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IRRIGATION ENGINEERING

[BTAI 2201]

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Soil Water/Soil Moisture

The soil profile lying below the soil surface up to the impervious strata/bed rock can be divided in to (i) zone of aeration (also called as unsaturated zone) and (ii) zone of saturation.

Soil water is defined as the suspended water in the zone of aeration. It includes

Gravitational water,

Capillary water and

Hygroscopic water.

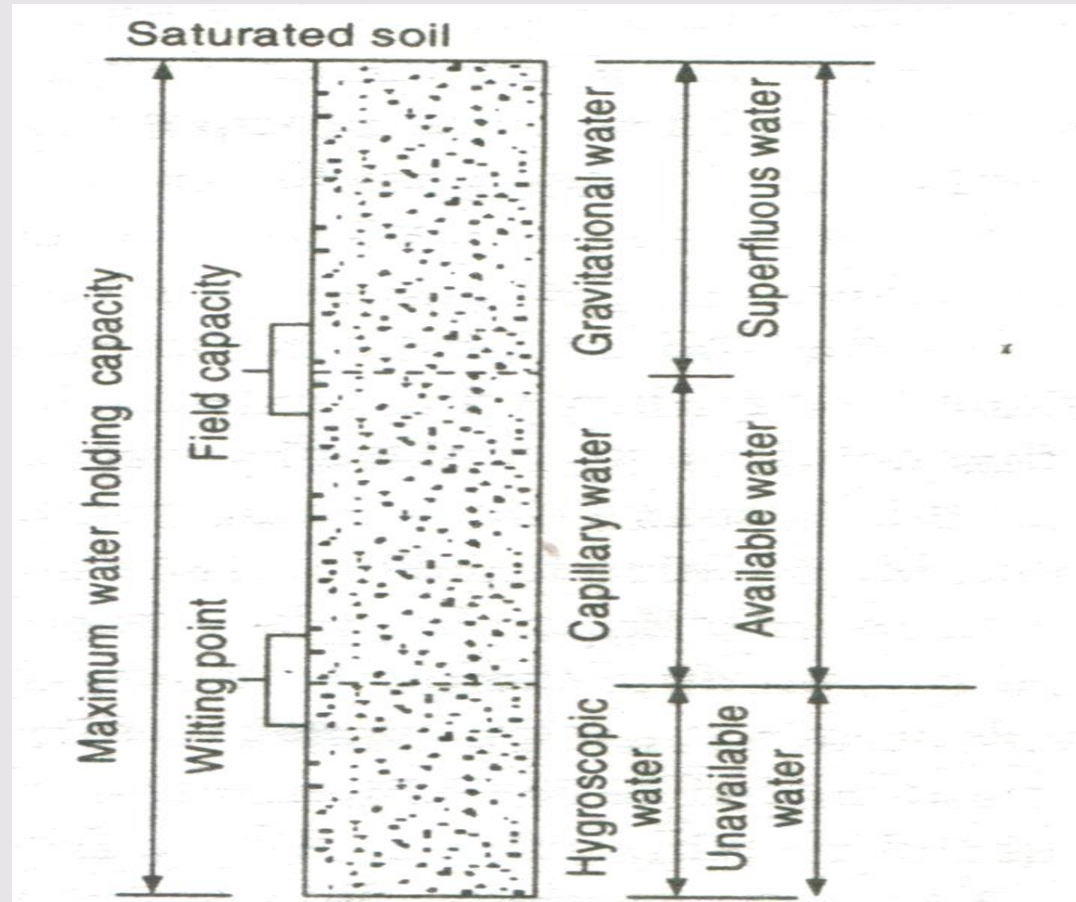
Fig. 6.4 represents the classification of soil moisture.



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Classification of soil moisture





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Zone of aeration is important from the point of view of plant growth. Zone of aeration comprises of (i) soil water belt,

(ii) intermediate belt and

(iii) capillary zone.

Soil water belt refers to the zone of water adjacent to the ground surface consisting of top soil and the sub soil

Gravitational water is the water in the unsaturated zone in excess of hygroscopic & capillary water which moves out of the soil under favourable drainage condition.

Water held in the capillary spaces by surface tension is called as capillary water. This water moves freely under the influences of capillary forces and is available to the plants. Hence the capillary water is also called as available water.

Hygroscopic water is the water held in static state with the atmospheric water vapour. It is not capable of any movement by gravity or capillary forces and hence, is not available for use to plants.



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Saturation and Maximum Water Holding Capacity

In a soil sample, some space is occupied by water & rest is occupied by air. When soil gets wet either because of rainfall or irrigation, macro & micro pores gradually get filled with water & volume of air in soil decreases.

When all pores are filled with water, the air content in void space becomes zero. Under such cases, soil is said to be fully saturated (sometimes simply called as saturated). Degree of saturation of a fully saturated soil is 1.0 (100%).

Thus, for a perfectly dry soil sample there is zero degree of saturation. At saturation, soil moisture potential is maximum i.e. zero & moisture held by the soil is also maximum.

Capacity of the soil to hold moisture at saturation is called as maximum water holding capacity.



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Field Capacity

Field capacity (FC) is defined as the amount of water held by the soil after excess water has been drained away by gravity. At FC, the rate of downward movement of water has been materially decreased to negligible value which takes place two to three days after irrigation.

At FC, the macro pores are filled with air whereas micro pores are filled with water.

FC is the upper limit of available water (0.33 bar).

When crops are to be irrigated, care should be taken such that the soil moisture content comes to FC level and any addition of water beyond FC is a loss since it is drained out to the layer below the crop effective root zone & adds to percolation.



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Permanent Wilting Point (PWP)

PWP refers to the lowest limit of available SMC below which water extraction by a given plant is not sufficient to meet the ET requirement of the plants.

Irrigation to crops is to be provided before this stage reaches. It is to be remembered that PWP is not a fixed point on soil moisture potential curve; rather it refers to a range.

Crops start wilting at matric potential of wilting point varying from -12 to -23 bars. For most of the mesophytes (considering their growth and development), PWP refers to the matric potential of -15 bars.



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Available Soil Moisture (ASM)

As stated earlier, soil water at FC (potential = 0.33 bars) is the upper limit of available soil moisture for the plants. Similarly, soil water at PWP (potential = -15 bars) is the lower limit of available soil moisture. The soil moisture between these two values is called as ASM.



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Readily Available Soil Moisture

Readily available soil moisture sometimes also called as relatively available moisture is that portion of available soil moisture that can be easily extracted by the plants. It varies from 75-80% of the available moisture.

ASM of different soils are given in Table below.



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Soil types	Mechanical composition			Available soil moisture (%)
	Sand (%)	Silt (%)	Clay (%)	
Coarse sand	94	4	2	3
Sand	89	5	6	3
Loamy sand	82	10	8	6
loam	63	22	15	10
Fine sandy loam	59	24	17	12
Loam	40	36	24	17
Sandy clay loam	50	21	29	14
Clay loam	37	28	33	16
Clay	31	23	46	16



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Root Zone Depth

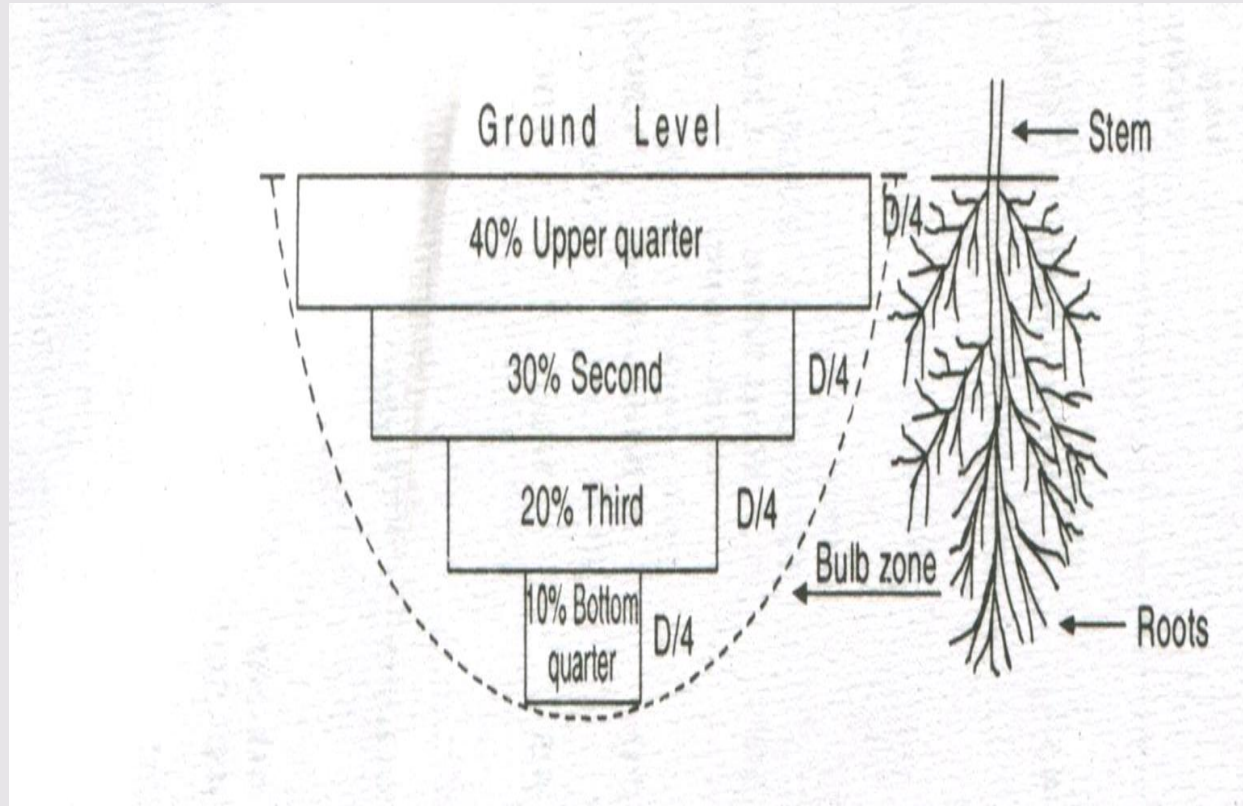
Depth below the ground surface in which the root systems of the plant develop to derive water and minerals from the underneath to prepare food and support growth is called as root zone depth. The root systems of the plants in the root zone may consist of (i) tap roots, (ii) shallow primary roots and (iii) lateral roots.

Crops, in general, develop most of their root systems in the upper most portion of the root zone. Pattern of moisture absorption of the plants varies from layer to layer in a given root zone. The first quarter of this depth uses 40% of the total soil moisture in the root zone whereas the second, third and the fourth quarter uses 30, 20 and 10% of the soil moisture, respectively (Fig. 6.8).



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Soil Water & Crop Yield Response to Soil Water

There are mainly two crop water production functions models available for assessment of soil water deficit affect on yield of dry land crops at different growth stages.

They are

- (i) multiplicative model and
- (ii) additive model.

Again each of the above two mentioned models may be **seasonal or dated**. Out of the various types, **additive dated model** is important. **An additive model of dated crop-water production function** derived from sensitivity factors for water stress in physiological growth stages as proposed by (Rao *et al.*, 1990) is given as:



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$$\frac{Y_a}{Y_p} = 1 - \sum_{tg=1}^{NP} K_{tg} \left(1 - \frac{ET_{crop}}{PET} \right)_{tg}$$

Y_a and Y_p = actual & potential yield of crops, respectively, kg ha^{-1}

K_{tg} = yield response factor for growth stage, tg (FAO 56)

ET_{crop} & PET = actual & potential evapotranspiration, respectively, mm;

tg = growth stage index and

NP = total number of periods for the crop (generally for all crops it is four).



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Following table gives data of actual and potential evapotranspiration and yield response factor of a crop at different growth stages. Find out the percentage reduction of yield due to water stress. If the potential crop yield is 10 q/ha, then find out the actual crop yield?

Growth stages	Potential evapotranspiration, mm	Actual evapotranspiration, mm	Yield response factor
Initial	22.0	20.0	0.5
Crop developmen t	30.0	25.0	0.8
Mid season	35.0	32.0	0.9
Maturity	20.0	15.0	0.5



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Growth stages	Potential evapotranspiration (<i>PET</i>), mm	Actual evapotranspiration (<i>ETcrop</i>), mm	Yield response factor, <i>Ktg</i>	<i>Ktg</i> ($1 - ET_{crop}/PE_T$)
Initial	22.0	20.0	0.5	0.045
Crop development	30.0	25.0	0.8	0.133
Mid season	35.0	32.0	0.9	0.077
Maturity	20.0	15.0	0.5	0.125
Total			0.380	

$$\frac{Y_a}{Y_p} = 1 - \sum_{tg=1}^{NP} K_{tg} \left(1 - \frac{ET_{crop}}{PET} \right)_{tg}$$

$$= 1 - 0.380 = 0.620$$

Hence, the percentage reduction of yield = $(1 - Y_a/Y_p) 100 = 38.0$

If potential yield is 10 q/ha, then the actual yield will be $0.620 \times 10 = 6.20$ q/ha.



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Infiltration

Infiltration is defined as the entry of water into soil through interstices or pores of the soil. It occurs both prior to and during occurrence of surface runoff but decreases with time until a minimum rate of infiltration is reached.

The rate at which infiltration takes place during a rainfall or when irrigation is applied to crop field, expressed in terms of depth of water per unit time (usually mm/hr, cm/hr) is called as infiltration rate. It is equal to the rainfall rate or infiltration capacity whichever is less.

It is maximum at first & gradually decreases with time. The infiltration capacity curve which is a graphical representation of infiltration rate vs. time is an exponential decay curve and indicates that the rate may be zero at infinite time.

A number of factors influences the infiltration capacity namely soil texture, soil structure, vegetation condition, slope, cultivation practices, AMC of soil etc. A number of models in hydrology are available to predict the infiltration rate: most of them are empirical



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Flow of Water into & Through Soils

The total energy (H) of a flowing fluid comprises potential energy, kinetic energy and pressure energy. This is given by Bernoulli's as:

$$H = \frac{V^2}{2g} + \frac{p}{\gamma} + Z$$

Since velocity of flow in soil is very small, kinetic energy head term of above Eq. can be ignored & hence the total energy head (H) is simplified as:

$$H = \frac{p}{\gamma} + Z$$

Head, H in above Eq can be used as in saturated soil by simple piezometer & in unsaturated soil by a tensiometer.



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Piezometer readings can be used to determine direction of flow of water in soil & can also be used to measure hydraulic gradient (i). Knowing hydraulic gradient & permeability of the soil (K), flow velocity in soil can be determined applying the Darcy's law

$$v = K \cdot i$$

Piezometric readings can be helpful to calculate percolation rate in soil in a given layer.

Darcy's Law can also be used to find direction of Groundwater Flow.

$$v = - K \cdot i = - K \cdot \frac{H_L}{L}$$

H_L = difference of piezometric head and

L = difference of elevation head of two piezometers put in soil.



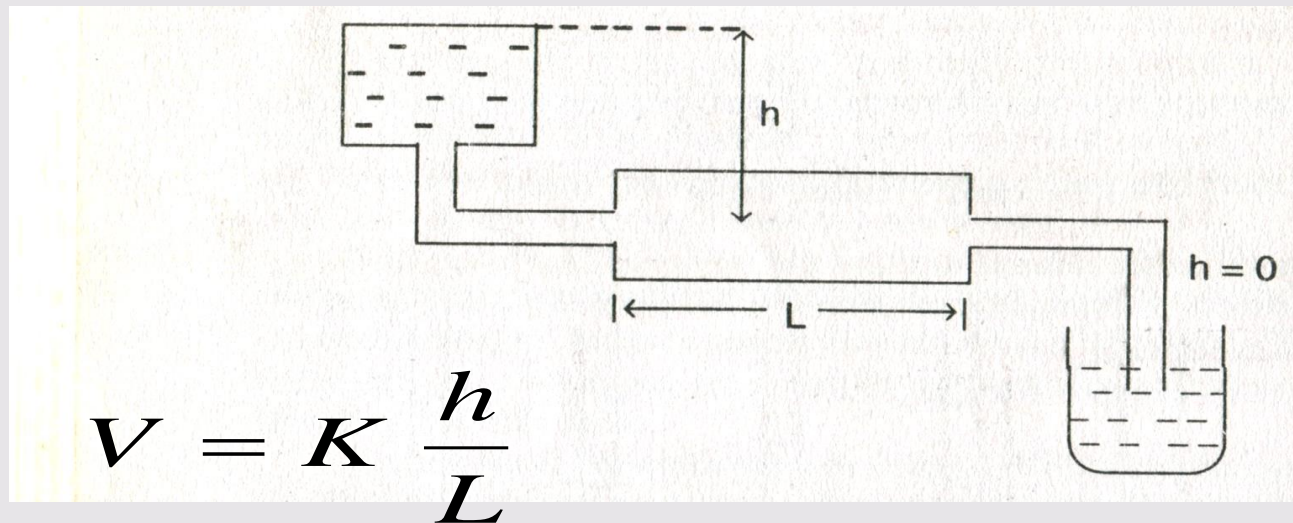
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Using the continuity equation, discharge, Q
as:

$$Q = A V = A K i = A K H_L / L$$

Flow of Water in Horizontal Soil Column in Unsaturated Condition

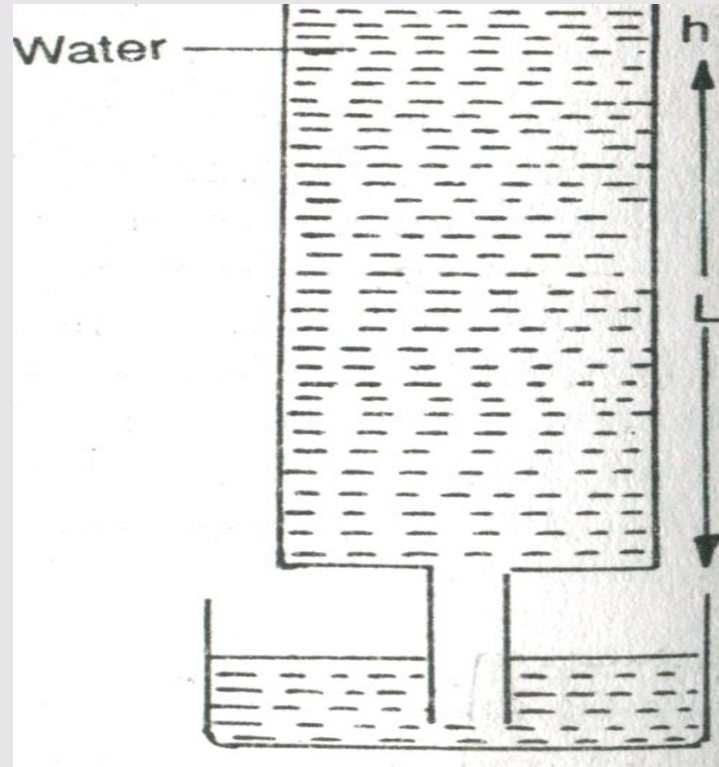




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Flow of Water in Vertical Soil Column in Unsaturated Condition



$$V = K i = K \frac{(h + L)}{L}$$



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