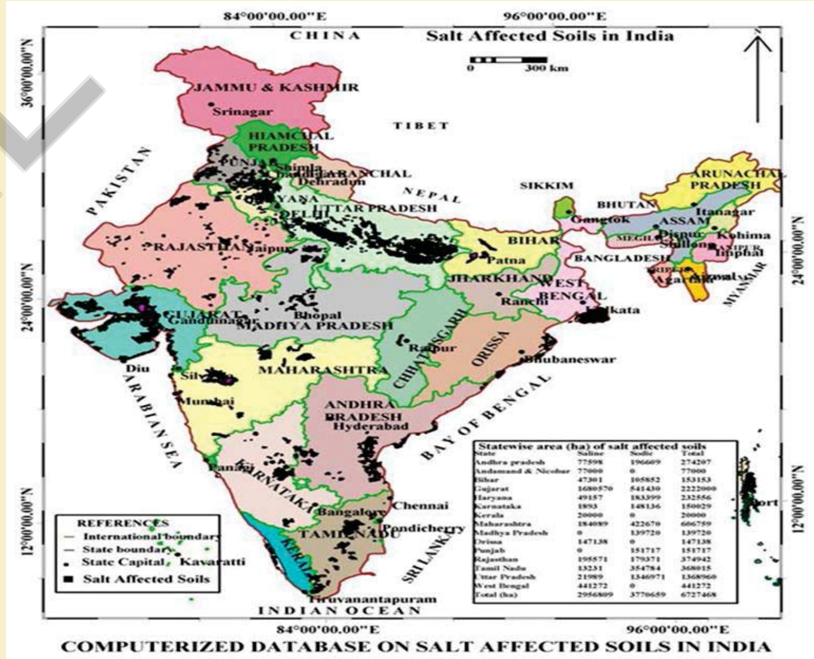
Introduction

- ✓ Salinity refers to the amount of soluble salts in soil
- ✓ Sodicity refers to the amount of sodium in soils
- ✓ 80 m-ha affected by salinity around the world (@ 3ha/min) (FAO)
- ✓ World area of saline and sodic soils are about 394 and 434 m-ha, respectively
- ✓ Extent and distribution of salt affected soils in India is 6.7 m-ha (CSSRI)



Source: CSSRI, 2012.(http://www.cssri.org/index)

Salinity Units

- ✓ Measured with an **electrical conductivity** meter
- ✓ Common units: decisiemens/meter (dS/m) or mmohs/cm
- ✓ Total salinity of irrigation water (in ppm or mg/L), $C_{iw} = 640 \times EC_{iw}$
- ✓ where EC_{iw} is the electrical conductivity of irrigation water (dS/m)
- ✓ Standard measurement for soil salinity is expressed as saturated paste extract salinity, EC_e.

Osmatic Potential Energy in Soil

- ✓ Water with a higher concentration of salts has a lower energy (more negative) than water with a lower concentration of salts.
- ✓ Water is driven toward the higher salinity region and therefore, plant has difficulty pulling water from the high saline soils.

- ✓ The osmotic potential energy in saturated soils:

$$\psi_o = -3.6 \times EC_e$$

Where EC_e is the electrical conductivity of the saturated paste extract, dS/m; ψ_o is the osmotic potential, m.

- ✓ As the soil dries, the salinity increases. The osmotic potential as a function of water content is

$$\psi_o = -3.6 \times ECe \times \frac{\theta s}{\theta}$$

Where θ_s is the saturated water content (by volume); θ is the actual water content (by volume)

Example 36.1:

Calculate osmatic potential in the soil at 25% water content if EC_e=1 dS/m, and water content is 50%.

Solution:

The osmotic potential as a function of water content is

$$\psi_o = -3.6 \times ECe \times \frac{\theta s}{\theta}$$

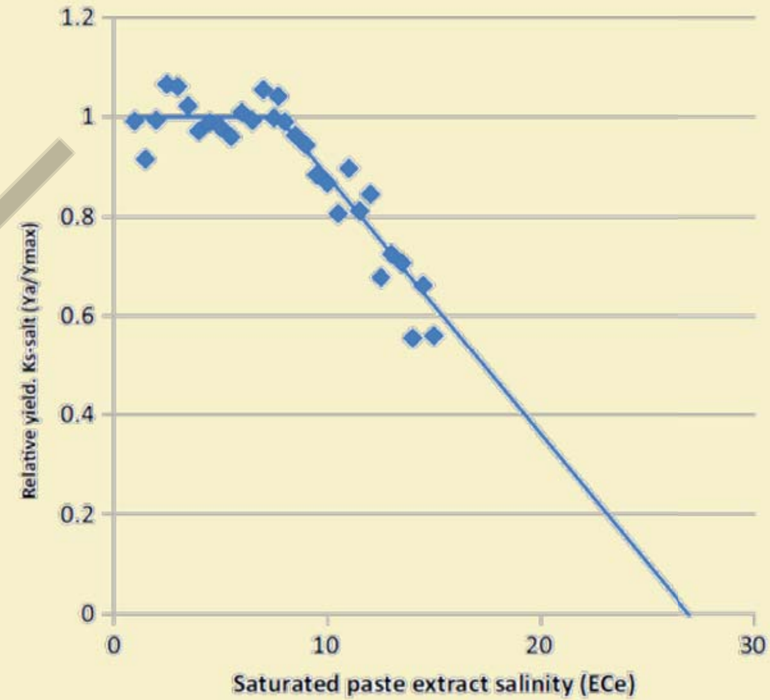
$$\psi_o = -3.6 \times 1 \times \frac{100}{50}$$

$$\psi_o = -7.2 \text{ m}$$

$$\psi_o = -0.72 \text{ atmospheres}$$

Salinity Stress Coefficient

- ✓ Increase in soil salinity decreases water uptake, thus, decreases yield.
- ✓ From Figure, when EC_e exceeds 7.7, the yield begins to decrease.
- ✓ Crops that are classified as sensitive, moderately sensitive, moderately tolerant, and tolerant to salinity have no reduction in yield at EC_e is 1.0, 3.0, 6.0, and 9.5-dS/m,



Response of cotton to increasing saturated paste extract salinity

Salinity Stress Coefficient

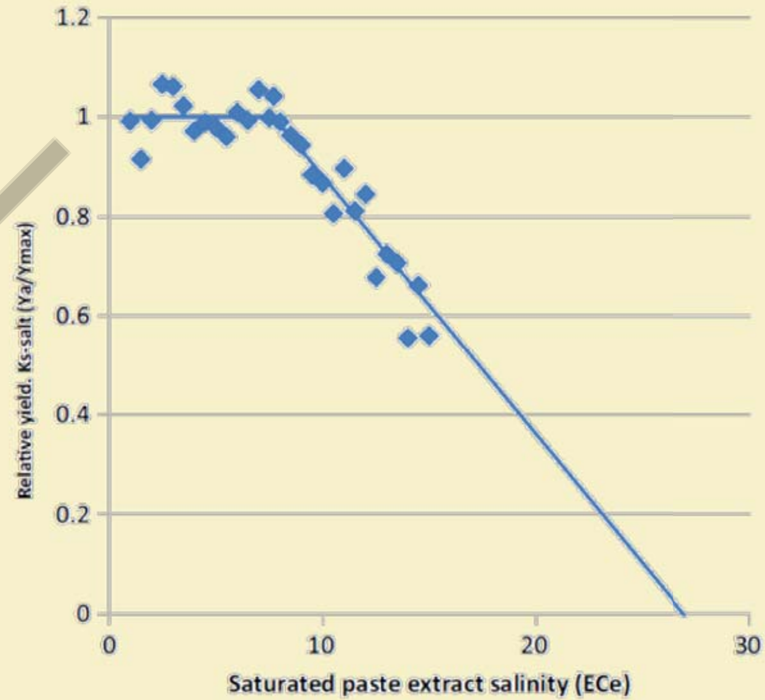
- ✓ Vegetable crops are generally sensitive to moderately sensitive to salinity.
- ✓ Field crops such as cotton, wheat, and barley tend to be less sensitive to salinity.
- ✓ The NRCS classifies irrigation salinity levels as no restriction on use ($EC_{iw} < 0.7$), slight to moderate restriction ($0.7 < EC_{iw} < 3.0$), and severe restriction ($3.0 < EC_{iw}$).

Salinity Stress Coefficient

The salinity stress coefficient is equal to 1 if $EC_e < EC_{et}$, otherwise

$$K_{s-salt} = 1 - \frac{b}{100 \times Ky}(EC_e - ECe_t)$$

Where *b* is the slope of EC_e/yield line, %/(dS/m); EC_{et} is the threshold saturated paste extract EC_e with no yield decrease, dS/m; $K_{s\text{-}salt}$ is the salinity stress coefficient, varies from 0 to 1; K_y is the crop sensitive to water stress



Response of cotton to increasing saturated paste extract salinity

Water Stress Coefficient

- ✓ As with salinity stress, the water stress coefficient is generally calculated under the assumption that yield decreases linearly with increased percent water depletion.
- ✓ The threshold percent depletion, θ_t, is the water content at which yield starts to decrease.
- ✓ Thus, Ks-water decreases linearly from 1 at θ_t to 0 at θ_{pwp}

$$K_{s\_water} = \frac{\theta - \theta_{pwp}}{\theta_t - \theta_{pwp}};$$

$$\theta_t = \theta_{FC} - \left(\frac{p}{100}\right)(\theta_{FC} - \theta_{PWP})$$

p is the point at which yield decreases in contrast to MAD, which may be equal to p or less than p

Water and Salt Stress Coefficient

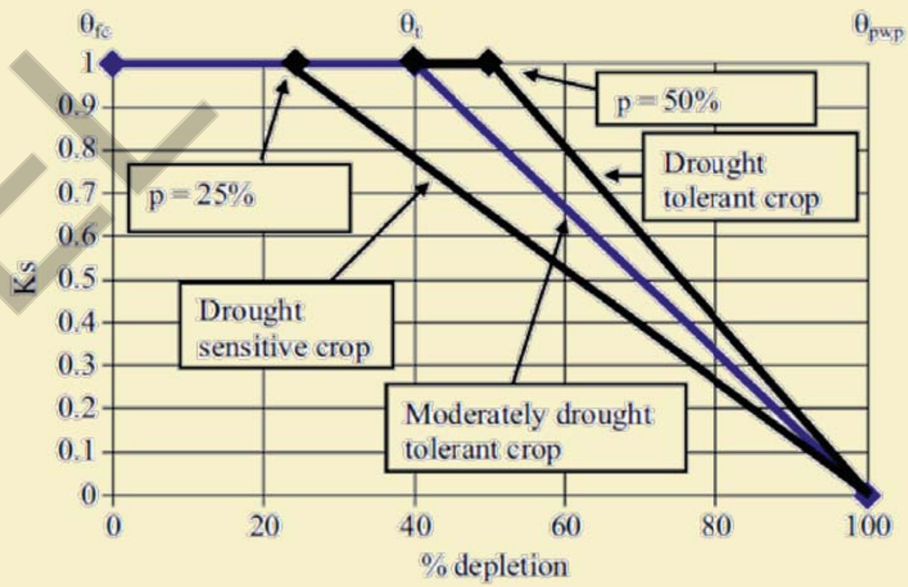
✓ Combined salt and water stress coefficient

$$K_s = K_{s\_salt} \times K_{s\_water}$$

The relationship between yield decrease and combined stress is:

$$1 - \left(\frac{Y_a}{Y_{max}}\right) = Ky(1 - Ks)$$

Where K_y is the crop sensitivity to water stress; Y_a is the actual yield, kg/ha; Y_{max} is the maximum potential yield, kg/ha.



Ks versus water content curve (after FAO 56)

Water and Salt Stress Coefficient

Equation, $1 - \left(\frac{Y_a}{Y_{max}}\right) = Ky(1 - Ks)$ can be rearranged to solve for actual yield:

$$Y_a = \left(1 - Ky(1 - Ks)\right)Y_{max}$$

Table: Crop sensitivity to water stress, K_y (FAO 56)

Crop	K_y	Crop	K_y
Alfalfa	1.1	Potato	1.1
Banana	1.2–1.35	Safflower	0.8
Beans	1.15	Sorghum	0.9
Cabbage	0.95	Soybean	0.85
Citrus	1.1–1.3	Spring Wheat	1.15
Cotton	0.85	Sugarbeet	1.0
Grape	0.85	Sugarcane	1.2
Groundnet	0.70	Sunflower	0.95
Maize	1.25	Tomato	1.05
Onion	1.1	Watermelon	1.1
Peas	1.15	Winter wheat	1.05
Pepper	1.1		

Example 36.2

Calculate actual yield for cotton for a growing season if average salinity during the growing season is 10.4 dS/m, and average water content is 14 %. θ_{fc} = 20%, θ_{pwp} = 10%. K_y = 0.85. Max yield = 1,285 kg/ha. MAD = 50%. Threshhold EC_{et} = 7.7 dS/m and b = 5.2.

Solution: $\theta_t = \theta_{FC} - (MAD/100)(\theta_{FC} - \theta_{PWP})$; $\theta_t = 20-(0.5/100)(20-10)=15\%$

$$K_{s\_water} = \frac{\theta - \theta_{pwp}}{\theta_t - \theta_{pwp}} = \frac{0.14-0.10}{0.15-0.10} = 0.8$$

Calculate K_{s_salt}

$$K_{s-salt} = 1 - \frac{b}{100 \times Ky}(EC_e - ECe_t) = 1 - \frac{5.2}{100 \times 0.85}(10.4 - 7.7) = 0.83$$

Calculate total K_s

$K_s = K_{s\_water} \times K_{s\_salt}$
$= 0.80 \times 0.83 = 0.67$

Calculate yield

$$Y_a = \left(1 - Ky(1 - Ks)\right)Y_{max} = \left(1 - 0.85(1 - 0.67)\right)1285 = 924 \text{ kg/ha}$$

Example 36.3

Calculate the yield reduction for sugar beets. Assume 80 cm is applied and 100 cm is required. Y_{max} = 40 tons/ha.

Solution:

From Table, K_y for sugar beat is 1.0.

The yield based on the FAO, K_y slope is calculated as follows:

$$Y_a = (1 - Ky(1 - Ks))Y_{max} = \left(1 - Ky\left(1 - \frac{ET_{c\ adj}}{ET_c}\right)\right)Y_{max}$$

$$= \left(1 - 1.0\left(1 - \frac{80}{100}\right)\right)40 = 32 \text{ t/ha}$$

Salt Balance at Farm Level

Principles of conservation of mass (Hillel, 1998) : Salt Inflow – Salt outflow = Change in salt content

$$\left[\rho_w\left(V_i C_i + V_r C_r + V_g C_g\right) + M_s + M_a\right] - \left[\rho_w\left(V_d C_d + V_{sd} C_{sd} + V_{pw} C_{pw}\right) + M_p\right] = \Delta M_{sw}$$

Where,

V_i, V_r, V_g = the volume of water added to the same volume of soil by irrigation, rainfall, and upward flux (capillary rise), respectively, LC_i, C_r, C_g = concentration of salt in irrigation water, rainwater, and groundwater, respectively, mg/l

V_d, V_{sd}, V_{pw} = volume of water removed by deep drainage, surface drainage, and plant uptake, respectively, L

C_d, C_{sd}, C_{pw} = concentrations of salt in deep drainage, surface drainage, and plant uptake water, respectively, mg/l

M_s = mass of salt dissolved from soil mineral of a specified (or unit) soil volume, mg

M_a = mass of salt from agricultural inputs, mg

M_p = mass of salts precipitated (turned into solid), mg

ΔM_{sw} = change in mass of salt in the soil's liquid phase

ρ_w = density of water, 1000 mg/L

Salt Balance at Farm Level

Steady-state salt model (Hillel, 1998) :

Assumptions:

- ✓ Salinity concentration during the season and the year is constant (ΔM_{sw}=0)
- ✓ in-situ precipitation (liquid to solid) and dissolution (solid to liquid) of salt is negligible (M_s =0; M_p =0; M_a =0)
- ✓ Crops remove a negligible amount of salt (M_c=0)

$$(V_i C_i + V_r C_r) = (V_d - V_g) C_d$$

If C_{in} is the average weighted salinity of the precipitation and irrigation water, and V_g is negligible, then

$$V_{in} C_{in} = V_{out} C_{out} \quad \textit{or} \quad d_{in} C_{in} = d_{out} C_{out}$$ by replacing water volume with water depth, d

Leaching Fraction

The leaching fraction, LF, is the leached depth or seepage depth divided by the applied depth where i in the following includes precipitation as well as irrigation if C_{in} is the average salinity of both.

$$LF = \frac{d_{out}}{d_{in}} = \frac{d_{seepage}}{i}$$

Since, $d_{in}C_{in} = d_{out}C_{out};$ $\quad d_{in}C_{in} = LF \times i \times C_{out};$ $\quad C_{out} = \frac{C_{in}}{LF}$

Because EC is propositional to the concentration C, the leachate salinity for uniform water application can be written as

$$EC_{dw} = \frac{EC_{iw}}{LF}$$

Where EC_{dw} is electrical conductivity of drainage water (leachate or seepage), dS/m. EC_{iw} is electrical conductivity of irrigation water, dS/m.

Leaching Fraction

Depth of drainage water is equal to the irrigation water minus d_{ET}.

Substitute into $LF = \frac{d_{out}}{d_{in}} = \frac{d_{seepage}}{i}$

$d_{out} = I - d_{ET}$

$$LF = \frac{i - dET}{i}$$

The maximum allowable EC_e can be calculated based on crop sensitivity to salinity stress. An equation based on field experiments conducted with low frequency irrigation systems. It has been a standard method for calculation of leaching fraction;

$$LF = \frac{EC_{iw}}{5 \times ECe - EC_{iw}}$$

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Thank You!!

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Irrigation and Drainage

Lecture No: 37 Management of salt affected soils

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Exercise 37.1:

Irrigation water salinity (EC_{iw}) = 1 dS/m. Applied water depth (d_{in}) = 1176 mm/season. Crop water demand (ET_c) = 1,000 mm/season. Assume that plants extract 40%, 30%, 20%, and 10% of their water from the upper quarter, 2nd quarter, 3rd quarter, and lowest quarter of the root zone, respectively. First, determine the leachate salinity treating the root zone as a single layer. Next, determine the seepage salinity from each of 4 layers and the average salinity for the 4 layers (Ayres and Westcott, 1985).

Solution:

Treating the entire root zone as a single layer, calculate seepage salinity.

$$LF = \frac{i - ET}{i} = \frac{1176 - 1000}{1176} = 0.15; \qquad EC_{dw} = \frac{EC_{iw}}{LF} = \frac{1}{0.15} = 6.7\ dS/m$$

Use the same equations to determine soil salinity at the bottom of each of the four quarters of the root zone.

$$LF_1 = \frac{i-ET}{i} = \frac{1176-0.4*1000}{1176} = 0.66; \qquad EC_1 = \frac{EC_{iw}}{LF_1} = \frac{1}{0.66} = 1.5\ dS/m$$

$$LF_2 = \frac{776-0.3*1000}{776} = 0.61; \qquad EC_2 = \frac{EC_1}{LF_2} = \frac{1.5}{0.61} = 2.5\frac{dS}{m}$$

$$LF_3 = \frac{476-0.2*1000}{476} = 0.58; \qquad EC_3 = \frac{EC_2}{LF_3} = \frac{2.5}{0.58} = 4.3\frac{dS}{m}$$

$$LF_4 = \frac{276-0.1*1000}{276} = 0.64; \qquad EC_4 = \frac{EC_3}{LF_4} = \frac{4.3}{0.64} = 6.7\frac{dS}{m}$$

The calculated seepage salinities, treating the soil as a whole and in layers, agree: 6.7 dS/m.

The average soil salinity is the average of the irrigation water salinity and the salinities at the bottom of the 4 layers.

$$EC_{ave} = \frac{\frac{1}{2} + 1.5 + 2.5 + 4.3 + \frac{6.7}{2}}{4} = 3.0\ dS/m$$

Rhoades (1974) recommended the following leaching fraction equation for high frequency sprinkler or trickle irrigation

$$LF = \frac{EC_{iw}}{2ECe}$$

Hoffman and Van Genuchten (1983) developed the following theoretical equation for LF. It has a wider range of salinity parameters for which it is accurate.

$$\frac{EC_e}{EC_{iw}} = \left(\frac{1}{LF} + \frac{\delta}{Z * LF} ln\left(LF + (1 - LF)e^{-z/\delta}\right)\right)$$

Where Z is the root zone depth, δ is the empirical constant = 0.2*Z

Relative Salt Tolerance of Crops

Table: The relative salt tolerance of field, forage, and vegetable crops

Electric conductivity (dS/m)	Annual crop	Forage crop
Non-saline to Slightly saline (0–4)	Soybeans, field beans, faba beans, peas, corn	Red clover, alsike, timothy
Moderately saline (4–8)	Canola, flax, mustard, wheat, oats	Reed canary, meadow fescue, intermediate wheat, crested wheatgrass, alfalfa, sweet clover
Severely saline (8–16)	Barley may grow but forages are more productive in severe salinity	Altai wild ryegrass, Russian wild grass, tall wheatgrass, salt meadow grass

Cotton can tolerate higher salinity levels than some other crops

Irrigation Application Depth and Leaching Fraction

If the goal is to maintain salinity within an acceptable range during the entire growing season, the depth of irrigation water that should be applied during any one irrigation event:

$$IR = \frac{100}{IE(1 - LF)} \times RAW$$

Where **IR** is the irrigation requirement during single irrigation event, cm; **IE** is the irrigation efficiency, percent.

Example 37.2:

Calculate the depth of irrigation water required (average for the field), IR, for melons based on the previous equation. The MAD is 45%, the irrigation system efficiency is 70%, the irrigation water EC_{iw} is 1.09 dS/m, and the TAW is 24 cm.

Solution:

Max. soil salinity in the saturated paste extract (from FAO 56) for melons with no yield reduction = 2.2 dS/m.

$$LF = \frac{EC_{iw}}{5ECe - ECi_w} = \frac{1.09}{5 \times 2.2 - 1.09} = 0.11$$

$$IR = \frac{100}{IE(1 - LF)} RAW = \frac{100}{70(1 - 0.11)} (0.45 * 24\ cm) = 17 cm$$

Yield reduction due to salinity

- ✓ **Relative yield (Yr in %)**

$$Y_r = 100 \times \frac{EC_0 - EC_e}{EC_0 - EC_{100}}$$

$$Y_{act} = Y_r \times Y_p$$

Where,

EC_0 = Electrical conductivity (EC) of soil at zero yield, dS/m

EC_e = EC of the soil saturation extract, dS/m

EC_{100} = the salinity threshold level above which the crop yield starts to decline

Y_{act} = actual yield

Y_p = potential yield

Exercise 37.3:

In a saline area, the EC of a wheat field during its growth period was found 7.0 dS/m. Estimate yield reduction due to salinity, if the wheat cultivar can maintain potential yield up to 4 dS/m, and the yield at EC>22 dS/m is zero.

Solution:

EC_0 = 7 dS/m
EC_e = 22 dS/m
EC_{100} = 4 dS/m

$$Y_r = 100 \times \frac{EC_0 - EC_e}{EC_0 - EC_{100}}; = 100 \times \frac{22-7}{22-4} = 83.33\ \%$$

$$Yield\ reduction = (100 - 83.33)\%$$
$$= 16.67\%$$

Project Planning and Salinity

- ✓ Irrigation water with a salinity lower than 450 mg/L (EC_{iw} = 0.7) does not present a hazard for irrigation salinity.
- ✓ Irrigation water with salinity in excess of 2,000 mg/L (EC_{iw} = 3) presents a hazard for many crops.
- ✓ Rao et al. (1994) developed Table that specifies the maximum acceptable salinity of irrigation water as a function of rainfall, soil type, and crop sensitivity to salinity

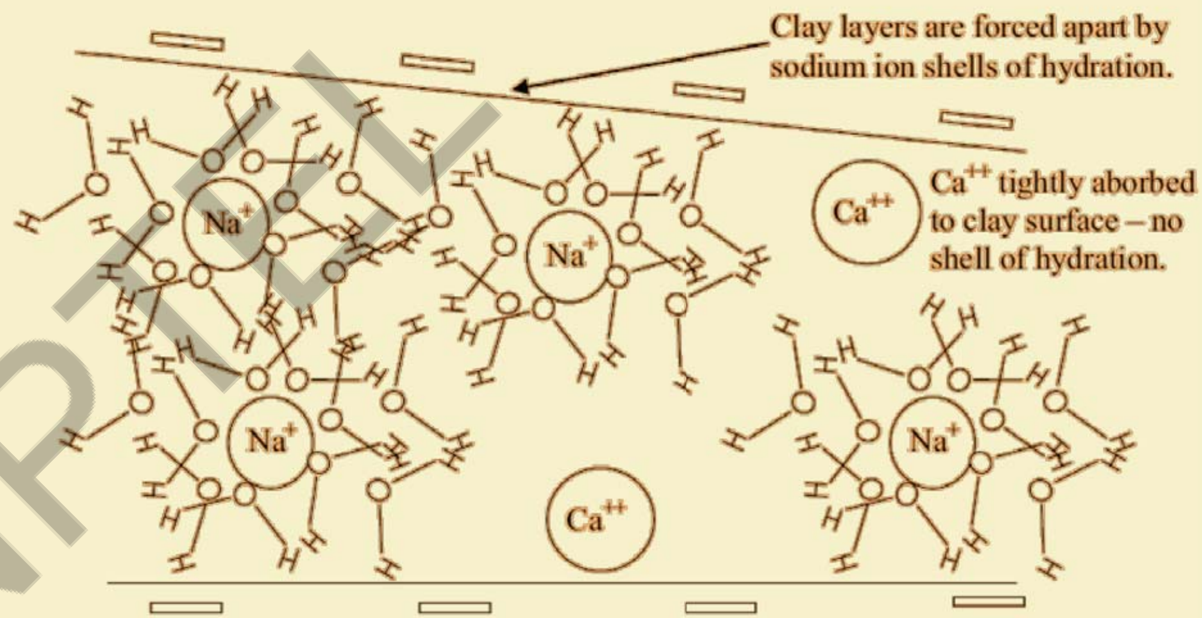
Project Planning and Salinity

Maximum acceptable salinity in irrigation water as a function of soil type, rainfall per year, and crop sensitivity to salinity (Rao et al. 1994)

Soil texture (percent clay)	Crop tolerance	Annual rainfall <350 mm	350–500	550–750
Fine (>30 %)	Sensitive	1	1	1.5
	Semi-tolerant	1.5	2	3
	Tolerant	2	3	4.5
Moderately fine (20–30 %)	Sensitive	1.5	2	2.5
	Semi-tolerant	2	3	4.5
	Tolerant	4	6	8
Moderately coarse (10–20 %)	Sensitive	2	2.5	3
	Semi-tolerant	4	6	8
	Tolerant	6	8	10
Coarse (<10 %)	Sensitive	–	3	3
	Semi-tolerant	6	7.5	9
	Tolerant	8	10	12.5

Sodicity

- ✓ Excess sodium reduces water availability
- ✓ It leads to breakdown of clay particle structure (dispersion)
- ✓ The clay particles can clog the soil and reduce infiltration rate to nearly zero.

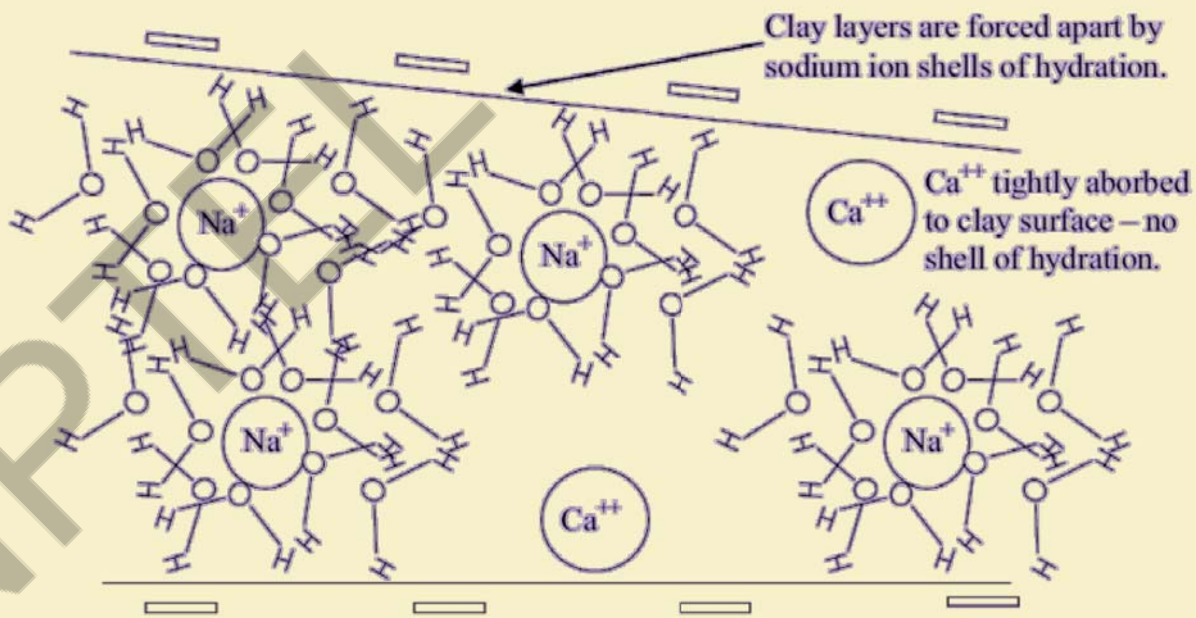


Sodium hydration shell and calcium ions between clay layers

Sodicity

- ✓ **Calcium,** is attracted much more strongly to the clay particles because they have a charge of +2.

- ✓ If too many sodium molecules, with their large shell of hydration, force the clay layers apart and break down the soil structure.



Sodium hydration shell and calcium ions between clay layers

Sodicity

The sodium hazard associated with irrigation water can be determined by the sodium adsorption ratio (SAR);

$$SAR = \frac{|Na^{+}|}{\sqrt{\frac{|Ca^{++}| + |Mg^{++}|}{2}}}$$

Where Na^{+} is the sodium normality, meq/L; Ca^{++} is the calcium normality, meq/L; Mg^{++} is the magnesium normality, meq/L.

Sodicity

- ✓ The sodium hazard level is a function of both the SAR and the overall salinity
- ✓ Higher salinity in the soil water decreases the osmotic potential (more negative) of water in the soil water solution, and, as such, decreases the amount of water in the hydration shells around the sodium ions in the interlayer between clay particles.
- ✓ Thus, it may be very detrimental to irrigate with low salinity water in a field that was previously irrigated with high salinity and sodicity water

Sodicity hazard to soils as a function of irrigation water sodicity and salinity

SAR	EC_{iw}		
	None	Slight to moderate	Severe
0–3	>0.7	0.7–0.2	<0.2
3–6	>1.2	1.2–0.3	<0.3
6–12	>1.9	1.9–0.5	<0.5
12–20	>2.9	2.9–1.3	<1.3
20–40	>5.0	5.0–2.9	<2.9

Example 37.4:

Irrigation water has 460 mg/L sodium (Na+), 40.1 mg/L calcium (Ca++), and 24.3 mg/L magnesium (Mg++). If irrigation water salinity is 1,280 ppm, then what level of hazard is presented by sodicity?

Solution:

Calculate meq/L for each cation.

$$\frac{460\frac{mg}{L}Na^{+}}{23\frac{mg}{meq}} = 20\,\frac{\text{meq}}{\text{L}}\ \text{Na}^{+}; \qquad \frac{40.1\frac{mg}{L}Ca^{++}}{20.05\frac{mg}{meq}} = 2\,\frac{\text{meq}}{\text{L}}\ \text{Ca}^{++}; \qquad \frac{24.3\frac{mg}{L}Mg^{++}}{12.15\frac{mg}{meq}} = 2\,\frac{\text{meq}}{\text{L}}\ \text{Mg}^{++}$$

$$SAR = \frac{|Na^{+}|}{\sqrt{\frac{|Ca^{++}|+|Mg^{++}|}{2}}} = \frac{20}{\sqrt{\frac{2+2}{2}}} = 7$$

The EC_{iw} of the irrigation water is 1,280 ppm/640 = 2 dS/m. From Table (previous slide), there is no possible hazard due to sodicity from this water.

Salinity Management Options

- ✓ **Removing Surface Salts:** Surface Scraping or Surface Flushing
- ✓ **Control of Saline Water:** Removing surface water by drainage
- ✓ **Engineering Practices**
  - ✓ Leaching
  - ✓ Drainage
  - ✓ Artificial Recharge of Rainwater to Aquifer Through Recharge Well
- ✓ **Irrigation and Water Management Practices**

Engineering Practices for Salinity Management

✓ **Leaching :**

- It consists of applying enough good quality water to thoroughly leach excess salts from the soil.
- There are two ways to manage saline soils using this approach:
  - **Leaching requirement method:** Salts can be moved below the root zone by applying more water than the plant needs.
  - **Leaching plus artificial drainage:** When Shallow water tables limit the use of leaching, combination of leaching requirement method with artificial drainage is preferred.

Engineering Practices for Salinity Management

✓ **Drainage**

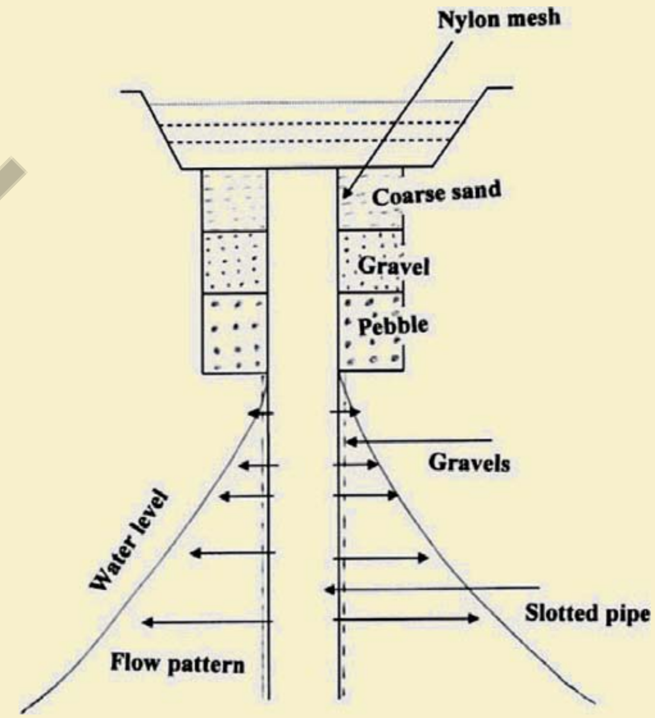
Drainage system are provided where the subsoils are not permeable.

- **Surface drainage:** Ditches are provided on the surface to runoff excess water.
- **Subsurface drainage:** Deep open ditches or tile are provided to control of groundwater table.
- **Mole drainage:** Shallow channels created (moles) in clay soils, which drains to main drainage system.
- **Vertical drainage:** Pumping out excess water from tubewells.

Engineering Practices for Salinity Management

✓ **Artificial Recharge of Excess Rainwater to Aquifer through Recharge Well**

- The salinity of the aquifer water will be lower due to dilution and become within acceptable range
- Shallow depth recharge structures with tubewells are often better choice than surface storage in flat topography with good aquifer properties.



Schematic of a recharge well

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Irrigation and Drainage

Lecture No: 38 Agricultural Drainage: Related Concepts

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Pressure in the Soil Water

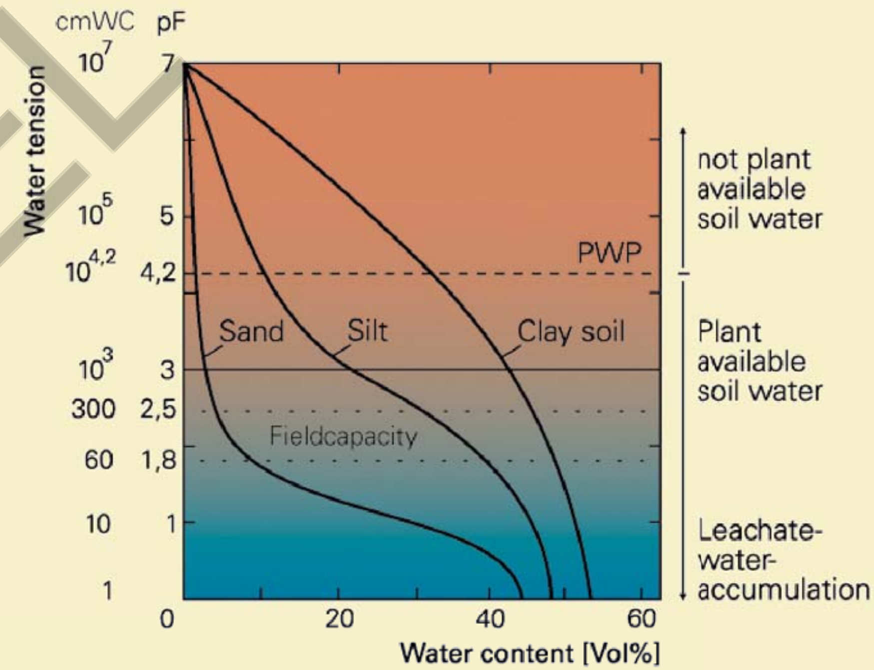
- ✓ Pressure = Force/Area

  P (in Pascals) = P(in m) × ρ_w (in kg/m^3) × g (in m/s^2).

  1 bar = 10^5 Pa ~ 1 atm = 10 m head

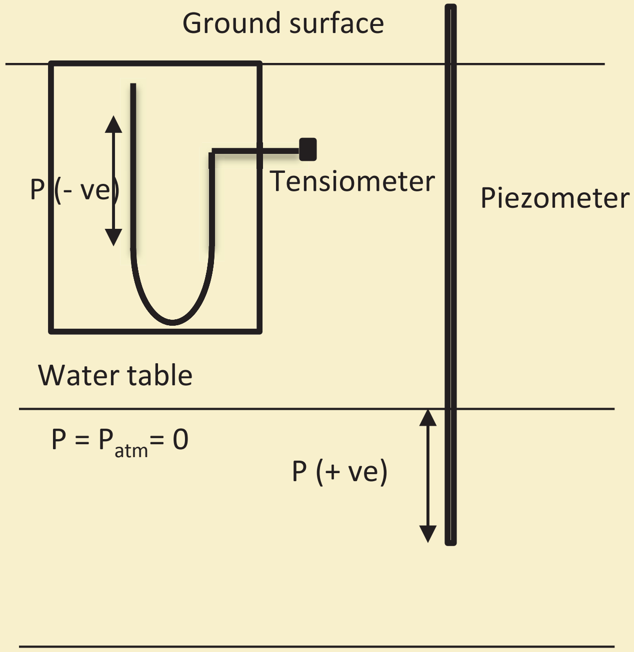
- ✓ -ve pressure in the soil moisture are also conventionally expressed by their pF value.

  pF = $\log_{10}P$, where P is the head in cm



Pressure in the Soil Water

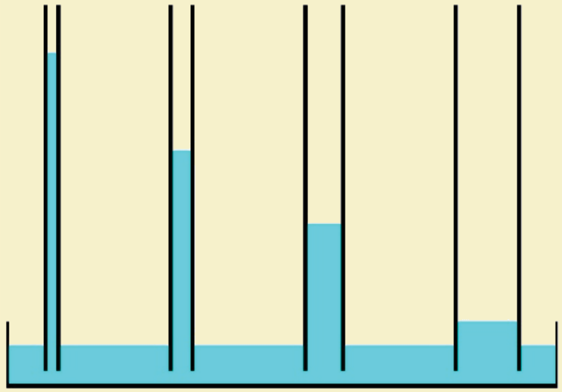
- ✓ Pressure at water table is always atmospheric pressure
- ✓ **Pressure below water table**
  - ✓ > atmospheric pressure
  - ✓ Positive pressure- measured with Piezometer
- ✓ **Pressure above water table**
  - ✓ < atmospheric pressure
  - ✓ Negative pressure-soil moisture tension or suction pressure
  - ✓ Measured in with tensiometers



Pressure in the Soil Water

Pressure above the water table consists of

1. Capillary forces
2. Adsorptive forces
3. Osmotic forces (Saline Soils)



Capillary Forces:

- ✓ Capillary action, also referred to as capillary motion or capillarity, is a combination of cohesion/adhesion and surface tension forces.
- ✓ Capillary action is demonstrated by the upward movement of water through a narrow tube against the force of gravity.

Pressure in the Soil Water

✓ Capillary action occurs when the adhesive intermolecular forces between a liquid, such as water, and the solid surface of the tube are stronger than the cohesive intermolecular forces between water molecules.

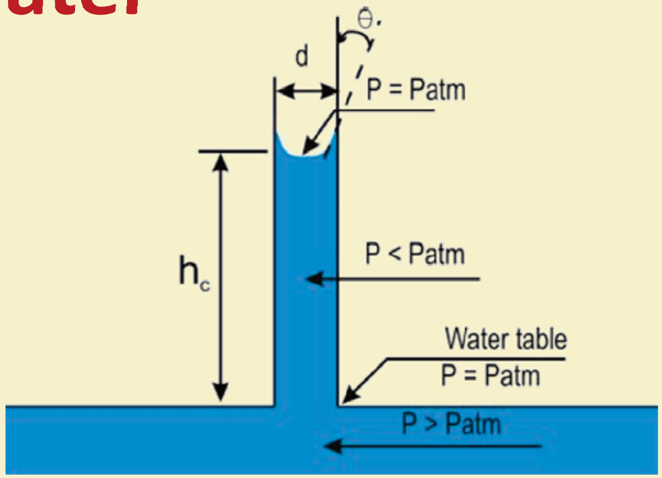
$$h_c = \frac{-2\gamma cos\theta}{\rho\, g\, r}$$

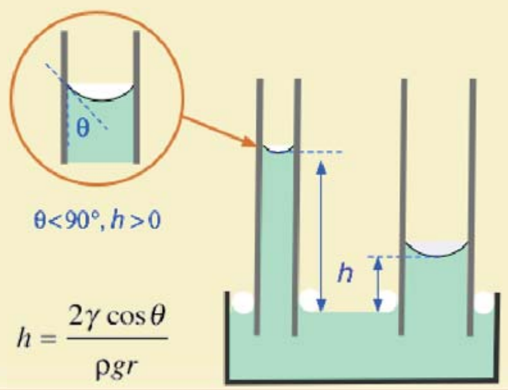
where γ is surface tension, N/m; h_c capillary rise, m; r radius of curvature, m; ρ unit weight of water, $\frac{\text{kg}}{\text{m}^3}$; g acceleration due to gravity, $\frac{\text{m}}{\text{s}^2}$

✓ In a pore, curvature of a meniscus attains a maximum value when its radius equal to the radius of the pore (θ = 0)

$$h_c = \frac{-4\gamma}{\rho\, g\, D} \text{ or } = \frac{-3000}{D}$$

where, D is diameter of the pore in microns





Pressure in the Soil Water

Adsorptive Forces

✓ Includes Van der Waals and electrostatic forces exerted on the water by the charged colloidal surface of the soil particles.

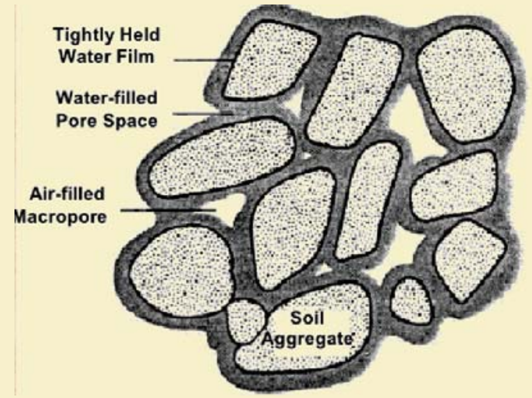
✓ Tensiometrs measure matric suction (capillary + adsorption forces)

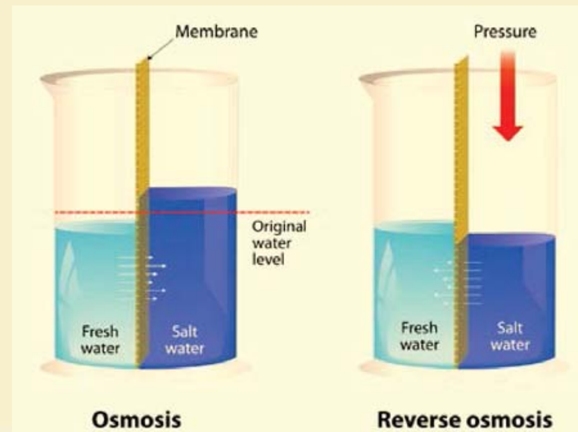
Osmotic Pressure:

✓ Occurs when solutions of different concentrations are separated by a semi-permeable membrane

✓ Random motion of water and solute molecules create a net movement of water to the compartment with higher concentration, until equilibrium is reached.

✓ At equilibrium, net water movement is eliminated by increase in water pressure.

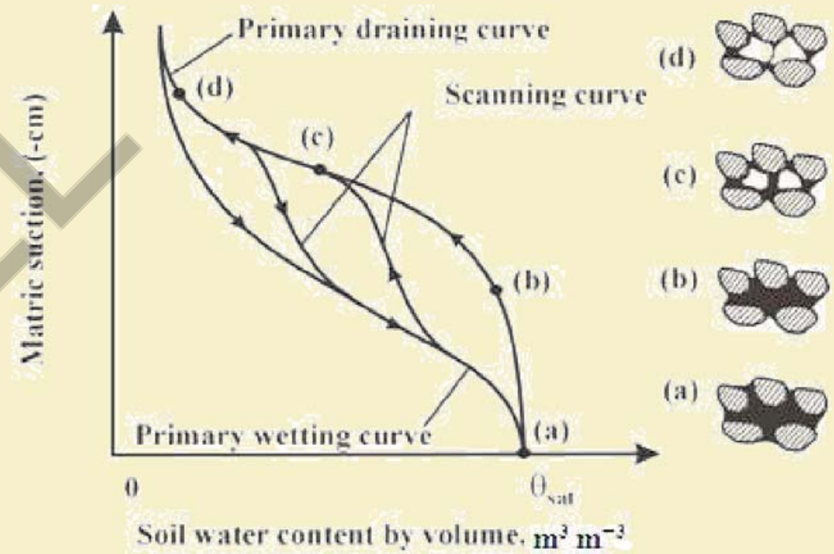




Soil Moisture Characteristic Curves

- ✓ Total water potential, $\Psi_t = \Psi_g + \Psi_m + \Psi_o$

  Where Ψ_g is gravitational potential; Ψ_m is the matric potential, Ψ_o is the osmotic potential
- ✓ Relationship between the soil moisture content (θ) and matric potential (Ψ_m).
- ✓ Used to predict the soil water storage, water supply to the plants (field capacity) and soil aggregate stability.
- ✓ Due to the hysteretic effect of water filling and draining the pores, different wetting and drying curves may be distinguished.
- ✓ For drainage **drying curve** is more relevant

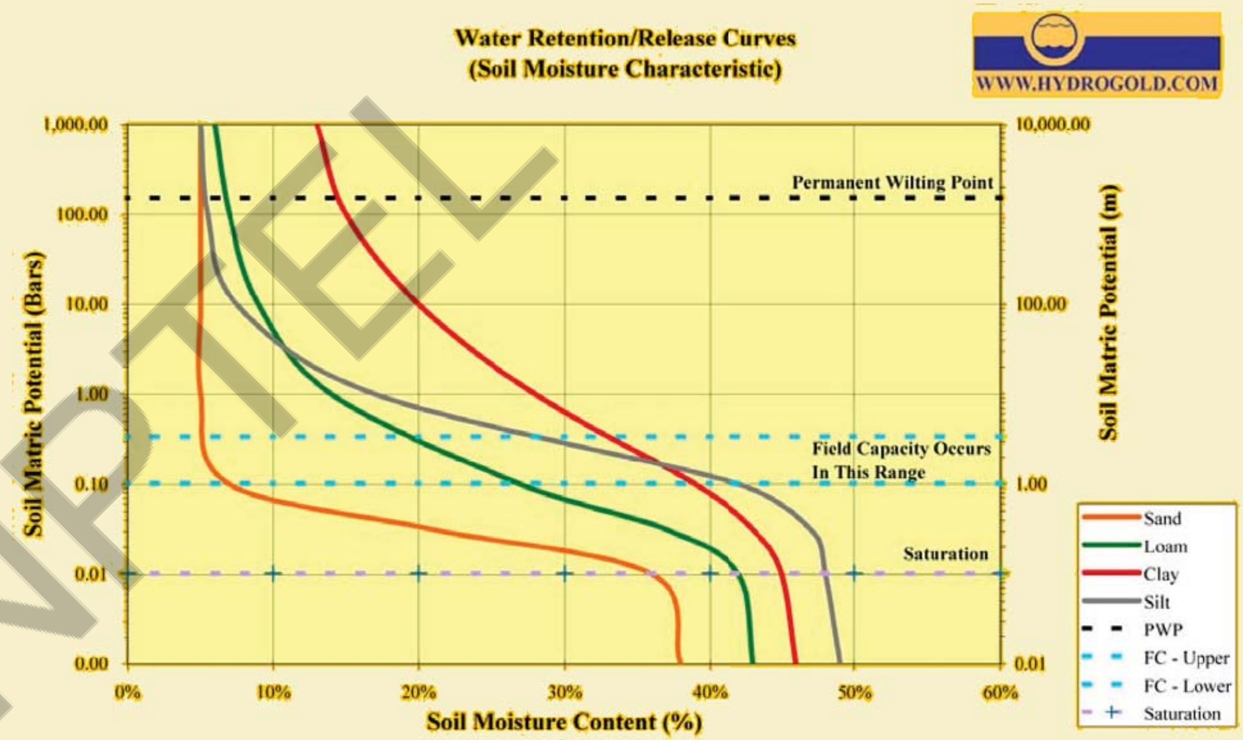


Soil Moisture Characteristic Curves

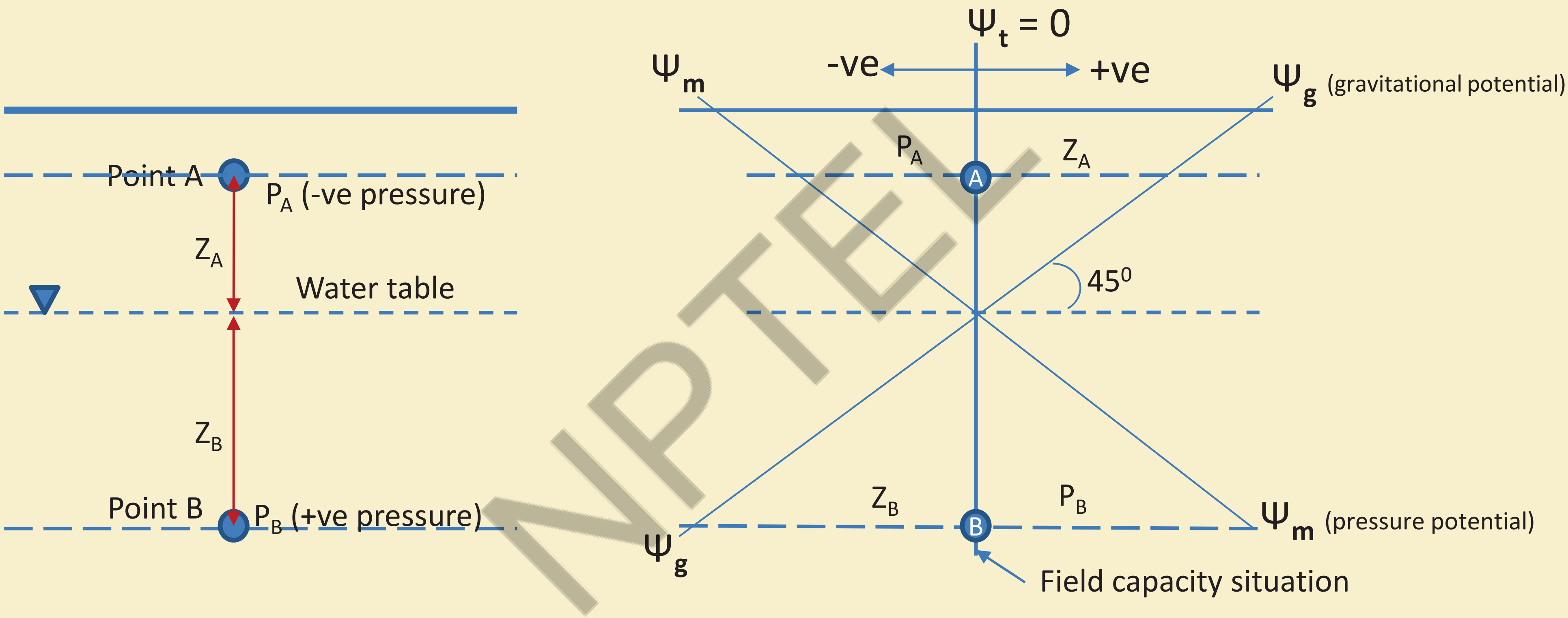
Capillary rise of water in soil:

$$h_c = \frac{-4\gamma}{\rho\, g\, D} \text{ or } = \frac{-3000}{D}$$

- ✓ At -100 cm h_c, 30µ pores will completely drain.
- ✓ At -10 cm h_c, 300µ pores will completely drain
- ✓ At -10,000 cm h_c, 0.3µ pores will completely drain.



Soil Water Potential



Components of total soil water potential in the static equilibrium

Soil Water Potential

It is the work required to move a unit quantity of water from the reference state to that point

$\mathbf{\Psi_t = (\Psi_g + \Psi_m)}$

Ψ_g energy needed to move against gravity; Ψ_m energy needed to move against pressure

For point A: $\Psi_A = Z_A + (-P_A)$

For point B: $\Psi_B = -Z_B + (P_B)$

Under field capacity situation and no evapotranspiration, the water will percolate until $P_A = Z_A$

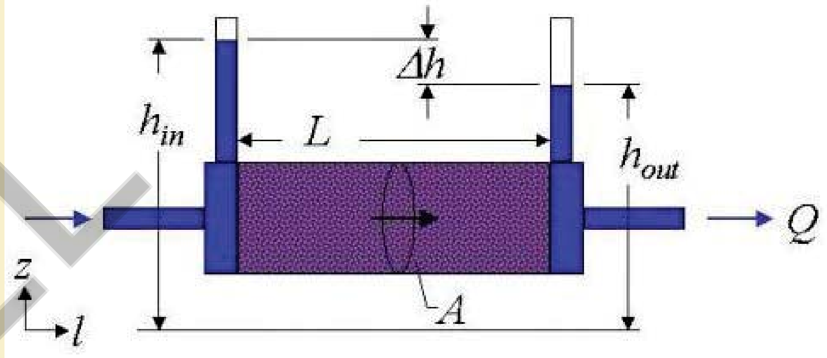
At point A, $\Psi_t = (\Psi_g + \Psi_m) = Z_A + (-Z_A) = 0$

For zero flow in the ground water (point B): $\Psi_t = (\Psi_g + \Psi_m) = -Z_B + (Z_B) = 0$

Soil Water Movement: Darcy’s Law

Darcy’s Law:

- ✓ The principle that governs how fluid moves in the subsurface is called Darcy's law.
- ✓ It relies on the fact that the amount of flow between two points is directly related to the difference in pressure between the points, the distance between the points, and the interconnectivity of flow pathways in the rock between the points.



$$q = -K.\frac{h_{out}-h_{in}}{L}.A = -K.\frac{\Delta h}{L}.A = K\ i\ A$$

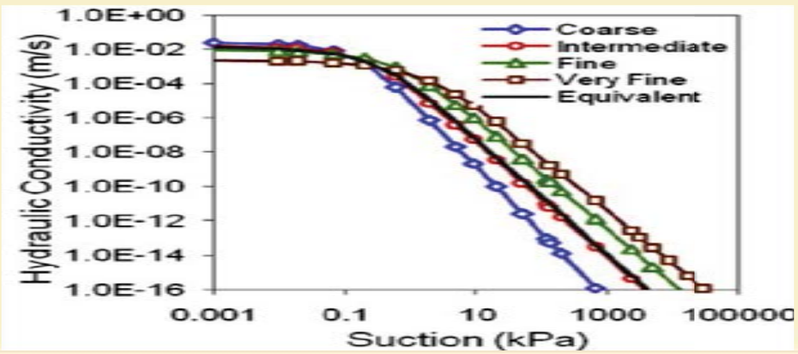
Where, q = Discharge per unit time (cm^3/s); A = Area of c/s of soil mass (cm^2); i = Hydraulic gradient (-); K = Darcy’s coefficient of Permeability (cm/s)

✓**It is assumed** that the soil is saturated, the flow through soil is laminar, continuous and steady.

Hydraulic Conductivity (K)

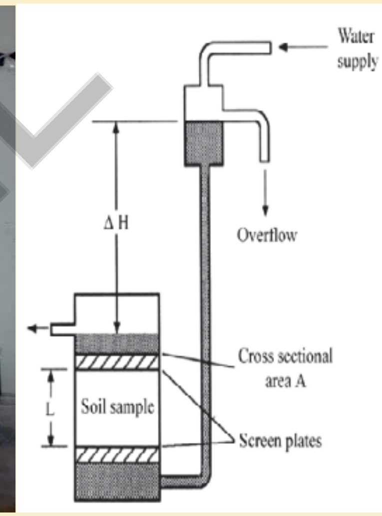
- ✓ Depends on geometry and distribution of the water filled pores.
- ✓ Hydraulic conductivity is defined as ratio of Darcy's velocity to applied hydraulic gradient.
- ✓ Temperature effect is negligible for drainage point of view.
- ✓ Values are low when the water has to follow a tortuous path through the soil.

Soil Texture	K_{sat} (m/d)
Coarse gravel, sand	10-50
Medium sand	1-5
Very fine sandy loam	0.2-0.5
Clay loam	0.02-0.2
Dense clay	<0.002



Measurement of Saturated Hydraulic Conductivity

Constant-Head Permeameter (LT)



$$K_S = \frac{QL}{\triangle\, h\, A}$$

Where, Q = Discharge , cm^3/sec; L = length of soil specimen, cm; $\triangle h$ = difference in water level, cm; A = cross-section area of soil sample

Measurement of Saturated Hydraulic Conductivity

Inverse Auger Hole Method

Requirement: Soil auger, stopwatch, bucket of water, scale, note book & pen.

Saturated hydraulic conductivity (K_S)

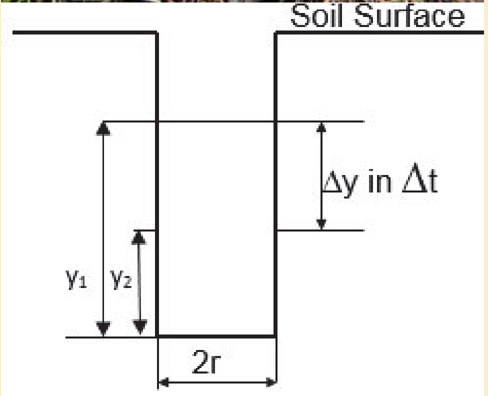
$$K_S = 1.15r \tan \alpha$$

$$\tan \alpha = \frac{(\log(y_1 + 0.5r) - \log(y_2 + 0.5r))}{t - t_0}$$

Where, r= radius of the hole, cm

y_1= height of water column at initial time (t_0)

y_2= height of water table at time t, sec



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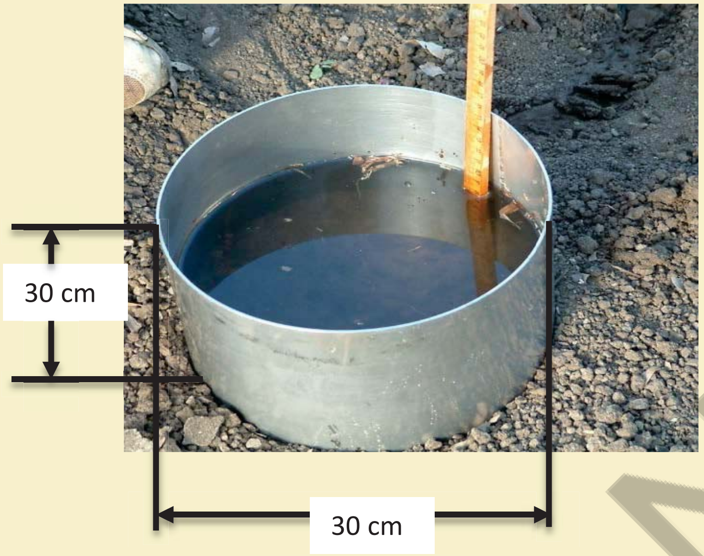
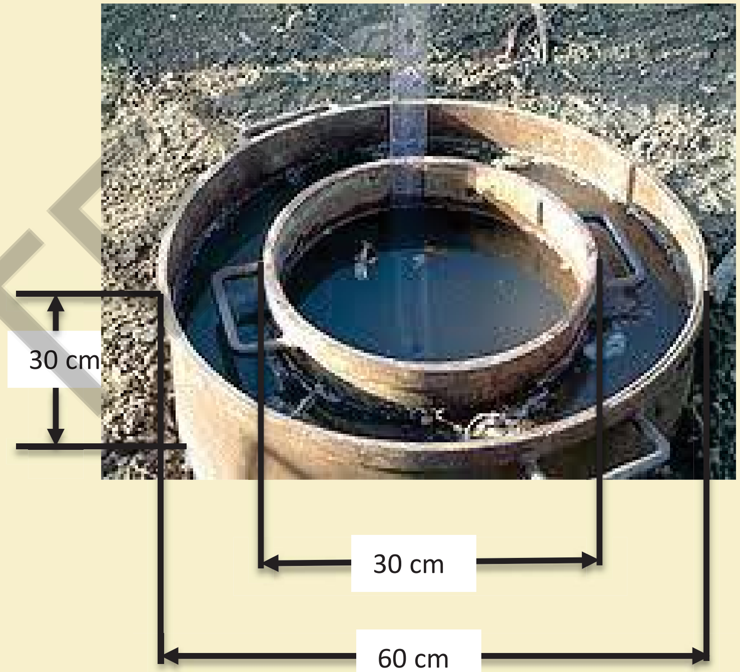
Measurement of Saturated Hydraulic Conductivity

Ring infiltrometer



Single ring Infiltrometer



Double ring Infiltrometer

Ring Infiltrometer Data Analysis

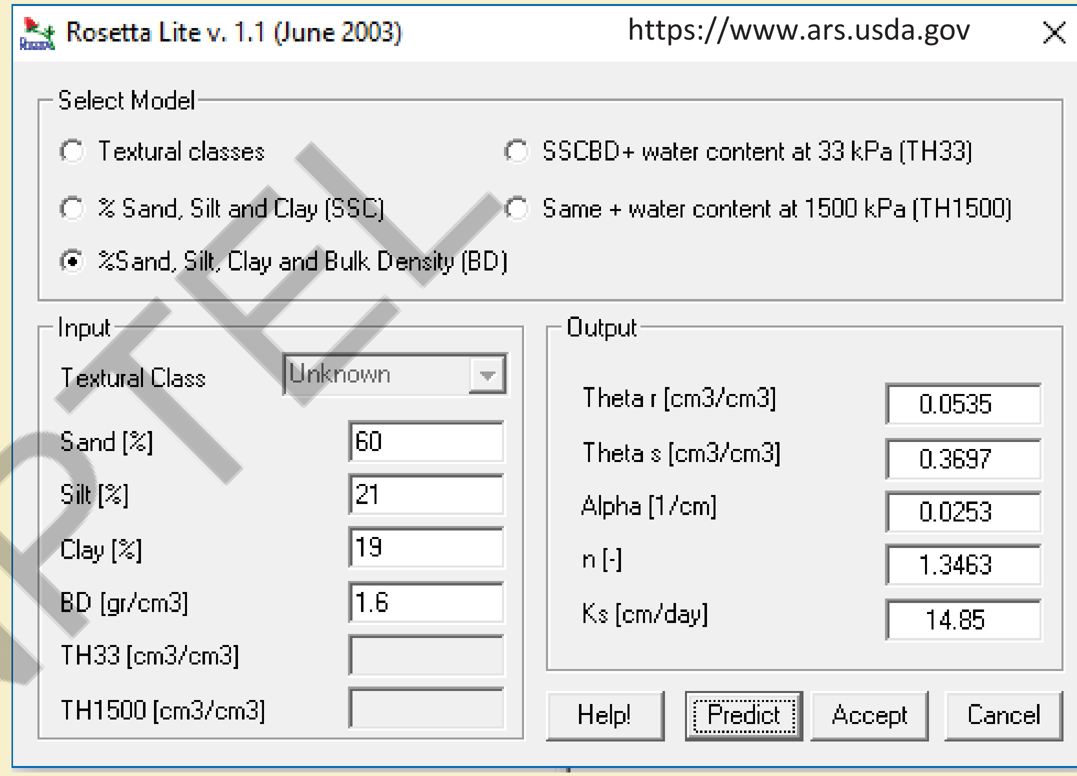
Sl. No. (1)	Clock Time (2)	Time Elapsed (min) (3)	Time Interval (min) (4)	Actual Reading (cm) (5)	Drop in Water Level (cm) (6)	Remarks (7)	Cumulative Infiltration (mm) (8)	Infiltration Rate (mm/h) (9)=(6)/(4)
1	8:40:00 AM	0	0	28	0		0	0
2	8:45:00 AM	5	5	27.07	0.93		9.3	111.6
3	8:50:00 AM	10	5	26.6	0.47		14	56.4
4	8:55:00 AM	15	5	26.25	0.35		17.5	42
5	9:00:00 AM	20	5	27.67	0.33	Refilling	20.8	39.6
6	9:05:00 AM	25	5	27.35	0.32		24	38.4
7	9:10:00 AM	30	5	27.07	0.28		26.8	33.6
8	9:20:00 AM	40	10	26.57	0.5		31.8	30
9	9:30:00 AM	50	10	26.14	0.43		36.1	25.8
10	9:40:00 AM	60	10	27.7	0.3	Refilling	39.1	18
11	9:55:00 AM	75	15	27.2	0.5		44.1	20
12	10:10:00 AM	90	15	26.71	0.49		49	19.6
13	10:25:00 AM	105	15	27.68	0.32	Refilling	52.2	12.8
14	10:40:00 AM	120	15	27.38	0.3		55.2	12
15	11:10:00 AM	150	30	26.59	0.79		63.1	15.8
16	11:40:00 AM	180	30	27.47	0.53	Refilling	68.4	10.6
17	12:10:00 PM	210	30	26.8	0.67		75.1	13.4
18	12:40:00 PM	240	30	27.4	0.6	Refilling	81.1	12
19	1:40:00 PM	300	60	26.35	1.05		91.6	**10.5**
20	2:40:00 PM	360	60	27	1	Refilling	101.6	**10**
21	3:40:00 PM	420	60	26	1		111.6	**10**
22	4:40:00 PM	480	60	26.78	1.22	Refilling	123.8	**12.2**
23	5:40:00 PM	540	60	27	1	Refilling	133.8	**10**

K_s= 10 mm/h

Estimation of Hydraulic Conductivity

ROSETTA pedotransfer function (RPTF):

- ✓ Implements five hierarchical pedotransfer functions (PTFs)
- ✓ ROSETTA is based on neural network analyses combined with the bootstrap method
- ✓ The hierarchy in PTFs allows the estimation of van Genuchten water retention parameters and the saturated hydraulic conductivity
- ✓ Using soil texture (Sand %, Clay%, Silt %) and bulk density data



Rosetta data input window

Thank You!!

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NPTEL ONLINE CERTIFICATION COURSES

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Irrigation and Drainage

Lecture No: 39 Agricultural Drainage: Introduction

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What is Drainage?

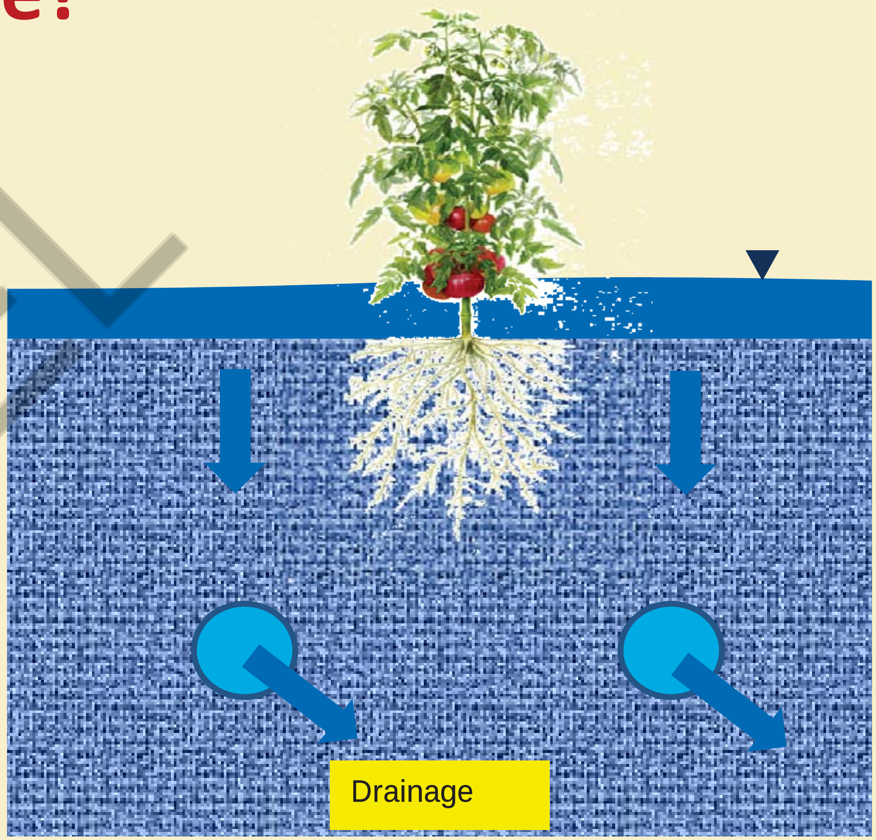
Removal of excess surface and sub-surface water and dissolved salts from the land surface as well as crop root-zone in order to improve the soil condition and enhance crop production.

Surface drainage

Removal of excess water from the land surface by diverting it into natural or constructed surface drains

Sub-Surface drainage

Removal of (i) excess water and (ii) dissolved salt from the crop root-zone through ditches or underground pipes such that water table is lowered, salinity controlled and crop production increased.



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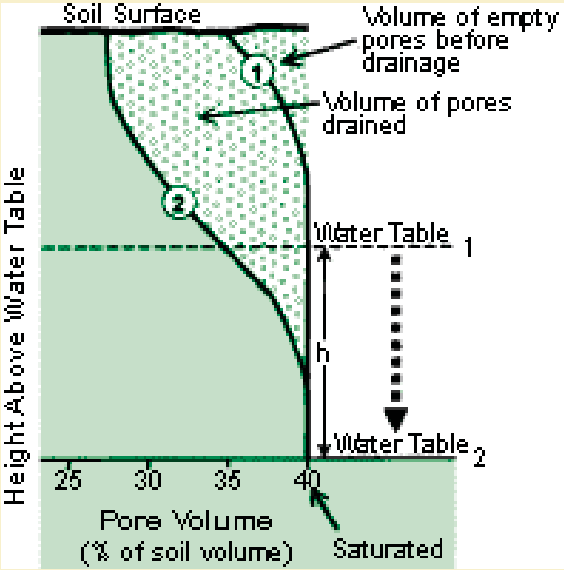
Benefits of Agricultural Drainage

- ✓ Facilitates early ploughing and planting
- ✓ Improves soil structure and maintains productivity
- ✓ Increases cropping intensity
- ✓ Enhances exchange of air between soil and the atmosphere- microbiological activity
- ✓ Increases infiltration capacity of soil- problem of erosion reduces
- ✓ Reduces soil compaction and eases farming operations
- ✓ Minimizes crop damage at the harvest time

Drainable Pore Space (μ)

- ✓ The pore space which drains or fills with a fall or rise of the water table is known as drainable pore space.
- ✓ It is the percentage of air-filled pores present when soil has drained to field capacity
- ✓ Drainable Porosity (μ)= $\frac{\text{Drainable pore water}}{\text{Water table drop}} \times 100$
- ✓ $\mu = Total\ porosity\ - water\ content\ after\ gravity\ drainage$
- ✓ μ value for field soils typically varies from 2-10 %
- ✓ **Drainage intensity or drainage coefficient (mm/d) -** defined as the depth of water that is removed or to be removed per day from a field for successful growth of crop.



Drainable Pore Space (μ)

- ✓ Drainable porosity is influenced by soil texture and structure
- ✓ The drainable water is held by the weakest forces, at moisture contents between field capacity and complete saturation of the soil
- ✓ Subsurface drainage provides a pathway for "excess" or "drainable" water to leave the soil
- ✓ Response of water table depends on the drainable pore space
- ✓ As drainable pore space increases water table level decreases and vice versa

Soil texture	Field capacity (% by vol.)	Wilting point (% by vol.)	Drainable porosity (% by vol.)
Clays, clay loams, silty clays	30-50%	15-24%	3-11%
Well structured loams	20-30%	8-17%	10-15%
Sandy	10-30%	3-10%	18-35%

Drainable Porosity

Example 38.1

How much water is drained from rootzone when water table drops from 6 cm to 48 cm and drainable porosity is 8%?

Solution

$$\text{Drainable Porosity } (\mu) = \frac{\text{Drainable pore water}}{\text{Water table drop}} \times 100$$

Drainable pore water = 8x(48-6)/100 = 3.36 cm

Exercise 38.2:

A soil has saturation moisture content of 37%, field capacity moisture content of 20% (both on dry mass basis) and a dry bulk density of 1.25 g/cm^3. find out the drainable porosity.

Solution:

Given, Bulk density (BD)= 1.25 g/cm^3

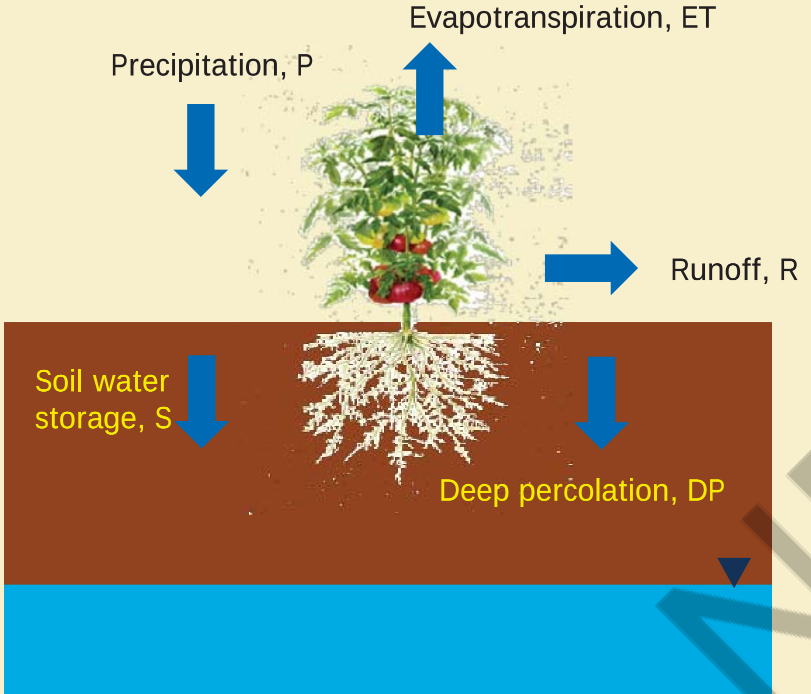
Saturation moisture content (SMC) = 37%

Field capacity (FC)= 20%

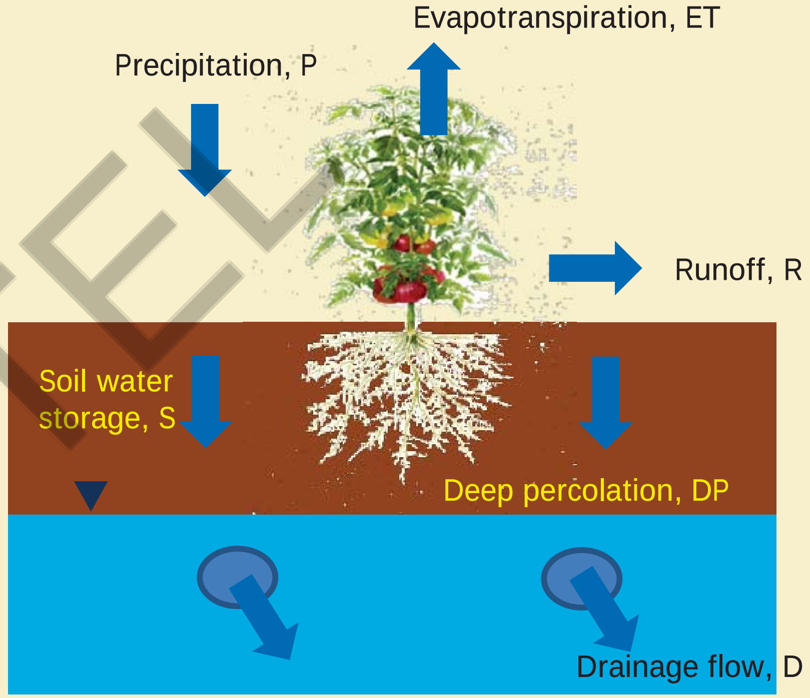
$$Drainable\ porosity = \frac{SMC - FC}{100} \times BD = \frac{37 - 20}{100} \times 1.25 = 0.2125$$

$$= \mathbf{21.25\%}\ \textbf{(Ans.)}$$

Water Balance Equation



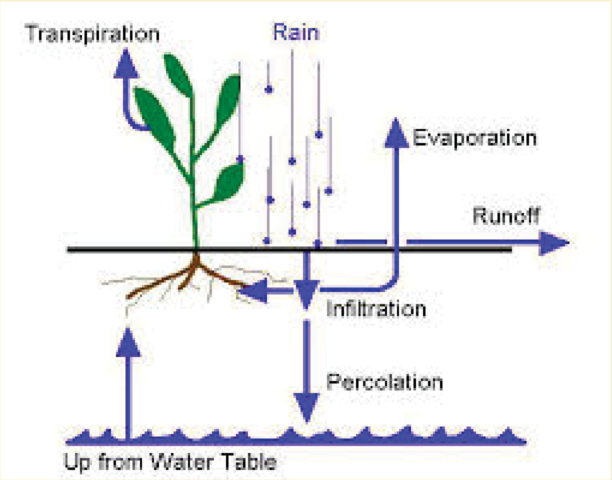
$$P = R + ET + DP + S$$



$$P = R + ET + DP + S + D$$

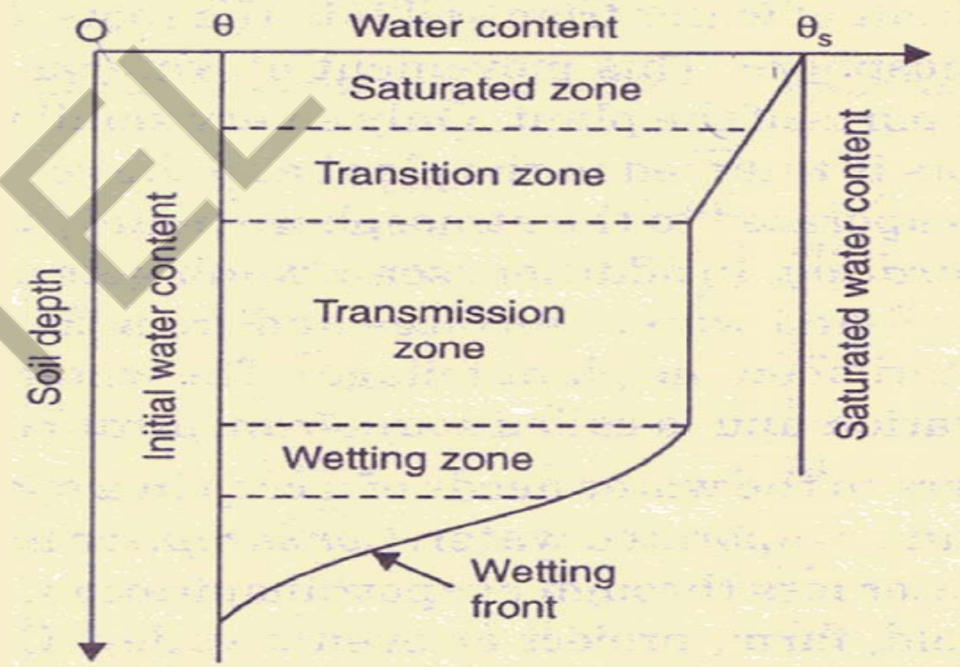
Infiltration and Percolation

- ✓ Related but different processes describing the movement of moisture through soil.
- ✓ **Infiltration:** the downward entry of water into the soil or rock surface.
- ✓ **Percolation:** the flow of water through soil and porous or fractured rock.
- ✓ **Infiltration rate:** the rate at which a soil under specified conditions absorbs rain water, melting snow, or surface water expressed in depth of water per unit time.
- ✓ **Percolation rate:** the rate at which soil moisture moves down through the soil or permeable rock.
- ✓ Darcy's law applies to the infiltration of the water into soil.



Infiltration and Percolation

- ✓ Water enters the soil under gravitational or pressure gradient.
- ✓ Pressure gradient is initially stronger due to the presence of air in the pore space and negative suction.
- ✓ The wetting front moves slowly downwards.
- ✓ As the infiltration continuous, the flow path becomes larger and the pressure gradient becomes smaller.



Moisture zones during infiltration.

Concept of Agricultural Drainage

- ✓ Agricultural drainage is primarily concerned with the free groundwater found in or directly below the soil layers (phreatic groundwater).
- ✓ When the phreatic groundwater occurs deep below the soil surface (25-50 m) it is a little concern to agricultural drainage (arid and semi-arid regions).
- ✓ Shallow groundwater depth (<5-10 m) has much more relevance to agricultural drainage.
- ✓ Objective of the drainage is to remove excess water from the field.
- ✓ Excess water is not always harmful, when
  - o The quantity is very small
  - o Periods of occurrence are of short duration
  - o Occurs during a non-critical season (off season)
- ✓ Lands only need artificial drainage when large quantity of water falls on longer duration.

Problems of Drainage

- ✓ Excess water may occur
  - o On the land surface (surface ponding, water logging)
  - o In the root zone (impeded percolation, shallow groundwater)

a) **Impaired crop growth:**

- ✓Effects crop respiration
- ✓Effects nutrient uptake
- ✓Increases toxicity

- ✓ Root zone aeration generally becomes inadequate when the air filled volume in the main root zone falls below 5-10 %.
- ✓ The effect is influenced by different stages of crop growth and crop health.

- ✓ Crops suffer much more from water logging under warm than the cold condition.
- ✓ Indirect effects of water logging:
  - o Soil biota (Ceases microbial activity – nitrogen deficiency)
  - o Soil structure (Snow formation –frost heaving)

b) Impaired farm operations (soil workability)

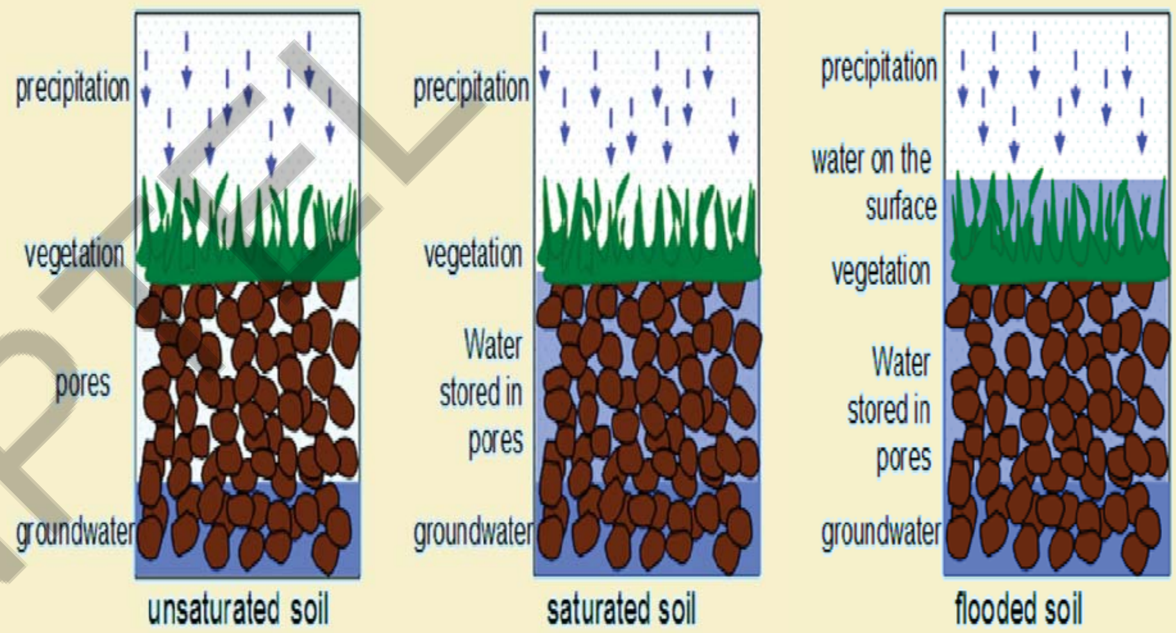
- ✓ Fewer working days on poorly drained soils.
- ✓ Compaction, puddling of soil – soil structure disturbs.
- ✓ Operation of modern machinery becomes very difficult in water logged soils (harvesters).

Other problems of drainage:

- ✓ ***Flooding***: River and coastal plain may be flooded due to high river flows
- ✓ ***Erosion by runoff***: lands having slopes greater than 1-2% will be effected by erosion.
- ✓ ***Soil salinization***: salt accumulation due to irrigation

Sources of Excess Water:

- ✓ Direct rainfall
- ✓ Snow melting
- ✓ Irrigation
- ✓ Seepage
- ✓ Runoff and flood water
- ✓ The Drainage load depends on
  - o Amount of rainfall (P)
  - o Storage capacity of the soil (S)
  - o Rate of evaporation (E)



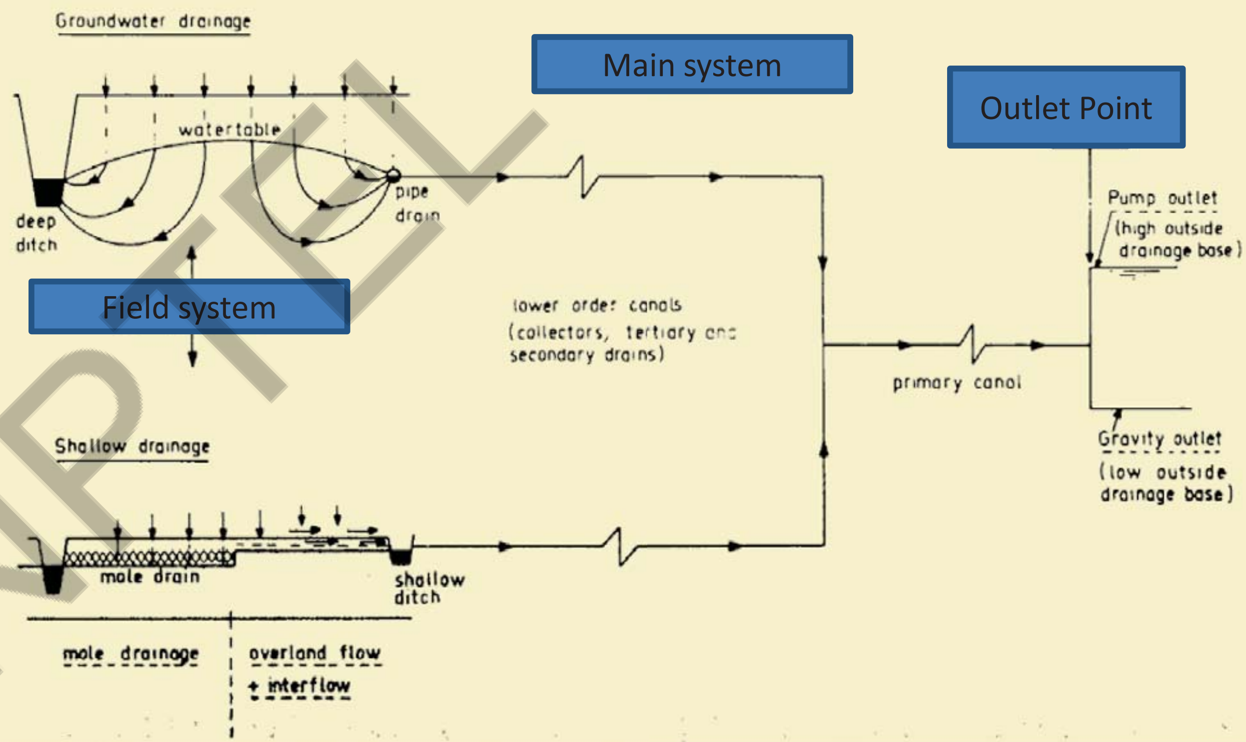
Components of Drainage System

An agricultural drainage system commonly consists of:

1. A Field Drainage System

- Gathers excess water from the land by means of network of field drains

- Two principle types
  - Ground water drainage system (subsurface drainage)
  - Shallow drainage system (surface drainage)



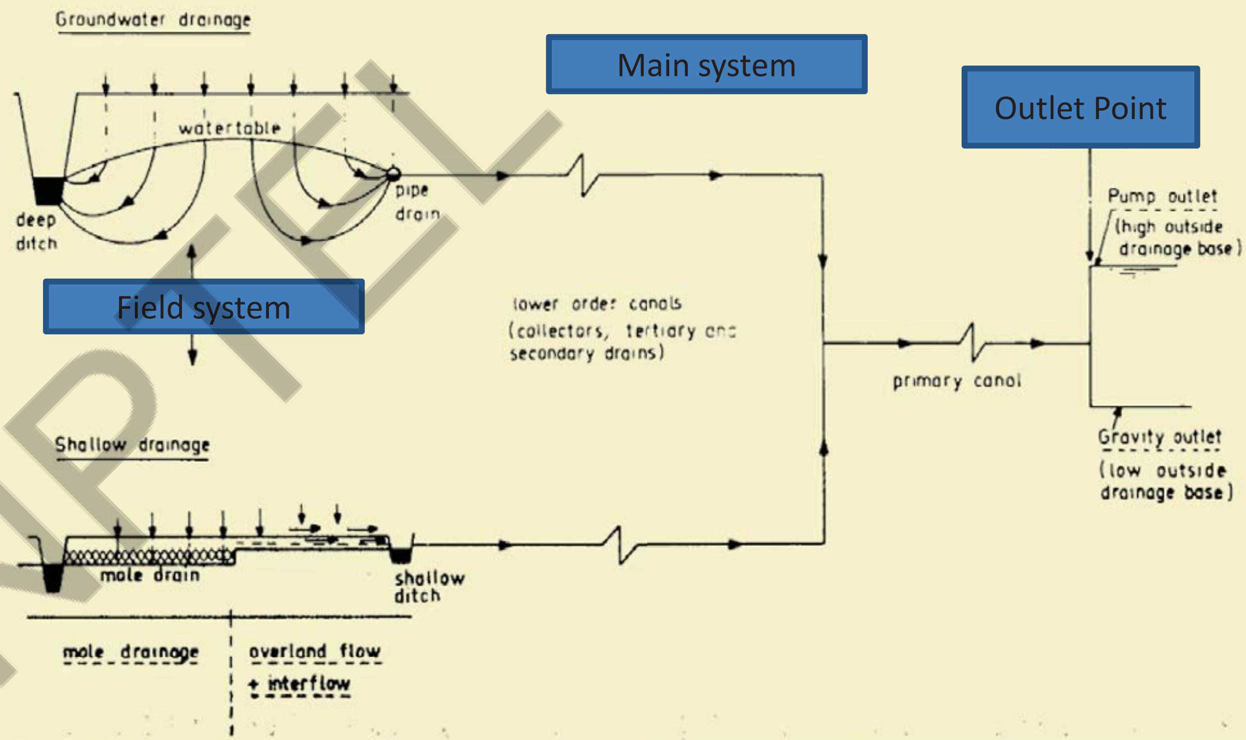
Components of Drainage System

2. A Main Drainage System

- Receives water from field system and convey it to outlet
- Composed of ditches and canals

3. An Outlet

- Terminal point of discharge into open water system
- Pump outlet
- Gravity outlet



Drainage Requirements

- ✓ Benefits vs cost (better yield with low cost)
  - o Improved crop condition (yield)
  - o Improved workability
- ✓ Low level farms does not recommend high cost drainage – installation of pipe drainage system.
- ✓ Soil and climate conditions together with farm system determine the economic scope for the drainage improvements
- ✓ Crop selection based on the soil drainability
- ✓ Planning of farm calendar so as to avoid critical farm operations

Thank You!!

Irrigation and Drainage

Lecture No: 40 Tutorial: W8

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Example W8.1:

If an irrigation water source has the concentrations of Na^+, Ca^{++} and Mg^{++} as 28, 10 and 5 milliequivalents per litre, respectively, then the Sodium adsorption ratio (SAR) of this water is **(Gate 2015)**

Solution:

Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

$$SAR = \frac{28}{\sqrt{\frac{10+5}{2}}}$$

$$= \mathbf{10.22\ milliequivalents\ per\ litre}$$ **(Ans.)**

Example W8.2:

A tile drainage system draining 12 ha flows at the design capacity for two days in response to a storm. If the system is designed using a drainage coefficient of 1.25 cm, the amount of water removed from the drainage area during two days is **(GATE 2008)**

Solution:

Given, A= 12 ha = 12×10^4 m^2

drainage coefficient = 1.25 cm=0.0125 m

$$Drainage\ coefficient = \frac{Q}{A}$$

$$0.0125 = \frac{Q}{12 \times 10^4} = 1500$$

$$= \mathbf{1500\ m^3/day}$$

= 3000 m^3 in two days

Example W8.3:

A soil has a field capacity of 25%, permanent wilting point of 11% and apparent specific gravity of 1.6. Irrigation is applied after depilation 40% of the available moisture to crop with root zone depth 600 mm, electrical concavity of the saturation extract of the soil is 10 mmho/cm and that of the irrigation water is 2.5 mmho/cm. Determine the leaching requirement and the total depth of the irrigation. **(GATE 1998)**

Solution:

Given,

Field capacity (FC)= 25%

Permanent welting point (PWP) =11%

Specific gravity (SG)= 1.6

Root zone depth (RZ) = 600 mm

Electrical conductivity of the saturation extract of the soil = 10 mmho/cm

Irrigation water Electrical conductivity = 2.5 mmho/cm.

$$Moisture\ content\ at\ the\ time\ of\ irrigation = (FC - PWP) \times depleation\ in\ moisture$$

$$Moisture\ content\ at\ the\ time\ of\ irrigation = (25 - 14) \times 0.4$$

$$= 19.4\%$$

$$Irrigation\ requirment = \frac{(FC - PWP) \times SG \times RZ}{100}$$

$$Irrigation\ requirment = \frac{(25 - 19.4) \times 1.6 \times 0.6}{100}$$

$$Irrigation\ requirment = \frac{5.376}{100}$$

$$Irrigation\ requirment = 0.05376\ \text{m}$$

$$LR = \frac{EC_{iw}}{5 \times EC_{ew} - EC_{iw}}$$

$$LR = \frac{2.5}{5 \times 10 - 2.5} = 0.053$$

$$Depth\ of\ water\ applied\ (AW) = \frac{Irrigation\ reuirment\ (IR)}{1 - LR} = \frac{5.376}{1 - 0.053}$$

$$= \mathbf{5.68\ cm\ (Ans.)}$$

Example W8.4:

An agricultural soil contains 47% pore space, and the moisture content after gravity drainage is 39% (by volume). Find the void ratio, drainable porosity, and drainable water volume from a 20 m × 15 m plot having 1.0 m root zone depth.

Solution:

Given,

$\text{Volume of void} = 47\%$

$\text{water content after gravity drainage} = 39\%$

We know, $\quad void\ ratio = (volume\ of\ void/volume\ of\ solid)$

$$= volume\ of\ void/(100 - volume\ of\ void)$$

$$= 47/(100 - 47)$$

$$= \mathbf{0.886}$$

$$Drainable\ porosity\ =\ total\ porosity\ -\ water\ content\ after\ gravity\ drainage$$
$$=\ 47\ -\ 39$$
$$=\ \mathbf{8\%}$$

$$Drainable\ water\ volume\ =\ drainable\ porosity\ \times\ drainable\ soil\ volume$$
$$=\ (8/100)\ \times\ (20\ \times\ 15\ \times\ 1\ m^3)$$
$$=\ \mathbf{24\ m^3}\ \textbf{(Ans.)}$$

Example W8.5:

Runoff water from the watershed enters into a drainage area for 5 hours at the rate of 24 m^3/s. The total rainfall during 24 h periods is 10 cm and infiltration during the same periods is 2 cm. If the total drainage area is 500 ha and the crop can tolerate a ponding of 14 cm, calculate the drainage coefficient of the land.

Solution:

$$Total\ volume\ entering\ the\ area\ in\ 5\ hours\ = 5 \times 3600 \times 24 = 432000\ \mathrm{m}^3$$

$$This\ is\ equivalent\ to\ a\ depth = \frac{432000}{500 \times 10000} = 0.0864\ m$$

$$= 8.64\ cm$$

$$Total\ depth\ input\ on\ the\ area\ = (10 - 2) + 8.64$$

$$= 16.64\ cm$$

Therefore,

$$Depth\ of\ water\ to\ be\ removed$$
$$= depth\ input - depth\ of\ infiltration - depth\ of\ ponding\ allowed$$
$$= 16.64 - 14$$
$$= \mathbf{2.64}\ \boldsymbol{cm}\ \textbf{(Ans.)}$$

This is the drainage co-efficient of the land

Thank You!!