Chapter one

1.0 Introduction

A prime requirement for successfully irrigated agriculture is the **development and maintenance of a soil zone** in which the moisture, oxygen-salt balance is favorable for plant growth. Plants require both moisture and oxygen to live. When saline water table rises and remains in the root zone longer than about 48 hrs, resulting in abnormally high saline moisture condition, agricultural production is usually seriously affected. The presence of oxygen in the interstices of the soil in the root zone is **as necessary as water** for both seed germination and plant growth. Oxygen content is markedly affected by the moisture content of a soil. Soils with initially **low moisture content** normally can be expected to have relatively open pore structure between soil particles, allowing oxygen to freely permeate through the interstices. As the moisture content increases, air in the pores is displaced by water. Once the oxygen has been expelled, the oxygen content recovery rate is extremely slow in the soil. The proper balance between soil moisture and oxygen is maintained to a considerable extent by **adequate drainage.**

A simple but comprehensive definition of **adequate drainage** is the removal of excess water and salt from the soil at a rate which will permit normal plant growth. Adequate drainage may also be defined as the amount of drainage necessary for agriculture to be maintained successfully and perpetually.

1.1 Main classes of soil Water:

The water added to a soil mass during irrigation or otherwise is held in the pores of the soil which is termed as soil water or soil moisture. The soil water may exist in the soil in various forms, on the bases of which it may be classified in the following three categories.

1. Hygroscopic water,
2. Capillary water, and
3. Gravitational water

Hygroscopic Water: is the water which is absorbed by the particles of dry soil from the atmosphere and is held as a very thin on the surface of the soil particles due to adhesion or attraction between surface of particles and water molecules. Below the permanent wilting point the soil contains only hygroscopic water (Fig. 1.1). Since hygroscopic water is held with considerable fore, it cannot be removed easily from the soil particles.

Capillary water: The water content retained in the soil after the gravitational water has drained off from the soil is called capillary water. It is held in the soil by surface tension as a continuous film around the soil particles and in the capillary pores between the soil particles. The capillary water is thus held in the soil against the force of gravity. The plant roots gradually absorb the capillary water which thus constitutes the principal source of water for plant growth. The capillary water supplies the water needed by plants. Hence, it is also designated as plant available water. Main factors that influence the amount of capillary water in the soil are the structure, texture and organic matter content of the soil. A greater amount of water is held by a fine textured soil than by a coarse textured one.

Capillary water is held between tensions of about 31 atmos. and ⅓rd atoms... Between 31 & 15, capillary adjustment is very sluggish, easy movement does not occur until the water film thickens and pressure near ⅓ rd atmos. reaches. The principal factors influencing the amount of the capillary water in the soil are texture, structure & organic matter. Finer the texture has greater its capillary capacity. Water held in the soil at the tension of ⅓ rd atmos. or less will respond to gravity. Of the three forms of the water, only capillary and gravitational water are interest to the irrigation.

Not all the water present in the soil is available for plant use. Some water drains beyond the rooting zone as deep percolation and is unavailable to plants. Soil can be viewed as a sponge composed of air and solid particles when dry. When water is added to soil, the pore spaces begin to be filled with water by pushing the air out. Usually the smallest pores are filled first, followed by the medium-sized, and finally the largest pores. At the point when all the pores are filled with water the soil is said to be ***saturated***. This is an undesirable condition for the growth of most plants because the available dissolved oxygen is quickly depleted. Water at the saturation point in soils is held at a tension of 0 MPa.

Gravitational water: It is that water which is not held by the soil but drains out freely under the influence of gravity. Within the adhesion of water to the soil during irrigation or otherwise, the water content of the soil is raised to a state of saturation. At this point the soil pores are completely filled with water and the soil contains the maximum possible water content, which thus constitutes the upper limit of the gravitational water.

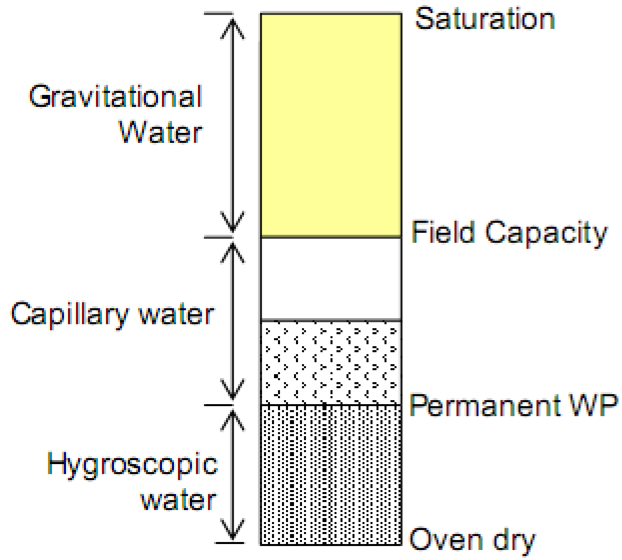

Fig 1.1 Classification of soil water

1.2 SOIL MOISTURE CHARACTERISTICS

Moisture extraction curves, also called **moisture characteristic curves,** which are plots of moisture content **Vs** moisture tension, show the amount of moisture a given soil holds at various tensions. Soil moisture tension depends on the texture, structure and other characteristics of the soil. Acknowledge of the amount of water held by the soil at various tensions is required, in order to understand that amount of water available to plants.

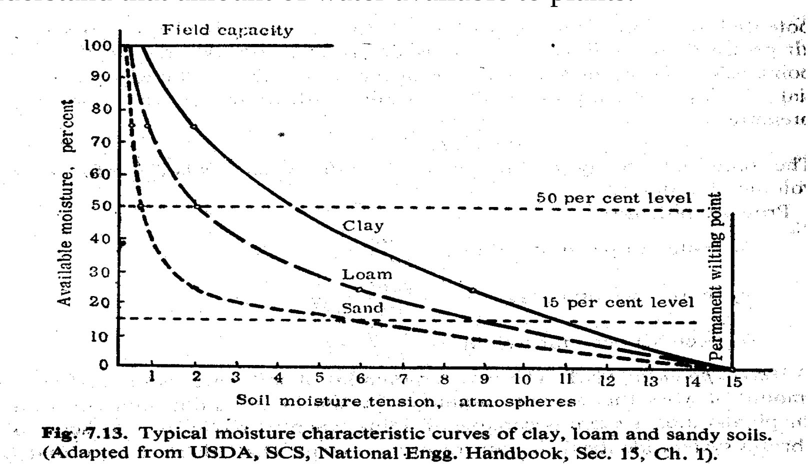

Fig 1.2 soil moisture characteristics curve

1.2.1 Soil Moisture Tension:

It is a measure of tenacity with which water is retained in the soil and shows the force per unit area that must be exerted to remove water from soil. The tenacity is measured in terms of **Potential energy** of the water in the soil, usually with respect to free water. It is usually expressed in **atmospheres** at the average air pressure at sea level.

In wet soil, as long as, there is a continuous column of water, it might be called **Hydrostatic potential,** in the intermediate range, the term **capillary potential** is appropriate. In the dry range, the term **hygroscopic potential** would be suitable. However, the term soil moisture potential, soil moisture suction and soil moisture tension are often used synonymously to cover entire range of moisture.

1.2.2 SOIL MOISTURE CONSTANTS

Soil moisture is always subjected to pressure gradients and vapor pressure differences that cause it to move. Thus, soil moisture cannot said to be constant at any pressure. The following are the certain moisture constants are of particular significance in agriculture.

1. **Saturation Capacity:** When all pores of soil are filled with water, the soil is said to be under saturation capacity or maximum water holding capacity. The tension at saturation capacity is almost **zero** and is equal to free water surface

2. **Field capacity (F.**C): Is the moisture content after drainage of gravitational water and moisture content become stable. At field capacity, the large soil pores are filled with air, micro pores are filled with water. The field capacity is the upper limit of available moisture range in soil and plant relations and moisture tension at field capacity varies from soil to soil, but generally range from $1/10^{th}$ to 1/3 rd atmosphere.

3. **Permanent Wilting Percentage(PWP) :** (Wilting point/ Wilting Coefficient)

   Is the soil moisture content at which plants can no longer obtain enough moisture to meet transpiration requirements, remain wilted unless water is added to soil. The moisture tension of soil at PWP ranges from 7 to 32 atmospheres. 15 atm is the pressure commonly used for this point. The moisture content at which the wilting is complete and the plants die is called **ultimate wilting.**

4. **Available Water:** The soil moisture between field capacity and permanent wilting point is referred as available moisture.

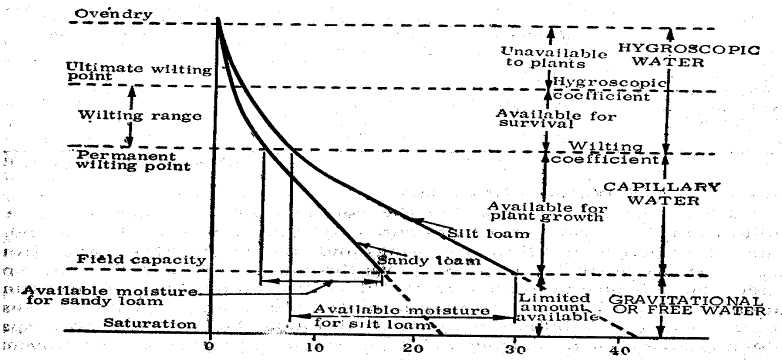

Fig. 7.14. Kinds of water in the soil and difference in available moisture content between a sandy and a silt loam soil. Note that the silt loam contains more than twice as much readily available water.

(Adapted from USDA, SCS Handbook Sec. 15, 1964).

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Fig 1.3 available moisture content

Range of available water holding capacity of soils

Soil type	% moisture, based on dry weight of soil.		Depth of available water per unit of soil(cm per meter depth of soil)
	Field Capacity	Permanent WP %	
Fine sand	3 -5	1 -3	2- 4
sandy loam	5 - 15	3 - 8	4 - 11
Silt loam	12 - 18	6 - 10	6 - 13
Clay loam	15 30	7 - 16	10 - 18
Clay	25 - 40	12 - 20	16 - 30

1.3. SOIL WATER POTENTIAL

The effect of a force on soil water may conveniently be described by potential energy of soil water in a particular force field. The forces governing soil-water flow can be described by the energy concept. According to this principle, water moves from points with higher energy status to points with lower energy status. The energy status of water is simply called 'water potential'. The relationship between the mechanical- force concept and the energy-water-potential concept is best illustrated for a situation in which the distance between two points approximates zero. The forces acting on a mass of water in any particular direction are then defined as

The negative sign shows that the force works in the direction of decreasing water potential.

The water potential is an expression for the mechanical work required to transfer a unit quantity of water from a standard reference, where the potential is taken as zero, to the situation where the potential has the defined value. Potentials are usually defined relative to water with a composition identical to the soil solution, at atmospheric pressure, a temperature of 293 K (20°C), and datum elevation zero. Soil-water potential is defined as the work expended on or by the soil water during the transfer of an infinitesimal quantity of water from point A to a reference pool or point B in the soil.

The total soil water potential is the sum of potentials resulting from different force fields.

It may be defined as the amount of work done by a unit quantity of water to transport reversibly and isothermally an infinitesimal quantity of water from a pool of pure water at a specified elevation at atmospheric pressure to the point of soil water under consideration.

Remember: Potential = Force x Distance = mgl = $\rho_w Vgl$ (Nm)

Soil water potential can be expressed in three different units:

Potential per unit mass (μ): μ = potential/mass = gl (Nm/kg)

Potential per unit volume (ψ): ψ = potential/volume = $\rho_w Vgl / V = \rho_w gl$ (N/m^2,water pressure units) Potential per unit weight (h) : h = potential/weight = mgl / mg = l (m, head unit) = equivalent height of water

Consequently, we do not need to compute the soil-water potential directly by computing the amount of work needed, but measure the soil-water potential indirectly from pressure or water height measurements

$$\frac{F_s}{m} = -\frac{\partial \psi}{\partial s}$$

where
F_s = total of forces (N)
m = mass of water (kg)
s = distance between points (m)
ψ = water potential on mass base (J/kg)

Water potential is more easily understood if we break it down into component potential .for water potential, Ψ_w we can write

$\Psi_w = \Psi_p + \Psi_s + \Psi_m$

Ψ_w =water potential Ψ_p, = pressure potential Ψ_s=solute potential Ψ_m=matric potential

We can also define, a gravitational potential, Ψ_z, which when combined with the water potential , Ψ_w, gives the total water potential, Ψ_t

$\Psi_t = \Psi_w + \Psi_z$

If we concerned only with liquid water, the flow in the soil, the solute component is essentially zero. If there are no semi permeable membranes $\Psi_t = \Psi_h = \Psi_z + \Psi_m + \Psi_p$

1.3.1 GRAVITATIONAL POTENTIAL

Weight is one of the most convenient methods of specifying the unit of water. In this case, Ψ_z is the difference in elevation of the point in question and the reference point. If the point in question is above the reference, Ψ_z is positive; if the point in question is below the reference, Ψ_z is negative.

1.3.2 MATRIC POTENTIAL

The matric potential, Ψ_m, is related to the adsorptive forces of the soil matrics. If the unit quantity of water is expressed as a weight, then, Ψ_m at a point is the vertical distance between that point in the soil and the water surface of manometer filled water and connected to the soil point in question via a ceramic cup. In theory matric potential can measured with the device (tensiometer) Illustrated in figure below. In practice, one cannot get into the soil to install take reading from this type of tensiometer. The commercially available instruments are, therefore, modified so that the water manometer is replaced with a mercury manometer or with a vacuum gage.

As we can see from the figure a distance, z is the distance from the top of the mercury column to the center of the ceramic cup. z_{Hg} is defined as the distance from the top of the mercury column to the surface of mercury in the reservoir. From this the weight matric potential, Ψ_m, is defined by taylor and ashcorft as

$\Psi_{m=}\ z_{Hg*}\rho_{Hg}/\rho_w + z$

In which ρ_{Hg} is the density of mercury (13.6g/cm3) and ρ_w is the density of water(1.o g/cm3)

$\Psi_{m=}-13.6\ z_{Hg\ +}z$

1.3.3 PRESSURE POTENTIAL

Is the vertical distance from the point in question in the soil to water surface of apiezometer connected to the point in question figure beow.

In the field, Ψp is zero above and at level of the water in the piezometer. Below this level, Ψp, is always positive. (Pressure potential can be both negative and positive. If soil is saturated, Ψp is positive, and also denoted by hydrostatic pressure potential. If the soil is unsaturated, Ψ_p is negative).

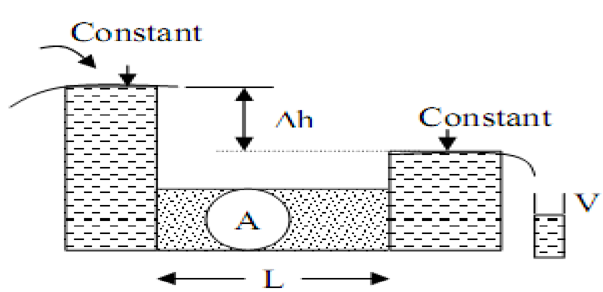
1.4 MOVEMENT OF WATER INTO SOIL

Movement: This is the change of position of water with respect to a chosen frame of reference, usually the soil matrix

1.4.1 DRIVING FORCE

- When a system is at static equilibrium there is, by definition, no transport of matter taking place in that system. Transport occurs when equilibrium conditions are disturbed.
- Liquid water flow occurs in response to a hydraulic potential gradient and not necessarily in response to a water content gradient.

Darcy's Law



The rate of discharge Q = V/t is simply measured by the volumetric overflow V in time t. The flux density q (LT^{-1}) (macroscopic flow rate) is

$$q = \frac{V}{At}$$

Where A is the cross-sectional area of the soil column perpendicular to the direction of flow sometimes the, the term q is also called the Darcian flow rate.

The equation of Darcy may be written as Victorial form as

$$\bar{q} = -K\nabla H$$

Where q is the specific discharge or flux (transport volume of water per unit time per unit area)

in $m^3 \cdot m^{-2} \cdot s^{-1} = m \cdot s^{-1}$, K is the hydraulic conductivity in $m \cdot s^{-1}$, H is the

hydraulic head in m and ∇ is Laplace operator ($\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$).

Israelson (1927) noticed that the equation for flow in unsaturated media presented by Buckingham in 1907 is equivalent to Darcy's law, the only difference being that the hydraulic conductivity is dependent on the moisture content, K (θ). With the hydraulic head or soil moisture potential defined as

$$H + z \ (m)$$

Darcy's law for unsaturated media may be written as

$$q_x = -K(\theta)\frac{\partial H}{\partial x} = -K(\theta)\frac{\partial h}{\partial x}$$

$$q_y = -K(\theta)\frac{\partial H}{\partial y} = -K(\theta)\frac{\partial h}{\partial y}$$

$$q_z = -K(\theta)\frac{\partial H}{\partial z} = -K(\theta)\left(\frac{\partial h}{\partial z} + 1\right)$$

These equations state that the flux density is proportional to the driving force of the water flow that is the gradient of the potential.

The negative sign in the above equations means that water flows in the direction of decreasing potential or against the positive direction of z in Fig. above.

Confusion is sometimes experienced in evaluating $\Delta H / \Delta z$. This can be eliminated by designating one location as point 1 and other as point 2 and then designating the location and hydraulic potential with appropriate subscript (e.g. ψ_{h1} and z_1 are hydraulic potential and height at point1). When evaluating $\Delta\psi / \Delta h$, always select values for ψ_h and z in same sequence (e.g. if you select $\psi_{h2} - \psi_{h1}$, then you must also select $z_2 - z_1$; if however, $\Delta\psi_h$ is evaluated as $\psi_{h1} - \psi_{h2}$, Δz must be evaluated as $z_1 - z_2$).

1.4.2 HYDRAULIC CONDUCTIVITY

Hydraulic conductivity, K, is a soil property that is highly dependent on the soil water content. It varies with the moisture content. Figure 3.1 shows examples of hydraulic conductivity relations in combination with the soil moisture characteristics for three types of soil. The shape of the pF-curves of the medium fine sand and sandy loam indicates a relatively large percentage of macro-pores in these soils. The low resistance to flow in the wide pores has resulted in a large saturated hydraulic conductivity Ks. Values for Ks are 10 to 100 times larger than for the fine-texture silty clay.

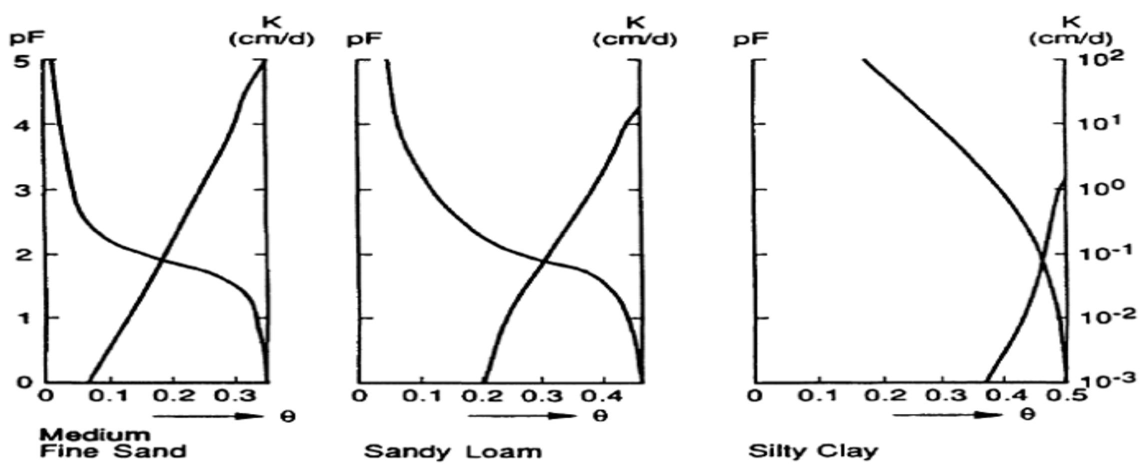


Fig 1.4 K-h relations for the three soils

The soil moisture characteristic may be used to convert the relation between K and θ into a relation between K and h. The resulting K-h relations for the three soils are plotted in figure 1.4 for comparison. The plot clearly demonstrates the nonlinear character of the K-h relation. For coarse-textured soils the hydraulic conductivity may easily vary by a factor of 10^8 between saturated and wilting point. The macro-pores in the medium fine sand and sandy loam loose their water rapidly upon drainage which results in a sharp decrease in the hydraulic conductivity. In contrast, silty clay soil showed a more gradual decrease. At higher moisture content condition the K value of the clay is relatively low, for dry situations the hydraulic conductivity may be 10 to 1000 times larger than for sandy soils. This allows transport of water from wet parts in the soil (e.g. near the water-table) to the roots during dry periods. Moreover, the available moisture is generally larger, which makes the soil physical properties of clayey soils superior to sandy soils. The low saturated hydraulic conductivity of the clay may, however, be a problem for the application of surface irrigation and drainage.

Inasmuch as $\theta(h)$ exists, the dependence of K upon h is deducible with many empirical formulae quoted in the literature.

Gardner (1958) modified Wind's (1955) empirical proposed

$$K = \alpha h^{-m}$$

to the relationship

$$K = K_s \exp(ch) \qquad (3.5)$$

The value of the empirical coefficient c with dimension $[L^{-1}]$ is related to soil texture and most frequently c= 0.1 to 0.01 cm^{-1}.

Mualem's model of K(h) is

$$\frac{K(h)}{K_s} = \frac{\left\{1 - (\alpha|h|)^{n-1}\left[1 + (\alpha|h|)^n\right]^{-m}\right\}^2}{\left[1 + (\alpha|h|)^n\right]^{m/2}}$$