

CHAPTER – 4

Soil Water Relationship

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LECTURE 10



Introduction

Root zone (depth of soil penetrated by roots) soil provides the storage reservoir which needs to be periodically recharged.

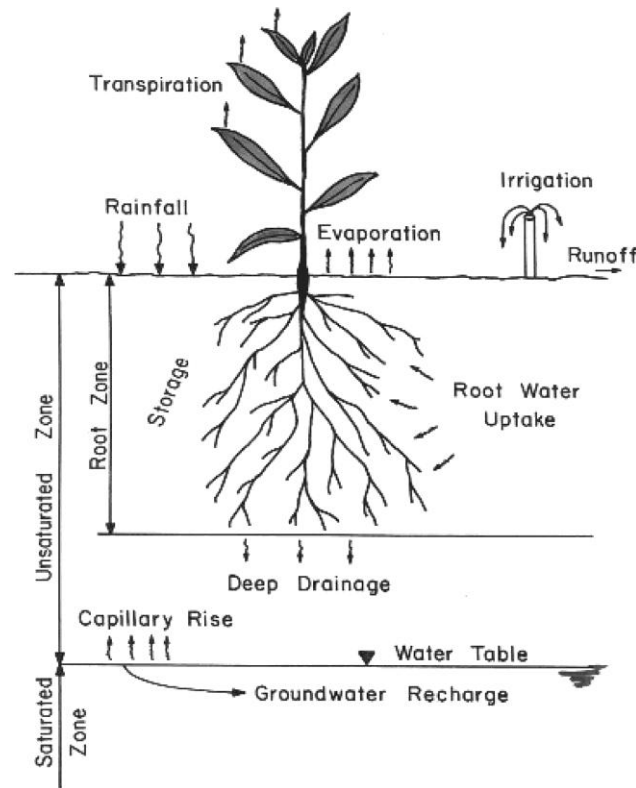
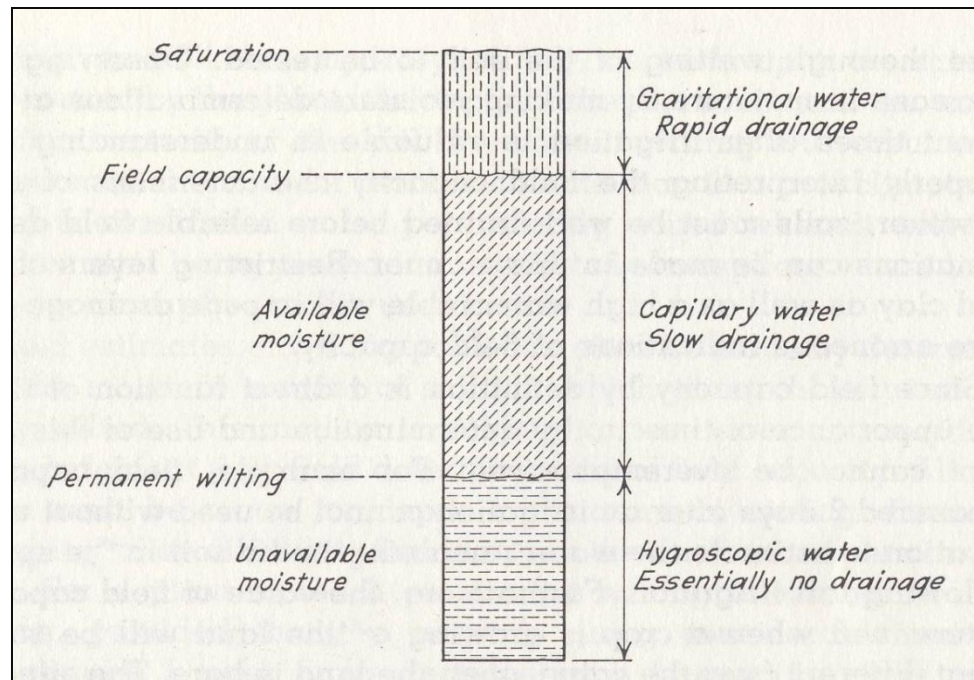


Fig: Schematic diagram of the sub-processes linked to field irrigation system

Classes and availability of soil water

- **Gravitational water:** Water moves freely in response to gravity.
- **Capillary water:** Water held by surface tension in the pore spaces.
- **Hygroscopic water:** Water held tightly to the surface of the grains by adsorption.



Field Capacity (FC):

The water content of the soil when gravitational water has been removed

- It represents the upper limit of available soil water range
- It is determined two days after an irrigation or thorough wetting. Limitations are: restricting layers, high water table, surface evaporation, consumptive use by crops
- Water content corresponding to a soil-moisture of 1/10 atm for sandy soil to 1/3 atm for silty or clay soil

Permanent Wilting Point (PWP):

The moisture content at which plants permanently wilt

- Wilting depends on the rate of water use, depth of root zone and water holding capacity of soil
- It is the lower end of available moisture range
- Water content corresponding to soil-moisture tension of 15 atm
- As an approximation, PWP can be estimated from:

$$\text{PWP} = \frac{\text{FC}}{\left[\begin{array}{c} \text{to } 2.4 \end{array} \right]}$$

Available Water (AW):

The difference of water content of the soil between field capacity and permanent wilting point

$$AW = FC - PWP$$

- ❑ It represents the moisture which can be stored in the soil for subsequent use by plants
- ❑ The moisture near the wilting point is not readily available to the plant. The portion of the available moisture which is most easily extracted by plants is termed as readily available moisture.
- ❑ Irrigation water should be supplied as soon as the moisture falls upto optimum level. The optimum level represents the maximum deficiency upto which the soil moisture may be allowed without any fall in crop yields.
- ❑ The amount of irrigation should be just enough to bring the moisture content upto its field capacity making allowance for application losses

Soil moisture content

(a) Moisture content by mass: $\theta_m = \frac{\text{Mass of water}}{\text{Mass of dry soil}} = \frac{M_w}{M_s}$

(a) Moisture content by volume: $\theta_v = \frac{\text{Volume of water}}{\text{Bulk volume of soil}} = \frac{V_w}{V_b}$

θ_v is more useful, since it represents the equivalent depth of water per unit depth of soil

$$\theta_v = \frac{d_w}{D_s} \Rightarrow d_w = \theta_v \times D_s \text{----- (i)}$$

Again, $\theta_v = \frac{V_w}{V_b} = \frac{\frac{M_w}{\rho_w}}{\frac{M_s}{\rho_b}} = \theta_m \times \frac{\rho_b}{\rho_w} = \theta_m \times A_s \text{----- (ii)}$

From equation (i) \Rightarrow

$$d_w = \theta_m \times A_s \times D_s$$

Soil moisture tension

- ❑ In saturated soils, water is held in the soil matrix under negative pressure due to attraction of the soil matrix for water
- ❑ Instead of referring to this negative pressure the water is said to be subjected to a tension exerted by the soil matrix
- ❑ The tension with which the water is held in unsaturated soil is termed as soil-moisture tension, soil-moisture suction. It is usually expressed in atmospheres, the average air pressure at sea level. Other pressure units like cm of water or cm or mm of mercury are also often used.

(1 atmosphere = 1023 cm of water = 76 cm Hg)

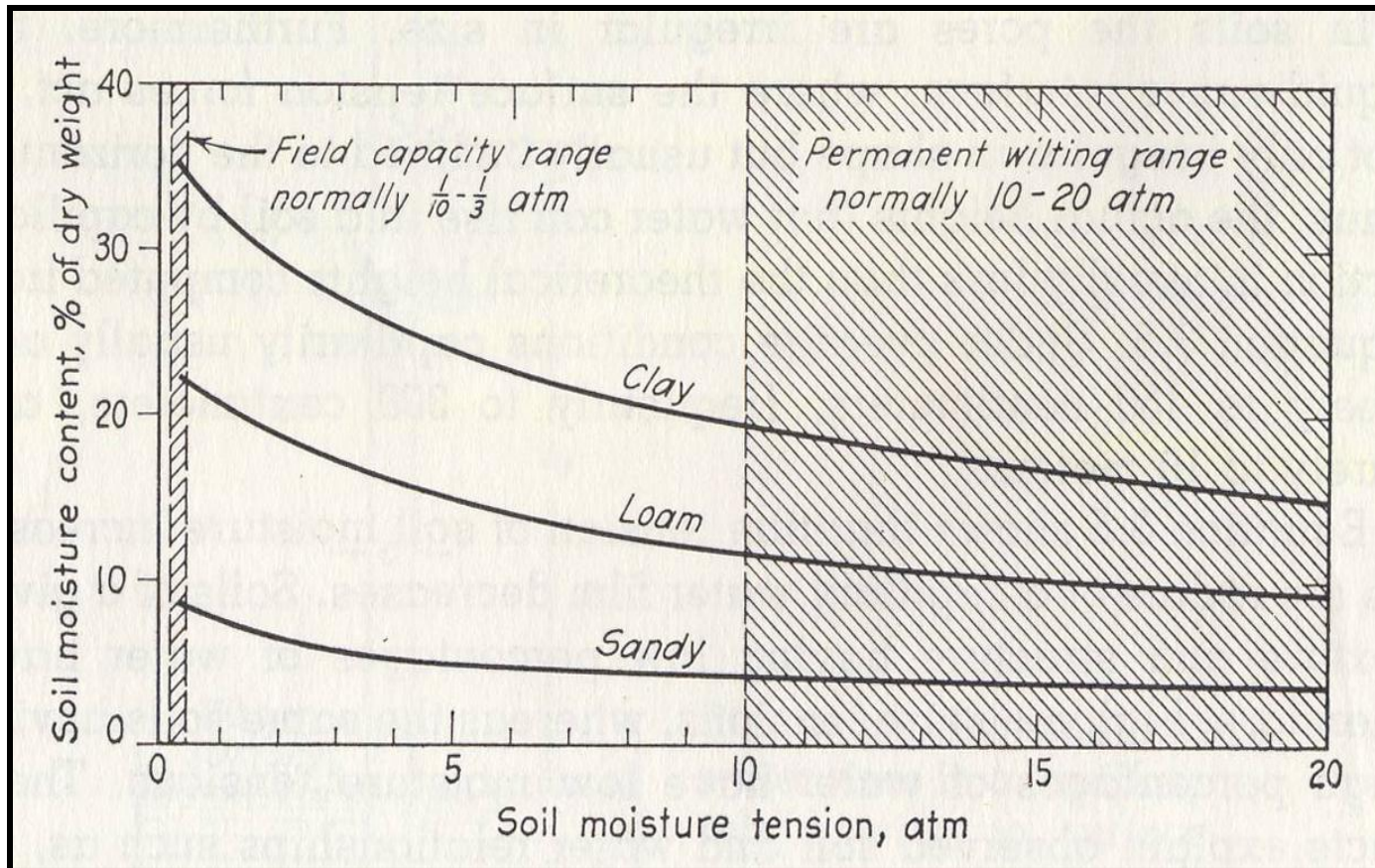


Fig: Typical curves of soil moisture variation with tension

Soil moisture characteristics

Moisture extraction curves, also called moisture characteristics curves, which are plots of moisture content versus moisture tension, show the amount of moisture a given soil holds at various tensions.



A knowledge of the amount of water held by the soil at various tensions is required in order to understand the amount of water that is available to plants, the water that can be taken up by the soil

Soil moisture stress

- ❑ In many irrigation soils, the soil solution contains an appreciable amount salts. The osmotic pressure developed by the soil solution retards the uptake of water by plants.
- ❑ Plant growth is a function of the soil moisture stress which is the sum of the soil moisture tension and osmotic pressure of soil solution.
- ❑ For successful crop production in soils having appreciable salts, the osmotic pressure of the soil solution must be maintained as low as possible by controlled leaching and the soil moisture tension in the root zone is maintained in a range that will provide adequate moisture to the crop.

Measurement of soil moisture

Objective or importance:

- To determine the time and amount of irrigation
- To estimate evapotranspiration/use rate

Methods:

- (a) Appearance and feel method
- (b) Gravimetric Method
- (c) Electro-resistance blocks
- (d) Tensiometer
- (e) Neutron method

Appearance and feel method

- Using the soil auger, soil samples throughout the root zone are collected.
- By looking and feeling the sample, soil moisture deficiency is determined using guideline
- Not precise and it requires experience and judgment
- Simple, quick and it requires no equipment except soil auger
- In many applications, greater accuracy is not needed, nor is it justified economically.

Gravimetric Method

- ❑ This method is used for primary measurement
- ❑ It involves weighting a sample of moist soil, drying to a constant weight at a temperature of $105^{\circ} \sim 110^{\circ}\text{C}$, and re-weighting. Usually 24 hours are required for drying.
- ❑ Most accurate and direct method
- ❑ Destructive, labor intensive and time consuming; several samples are required to obtain a satisfactory representative indication of moisture content.

Electro-resistance blocks

- ❑ The porous blocks (gypsum) are calibrated against a range of moisture. The blocks containing desired electrical elements are placed in the field of at required depth.
- ❑ As the moisture content of the blocks changes, the electrical resistance also changes
- ❑ The gypsum blocks are soluble and deteriorate in one to three seasons of use.
- ❑ Normally there is considerable variation between blocks and considerable changes occur in the calibration during the season

Tensiometer

- ❑ A porous ceramic cup filled with water is attached to a vacuum gauge or mercury manometer.
- ❑ A hole is bored or dug to a desired depth; a handful of loose soil is placed into the hole, and the cup pushed firmly into the soil. The water inside the cup comes into hydraulic contact through the pores in the cup. When initially placed in the soil, water contained in the tensiometer is generally at atmospheric pressure. Soil water, being generally at sub-atmospheric pressure, exercises a suction which draws out a certain amount of water within the tensiometer, thus causing a drop in its hydrostatic pressure. This pressure is indicated by the manometer or vacuum gauge.
- ❑ Tensiometer is effective upto a tension of 0.8 bar. At this pressure air enters the closed system through the pores of the cup and makes the unit inoperative.

Tensiometer..... ..continue

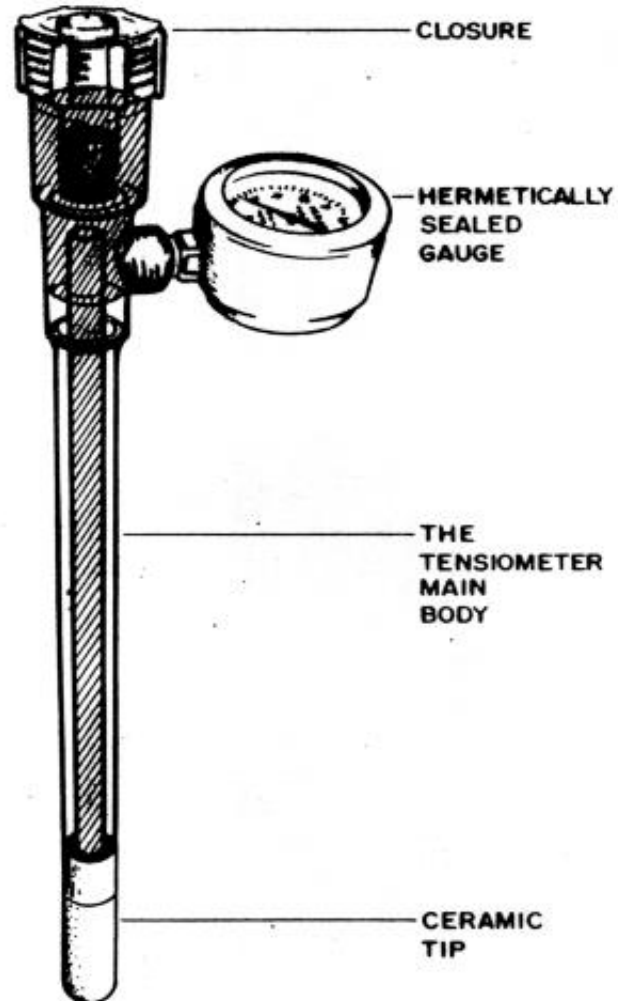


Fig: The essential parts of a tensiometer

Tensiometer..... ...continue

- ❑ Tensiometer readings are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special moisture-characteristic curve for the particular soil is needed to convert moisture tension measurements into available moisture percentage.
- ❑ Tensiometers are less well suited to use in fine-textured soils in which only a small part of the available moisture is held at a tension of less than 1 atmosphere.
- ❑ Since the unit operates satisfactorily only up to tensions of 0.8 atm, they are most useful in sandy soil, where this represents a major portion of the available water.
- ❑ Because of its narrow range of application the tensiometer is used for moist and resistance blocks for dryer soil conditions. Sometimes a combination of tensiometer and resistance blocks is used.

LECTURE 11



Neutron Method

- A hole is dug with an auger, and a metal tube is driven into the hole to retain the soil. The neutron source and counting device are lowered to the desired depth.
- Fast neutrons emitted from the source and slowed down by water in the surrounding soil. The resulting slow neutrons which reach the counting tube are recorded. Fast neutrons are not registered by the counter.
- The greater the water content of the soil, the greater is the number of slow neutrons reaching the counting tube.

Neutron method..... ..continue

□ There exists a good correlation between moisture content and the number of slowed down neutron reaching the counter.

$$\theta_v = (a + b) \frac{R_s}{R_{st}}$$

Where, a and b are calibration coefficient

R_s = Count rate in the soil

R_{st} = Standard count rate

It measures θ_v directly

It is expensive, can not be used to measure near the surface because of boundary effect and possible radiation hazard, and needs calibration

Flow of water through soil

Energy in fluid is in two forms:

- Kinetic Energy
- Potential Energy consisting of
 - Energy resulting from pressure difference
 - Energy resulting from elevation difference

Widely used Bernoulli's Energy Equation, showing energy per unit mass of fluid:

$$H = z + P/\gamma + V^2/2g$$

Since the velocity through soil is very small, the term $V^2/2g$ can be ignored. Thus,

$H = z + P/\gamma$ is called the piezometric head or hydraulic head

Flow of water in soil occurs in the direction of decreasing piezometric head.

Pressure head is due to adsorptive and capillary forces in unsaturated soil; elevation head due to gravitational potential.

Darcy's law relates velocity to head loss:

$$V = k (h_L/L)$$

Where,

V = Flow velocity

k = Co-efficient of permeability or hydraulic conductivity

h_L/L = Hydraulic gradient or slope of H.G.L

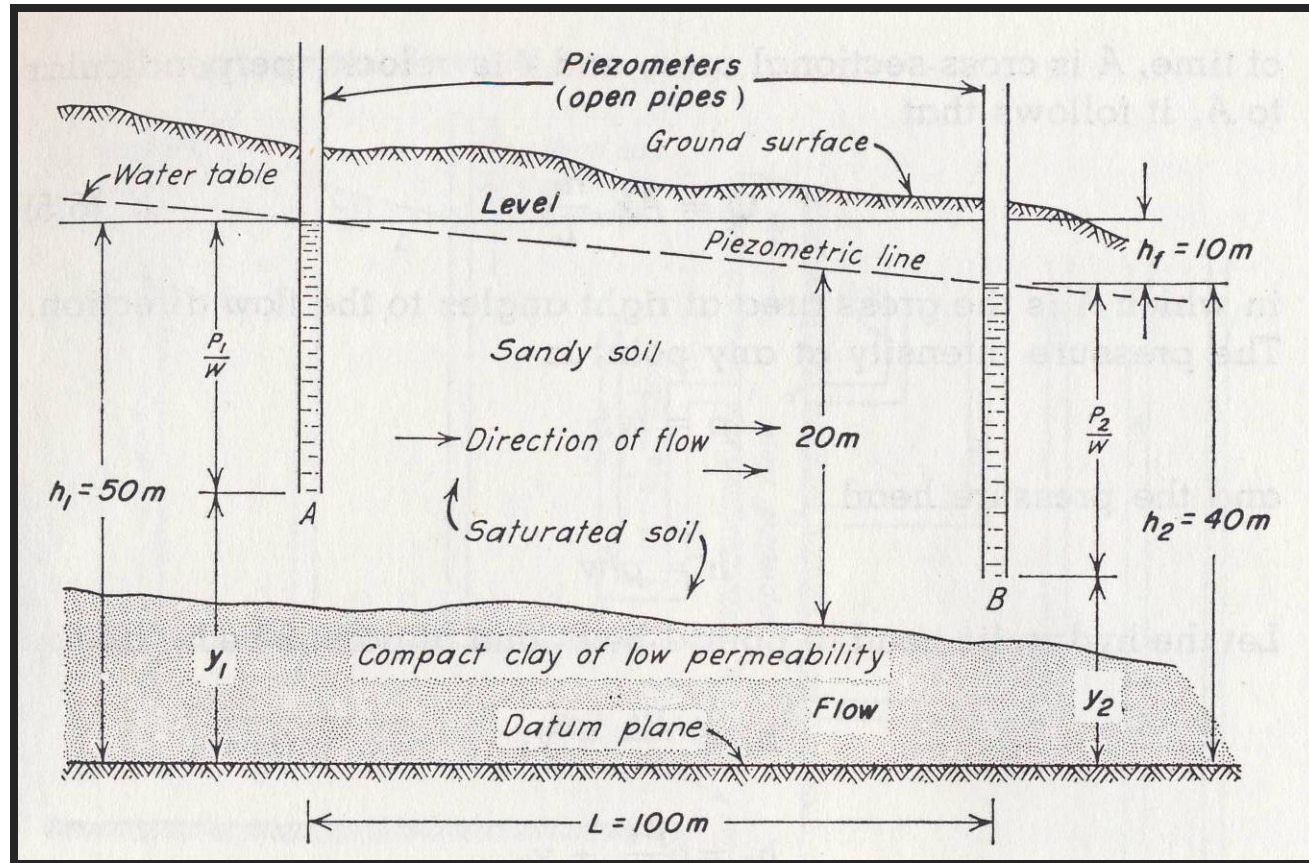
The hydraulic head h can be measured by piezometer in saturated soil and by tensiometer in unsaturated soil.

The quantity of flow,

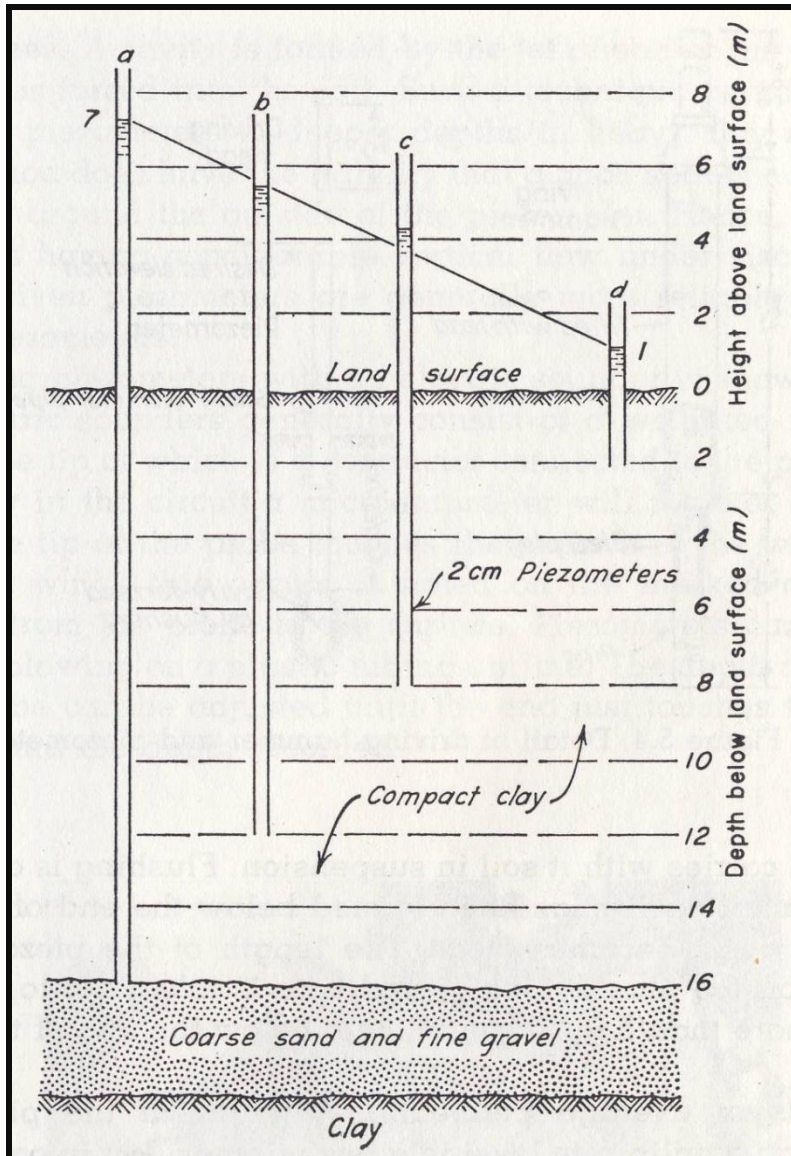
$$\begin{aligned} Q &= AV \\ &= A k (h_L/L) \end{aligned}$$

Where, A = Gross area at right angles to flow direction

Flow of unconfined ground water:



Flow of confined ground water:



$$\frac{h_L}{L} = \frac{h_a - h_d}{L} = \frac{6+7}{16-2} = \frac{13}{14} = 0.93$$

For unsaturated soil, the hydraulic conductivity decreases many folds as the moisture content decreases. Moreover, it is difficult to measure h because tensiometer becomes inoperative when the tension exceeds 0.8 atm. Furthermore, flow occurs in both liquid and vapor phases.

Infiltration/intake characteristics of soil

Infiltration is the time rate of entry of water into soil. Whenever the soil surface configuration influences the rate of entry, the term intake is used.

It has great practical importance: design and operation of water application system, intake rate of fine-textured soil is very low.

Factors influencing infiltration are:

- Initial moisture content
- Condition of soil surface
- Hydraulic conductivity of soil profile
- Depth of water on the surface
- Viscosity/temperature of water
- Soil texture

Infiltration/intake characteristics of soil

The intake rate plotted against time on a logarithmic scale gives a straight line.

$$I = a T^n$$

Where,

I = Intake rate

a = Constant (ordinate at $T = 1$)

n = slope of the line

When the observation of intake extends over long periods, a better representation of the data can be obtained by:

$$I = b + aT^n$$

Since, n is negative, I decreases with an increase in T . I approaches a constant value b as time increases. This value is called final intake rate.

$$I = k \frac{\delta h}{\delta s}$$

Initially I is high because of large difference in tension in addition to gravity, after several hours difference in tension becomes zero and hydraulic gradient equals to unity and I approaches to K_s .

Measuring Intake Rate

- ❑ 25 cm diameter cylinder is driven upto 15 cm below soil surface
- ❑ Water is applied at surface. The radial flow at bottom of cylinder causes great change in intake rate.
- ❑ Two concentric cylinders having same water level are used to create buffer ponds
- ❑ Depth of water for inner cylinder is recorded with time

Cylinder No. 3					
Watch	Time (hr)		Intake (mm)		
	Difference	Cumulative	Depth	Difference	Cumulative
4:15			260		
4:16	1	1	249	11	11
4:18	2	3	242	7	18
4:22	4	7	234	8	26
Refill			271		
4:30	8	15	260	11	37
4:48	18	33	248	14	61
Refill			270		
5:02	14	47	252	8	59
5:29	27	74	248	14	73
6:00	31	105	238	10	83
Refill			280		
6:29	29	134	269	11	94
5:57	28	162	260	9	103
7:23	26	188	253	7	110
7:43	20	208	248	5	115

Intake rate, $I = aT^n$

Accumulated intake,

$$\begin{aligned} D &= \int(I \times dT) \\ &= \frac{a}{n+1} \times T^{n+1} \\ &= C \times T^N \end{aligned}$$

Average Infiltration rate,

$$I_{\text{avg}} = \frac{D}{T} = CT^{N-1}$$

Instantaneous Infiltration rate,

$$I_{\text{inst}} = \frac{dD}{dT} = CNT^{N-1}$$

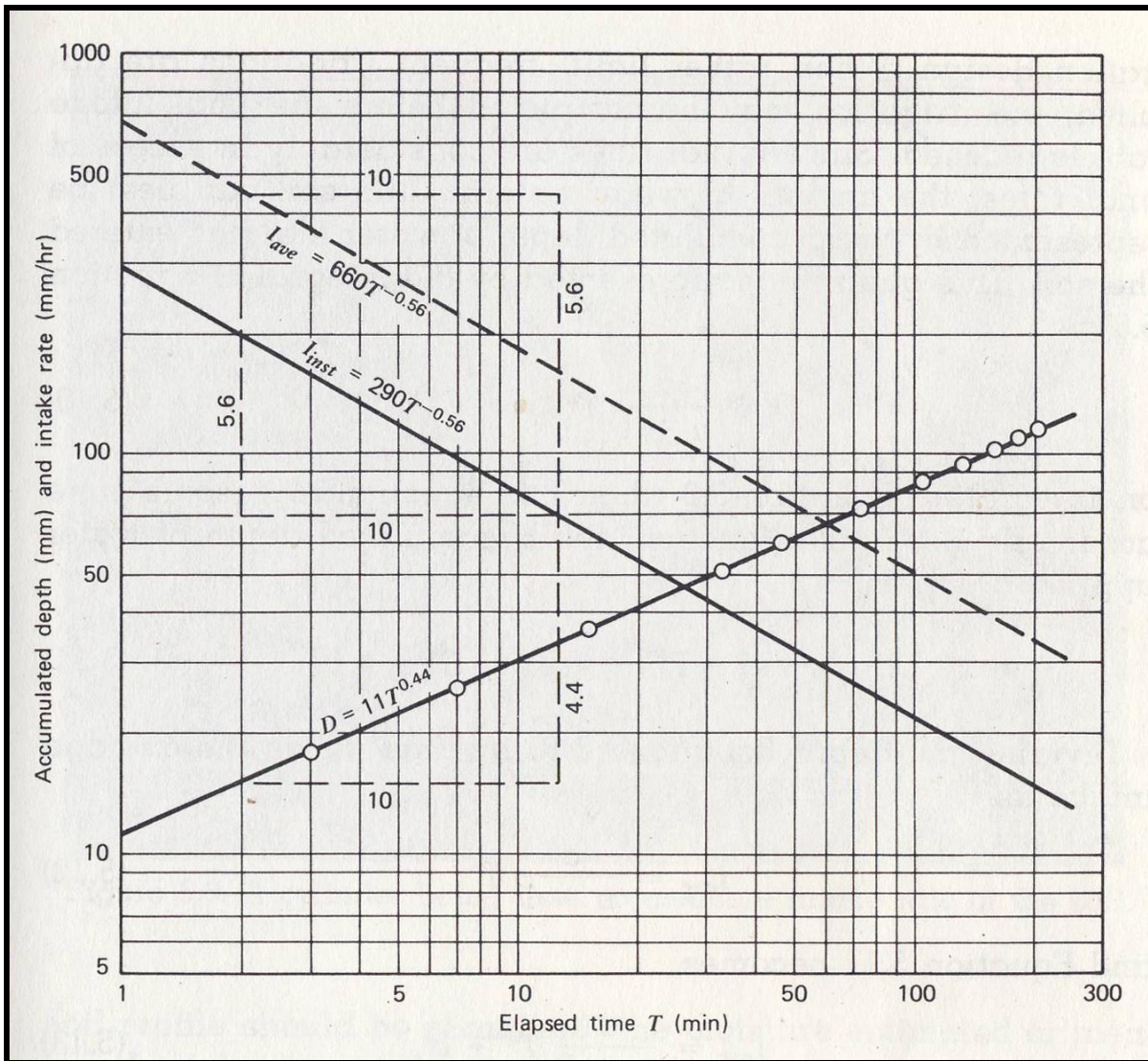


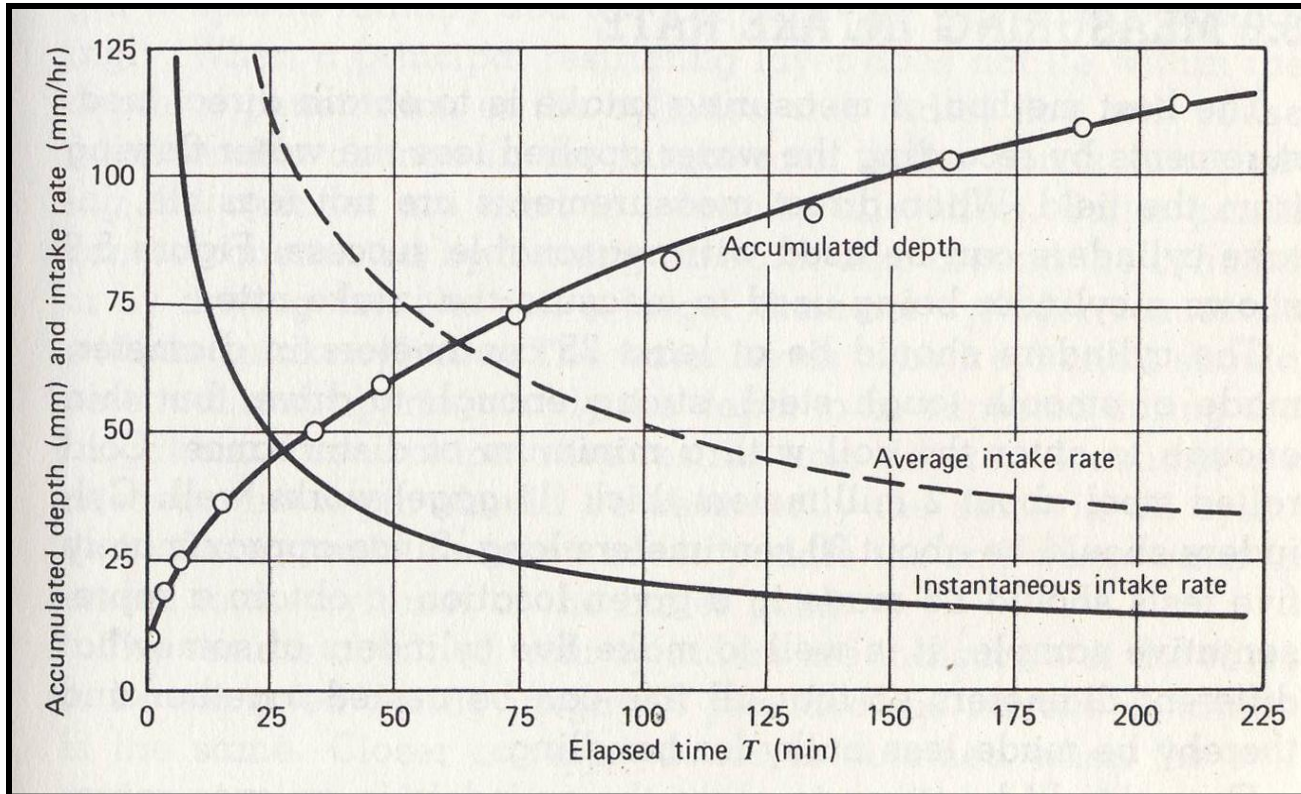
Fig: Typical Intake curves

The slope of the line on log-log plot,
 $N = 0.44$

Hence, $D = 11 T^{0.44}$

$$\begin{aligned} I_{\text{avg}} &= CT \\ &= (11 \ 60) T^{(0.44-1)} \\ &= 660 T^{-0.56} \end{aligned}$$

$$\begin{aligned} I_{\text{inst}} &= CN T^{N-1} \\ &= (11 \ 60) 0.44 T^{(0.44-1)} \\ &= 290 T^{-0.56} \end{aligned}$$



At $T = 1$ min, $D = 11$ mm,

$$\text{so, } D = CT^N$$

$$\Rightarrow 11 = C \times (1)^N$$

$$\therefore C = 11$$

End of Chapter – 4

