Module
3

Irrigation Engineering Principles

Lesson 2

Soil Water Plant Relationships

Instructional objectives

On completion of this lesson, the student shall learn:

1. The soil and water system that is needed for plant growth
2. Classification of soils with regards to agriculture
3. Classification of water held within soil pores
4. Soil – water constants and their significance
5. Watering interval for crops
6. Importance of water for plant growth

3.2.0 Introduction

Both soil and water are essential for plant growth. The soil provides a structural base to the plants and allows the root system (the foundation of the plant) to spread and get a strong hold. The pores of the soil within the ***root zone*** hold moisture which clings to the soil particles by surface tension in the driest state or may fill up the pores partially or fully saturating with it useful nutrients dissolved in water, essential for the growth of the plants. The roots of most plants also require oxygen for respiration. Hence, full saturation of the soil pores leads to restricted root growth for these plants. (There are exceptions, though, like the rice plant, in which the supply of oxygen to the roots is made from the leaves through aerenchyma cells which are continuous from the leaves to the roots).

Since irrigation practice is essentially, an adequate and timely supply of water to the plant root zone for optimum crop yield, the study of the inter relation ship between soil pores, its water-holding capacity and plant water absorption rate is fundamentally important. Though a study in detail would mostly be of importance to an agricultural scientist, in this lesson we discuss the essentials which are important to a water resources engineer contemplating the development of a command area through scientifically designed irrigation system.

3.2. 1 Soil-water system

Soil is a heterogeneous mass consisting of a three phase system of solid, liquid and gas. Mineral matter, consisting of sand, silt and clay and organic matter form the largest fraction of soil and serves as a framework (matrix) with numerous pores of various proportions. The void space within the solid particles is called the soil pore space. Decayed organic matter derived from the plant and animal remains are dispersed within the pore space. The soil air is totally expelled from soil when water is present in excess amount than can be stored.

On the other extreme, when the total soil is dry as in a hot region without any supply of water either naturally by rain or artificially by irrigation, the water molecules surround the soil particles as a thin film. In such a case, pressure lower than atmospheric thus results due to surface tension capillarity and it is not possible to drain out the water by gravity. The salts present in soil water further add to these forces by way of osmotic pressure. The roots of the plants in such a soil state need to exert at least an equal amount of force for extracting water from the soil mass for their growth.

In the following sections, we discuss certain important terms and concepts related to the soil-water relations. First, we start with a discussion on soil properties and types of soils.

3.2.2 Soil properties

Soil is a complex mass of mineral and organic particles. The important properties that classify soil according to its relevance to making crop production (which in turn affects the decision making process of irrigation engineering) are:

- Soil texture
- Soil structure

Soil texture:

This refers to the relative sizes of soil particles in a given soil. According to their sizes, soil particles are grouped into gravel, sand, silt and day. The relative proportions of sand, silt and clay is a soil mass determines the soil texture. Figure 1 presents the textural classification of 12 main classes as identified by the US department of agriculture, which is also followed by the soil survey organizations of India.

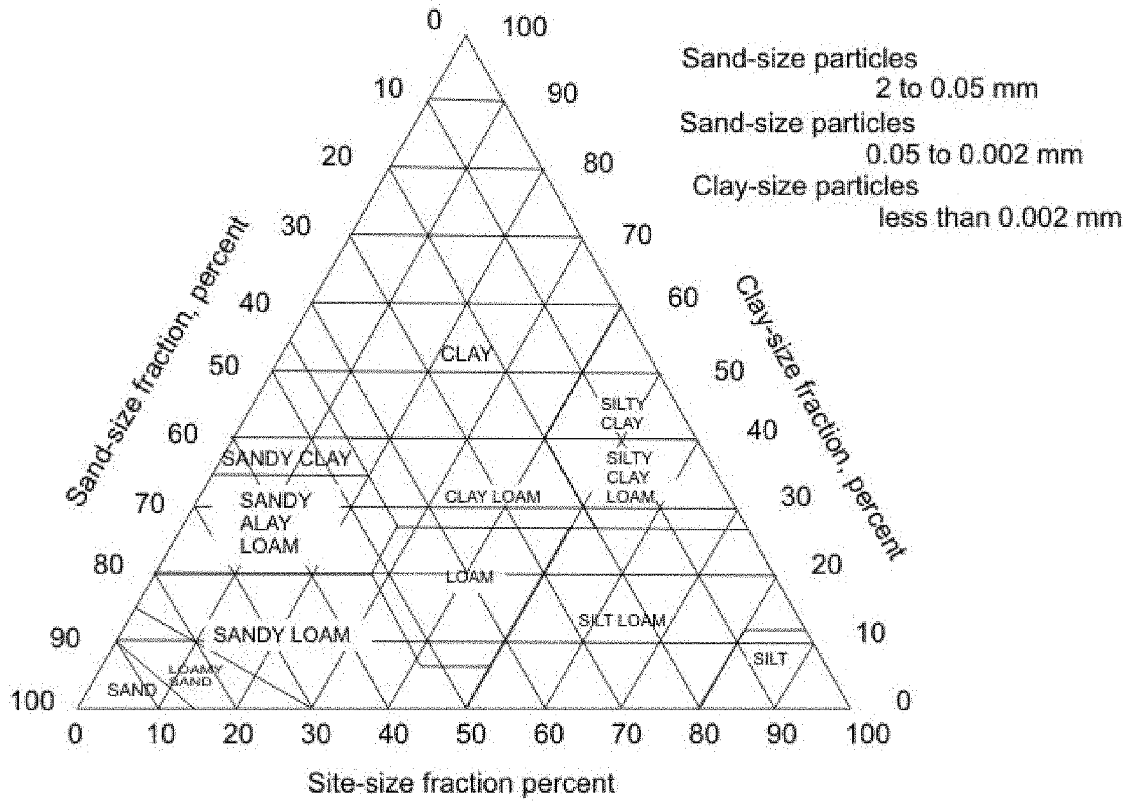

FIGURE 1. USDA textural classification chart

According to textural gradations a soil may be broadly classified as:

- Open or light textural soils: these are mainly coarse or sandy with low content of silt and clay.
- Medium textured soils: these contain sand, silt and clay in sizeable proportions, like loamy soil.
- Tight or heavy textured soils: these contain high proportion of clay.

Soil structure:

This refers to the arrangement of soil particles and aggregates with respect to each other. Aggregates are groups of individual soil particles adhering together. Soil structure is recognized as one of the most important properties of soil mass, since it influences aeration, permeability, water holding capacity, etc. The classification of soil structure is done according to three indicators as:-

- ***Type:*** there are four types of primary structures-platy, prism-like, block like and spheroidal.

- ***Class:*** there are five recognized classes in each of the primary types. These are very fine, fine, medium, coarse and very coarse.

- ***Grade:*** this represents the degree of aggradation that is the proportion between aggregate and unaggregated material that results when the aggregates are displaced or gently crushed. Grades are termed as structure less, weak, moderate, strong and very strong depending on the stability of the aggregates when disturbed.

3.2.3 Soil classification

Soils vary widely in their characteristics and properties. In order to establish the interrelation ship between their characteristics, they need to be classified. In India, the soils may be grouped into the following types:

- **Alluvial soils:** These soils are formed by successive deposition of silt transported by rivers during floods, in the flood plains and along the coastal belts. This group is by for the largest and most important soil group of India contributing the greatest share to its agricultural wealth. Though a great deal of variation exists in the type of alluvial soil available throughout India, the main features of the soils are derived from the deposition laid by the numerous tributaries of the Indus, the Ganges and the Brahmaputra river systems. These streams, draining the Himalayas, bring with them the products of weathering rocks constituting the mountains, in various degrees of fineness and deposit them as they traverse the plains. Alluvial soils textures vary from clayey loam to sandy loam. The water holding capacity of these soils is fairly good and is good for irrigation.

- **Black soils:** This type of soil has evolved from the weathering of rocks such as basalts, traps, granites and gneisses. Black soils are derived from the Deccan trap and are found in Maharashtra, western parts of Madhya Pradesh, parts of Andhra Pradesh, parts of Gujarat and some parts of Tamilnadu. These soils are heavy textured with the clay content varying from 40 to 60 percent.the soils possess high water holding capacity but are poor in drainage.

- **Red soils:** These soils are formed by the weathering of igneous and metamorphic rock comprising gneisses and schist's. They comprise of vast areas of Tamil nadu, Karnataka, Goa, Daman & Diu, south-eastern Maharashtra, Eastern Andhra Pradesh, Orissa and Jharkhand. They also are in the Birbhum district of West Bengal and Mirzapur, Jhansi and Hamirpur districts of Uttar pradesh. The red soils have low water holding capacity and hence well drained.

- **Laterites and Lateritic soils:** Laterite is a formation peculiar to India and some other tropical countries, with an intermittently moist climate. Laterite soils are derived from the weathering of the laterite rocks and are well developed on the summits of the hills of the Karnataka, Kerala, Madhya Pradesh, The eastern ghats of Orissa, Maharashtra, West Bengal, Tamilnadu and Assam. These soils have low clay content and hence possess good drainage characteristics.

- **Desert soils:** A large part of the arid region, belonging to western Rajasthan, Haryana, Punjab, lying between the Indus river and the Aravalli range is affected by the desert conditions of the geologically recent origin. This part is covered by a mantle of blown sand which, combined with the arid climate, results in poor soil development. They are light textured sandy soils and react well to the application of irrigation water.

- **Problem soils:** The problem soils are those, which owing to land or soil characteristics cannot be used for the cultivation of crops without adopting proper reclamation measures. Highly eroded soils, ravine lands, soils on steeply sloping lands etc. constitute one set of problem soils. Acid, saline and alkaline soils constitute another set of problem soil.

Some of the major soil groups of the country are listed in the following table:

Zone	Name	Climate	Regions	Major soil group
1	Western Himalayan Region	Humid	Jammu & Kashmir, Himachal pradesh, Uttaranchal	Submontane soils, Hill and terai soils
2	Bengal-Assam Basin	Humid	West Bengal, Assam	Riverine alluvium, terai soils, lateritic soils, red-yellow loams
3	Eastern Himalayan Region and bay islands	Humid	Andaman & Nicobar Islands, Arunachal Pradesh, Nagaland, Manipur, Tripura, Meghalaya	Red loamy soils, lateritic soils, red yellow soils, alluvial soils
			Punjab, Uttar	Calcareous alluvial soils, riverine

4	Sutlej-Ganga Plains	Sub-Humid	Pradesh, Bihar, Delhi, Uttaranchal	alluvium alkaline soils, red yellow loams, mixd red and black soils
5	Eastern and south eastern uplands	Sub-Humid to Humid	Orissa, Jharkhand, Chattisgarh, Andhra Pradesh	Lateritic soils, red yellow loams, mixed red and black soils, red loamy soils, coastal alluvium alluvial soils, red yellow soils, medium to deep black soils
6	Western plains	Arid	Harayana, Rajasthan, Dadra & Nagar Haveli	Lateritic soils, red yellow loams, mixed red and black soils, red loamy soils, coastal alluvium alluvial soils, red yellow soils, medium to deep black soils
7	Lava plateau and central highlands	Semi arid	Maharashtra, Goa, Madhya Pradesh, Daman & Diu	Riverine alluvium, coastal alluvium, mixed red and black soils, skeletal soils, shallow deep black soils and red sandy soils
8	Western Ghats and	Humid to semi	Karnataka, tamil Nadu, Kerala,	Lateritic soils, red sandy soils, deltaic

	Karnataka Plateau	arid	Pondicherry, Lakshadweep islands	coastal alluvium and red loamy soils.

3.2.4 Classification of soil water

As stated earlier, water may occur in the soil pores in varying proportions. Some of the definitions related to the water held in the soil pores are as follows:

- **Gravitational water:** A soil sample saturated with water and left to drain the excess out by gravity holds on to a certain amount of water. The volume of water that could easily drain off is termed as the gravitational water. This water is not available for plants use as it drains off rapidly from the root zone.

- **Capillary water:** the water content retained in the soil after the gravitational water has drained off from the soil is known as the capillary water. This water is held in the soil by surface tension. Plant roots gradually absorb the capillary water and thus constitute the principle source of water for plant growth.

- **Hygroscopic water:** the water that an oven dry sample of soil absorbs when exposed to moist air is termed as hygroscopic water. It is held as a very thin film over the surface of the soil particles and is under tremendous negative (gauge) pressure. This water is not available to plants.

The above definitions of the soil water are based on physical factors. Some properties of soil water are not directly related to the above significance to plant growth. These are discussed next.

3.2.5 Soil water constants

For a particular soil, certain soil water proportions are defined which dictate whether the water is available or not for plant growth. These are called the soil water constants, which are described below.

- **Saturation capacity:** this is the total water content of the soil when all the pores of the soil are filled with water. It is also termed as the maximum water holding capacity of the soil. At saturation capacity, the ***soil moisture tension*** is almost equal to zero.

- **Field capacity:** this is the water retained by an initially saturated soil against the force of gravity. Hence, as the gravitational water gets drained off from the soil, it is said to reach the field capacity. At field capacity, the macro-pores of the soil are drained off, but water is retained in the micropores. Though the soil moisture tension at field capacity varies from soil to soil, it is normally between 1/10 (for clayey soils) to 1/3 (for sandy soils) atmospheres.

- **Permanent wilting point:** plant roots are able to extract water from a soil matrix, which is saturated up to field capacity. However, as the water extraction proceeds, the moisture content diminishes and the negative (gauge) pressure increases. At one point, the plant cannot extract any further water and thus ***wilts.***

  Two stages of wilting points are recognized and they are:

    - Temporary wilting point: this denotes the soil water content at which the plant wilts at day time, but recovers during right or when water is added to the soil.

    - Ultimate wilting point: at such a soil water content, the plant wilts and fails to regain life even after addition of water to soil.

It must be noted that the above water contents are expressed as percentage of water held in the soil pores, compared to a fully saturated soil. Figure 2 explains graphically, the various soil constants; the full pie represents the volume of voids in soil.

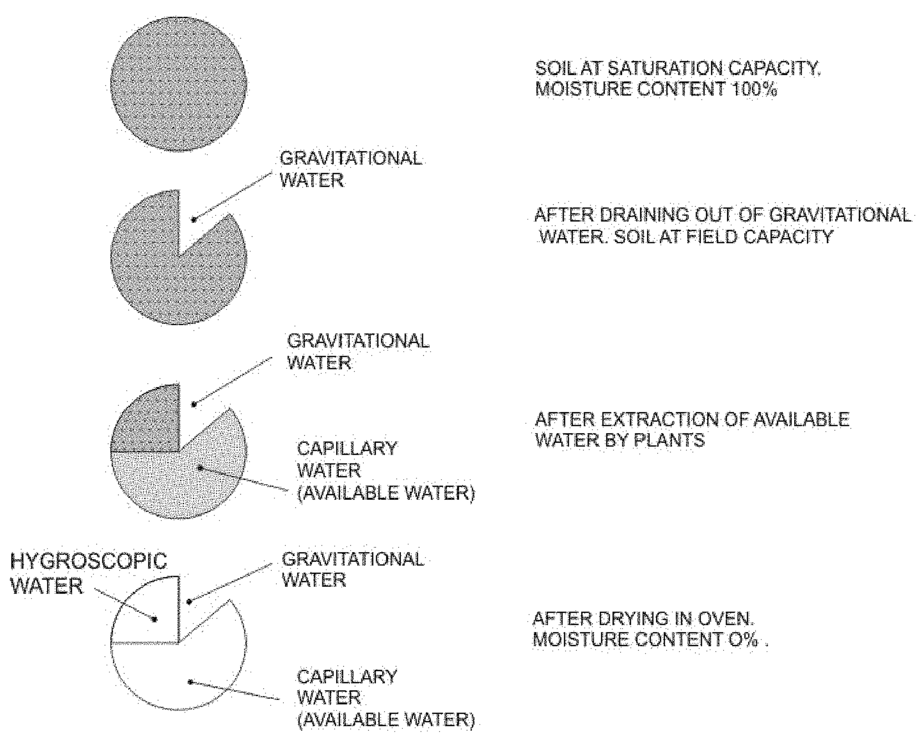

FIGURE 2. Classification of soil water

As shown in Figure 2, the available water for plants is defined as the difference in moisture content of the soil between field capacity and permanent wilting point.

Field capacity and Permanent wilting point: Although the pie diagrams in Figure 2 demonstrate the drying up of saturated soil pores, all the soil constants are expressed as a percentage by weight of the moisture available at that point compared to the weight of the dried soil sand sample.

3.2.6 Soil water constants expressed in depth units:

In the last section, the soil water constants were mentioned as being expressed as weight percentages of the moisture content (that is amount of water) held by the water at a certain state with respect to the weight of the dried soil sample. The same may also be expressed as volume of water stored in the root zone of a field per unit area. This would consequently express the soil water constants as units of depths. The conversion from one form to the other is presented below:

Assume the following:

- Root zone depth = D (m)
- Specific weight of soil = γ_s (kg/m^3)
- Specific weight of water = γ_w (kg/m^3)
- Area of plot considered = 1m x 1m

Hence, the weight of soil per unit area would be: γ_s x 1 x D (kg)

The weight of water held by the soil per unit area would be equal to: γ x 1 x d

Where d is equivalent depth of water that is actually distributed within the soil pores. Hence the following constants may be expressed as:

$$\text{Field capacity} = \frac{\text{Weight of water held by soil per unit area}}{\text{Weight of soil per unit area}}$$

$$= \frac{\gamma_w * 1 * d}{\gamma_s * 1 * D} \qquad (1)$$

Thus, depth of water (***d*** $_{Fc}$) held by soil at field capacity (***FC***)

$$= \frac{\gamma_s}{\gamma_w} * D * FC \qquad (2)$$

Similarly, depth of water (***d*** $_{wp}$) held by soil at permanent wilting point (***PWP***)

$$= \frac{\gamma_s}{\gamma_w} * D * PWP \qquad (3)$$

Hence, depth of water (***d*** $_{Aw}$) available to plants

$$= \frac{\gamma_s}{\gamma_w} * D * [FC - PWP] \qquad (4)$$

Therefore, the depth of water available to plants per meter depth of soil

$$= \frac{\gamma_s}{\gamma_w} \, [FC - PWP] \qquad (5)$$

It may be noted that plants cannot extract the full available water with the same efficiency. About 75 percent of the amount is rather easily extracted, and it is called the readily available water. The available water holding capacity for a few typical soil types are given as in the following table:

Soil Texture	Field Capacity (FC) percent	Permanent Wilting Point (PWP) percent	Bulk Density(γ_s) Kg/m^3	Available water per meter depth of soil profile(m)
Sandy	5 to 10	2 to 6	1500 to 1800	0.05 to 0.1
Sandy loam	10 to 18	4 to 10	1400 to 1600	0.09 to 0.16
Loam	18 to 25	8 to 14	1300 to 1500	0.14 to 0.22
Clay loam	24 to 32	11 to 16	1300 to 1400	0.17 to 0.29
Clay	32 to 40	15 to 22	1200 to 1400	0.20 to 0.21

3.2.7 Water absorption by plants

Water is absorbed mostly through the roots of plants, though an insignificant absorption is also done through the leaves. Plants normally have a higher concentration of roots close to the soil surface and the density decreases with depth as shown in Figure 3.

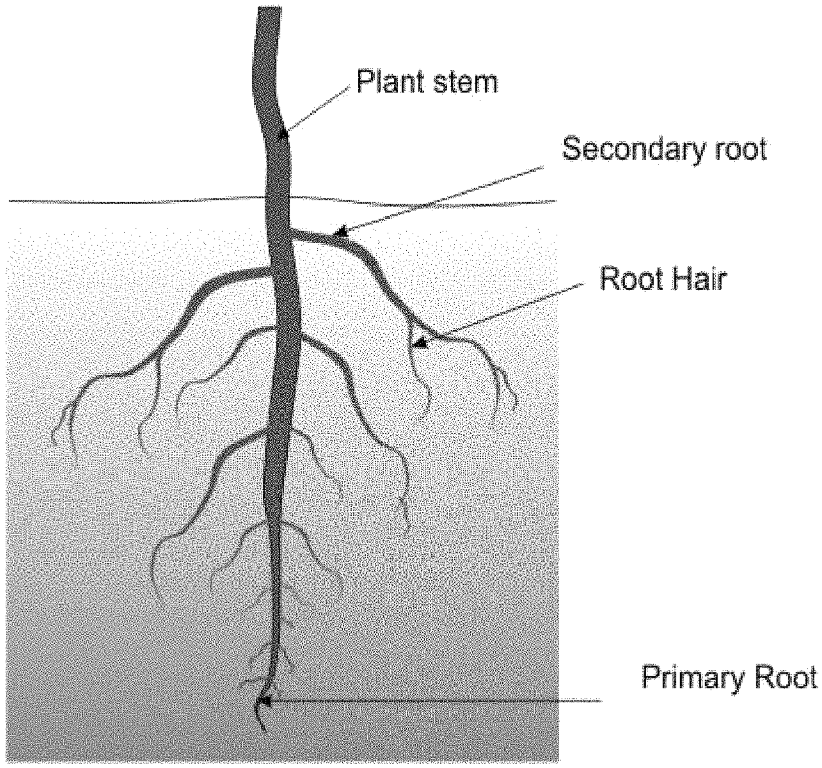

FIGURE 3. Typical root density variation of a plant with depth.

In a normal soil with good aeration, a greater portion of the roots of most plants remain within 0.45m to 0.60m of surface soil layers and most of the water needs of plants are met from this zone. As the available water from this zone decreases, plants extract more water from lower depths. When the water content of the upper soil layers reach wilting point, all the water needs of plants are met from lower layers. Since there exists few roots in lower layers, the water extract from lower layers may not be adequate to prevent wilting, although sufficient water may be available there.

When the top layers of the root zone are kept moist by frequent application of water through irrigation, plants extract most of the water (about 40 percent) from the upper quarter of their root zone. In the lower quarter of root zone the water extracted by the plant meets about 30 percent of its water needs. Further below, the third quarter of the root zone extracts about 20 percent and the lowermost quarter of root zone extracts the remaining about 10 percent of the plants water. It may be noted that the water extracted from the soil by the roots of a plant moves upwards and essentially is lost to the atmosphere as water vapours mainly through the leaves. This process, called transpiration, results in losing almost 95percent of water sucked up. Only about 5percent of water pumped up by the root system is used by the plant for metabolic purpose and increasing the plant body weight.

3.2.8 Watering interval for crops

A plot of land growing a crop has to be applied with water from time to time for its healthy growth. The water may come naturally from rainfall or may supplemented by artificially applying water through irrigation. A crop should be irrigated before it receives a set back in its growth and development. Hence the interval between two irrigations depends primarily on the rate of soil moisture depletion. Normally, a crop has to be irrigated before soil moisture is depleted below a certain portion of its availability in the root zone depending on the type pf plant. The intervals are shorter during summer than in winter. Similarly, the intervals are shorter for sandy soils than heavy soils. When the water supply is very limited, then the interval may be prolonged which means that the soil moisture is allowed to deplete below 50percent of available moisture before the next irrigation is applied. The optimum rates of soil moisture for a few typical crops are given below (Reference: Majumdar, D K, 2000)

- Maize : Field capacity to 60 percent of availability
- Wheat : Field capacity to 50 percent of availability
- Sugarcane: Field capacity to 50 percent of availability
- Barley : Field capacity to 40 percent of availability
- Cotton : Field capacity to 20 percent of availability

As for rice, the water requirement is slightly different than the rest. This is because it requires a constant standing depth of water of about 5cm throughout its growing period. This means that there is a constant percolation of water during this time and it has estimated that about 50 to 70 percent of water applied to the crop is lost in this way.

For most of the crops, except rice, the amount of water applied after each interval should be such that the moisture content of the soil is raised to its field capacity. The soil moisture depletes gradually due to the water lost through evaporation from the soil surface and due to the absorption of water from the plant roots, called transpiration more of which has been discussed in the next session. The combined effect of evaporation and transpiration, called evapo-transpiration (ET) decides the soil water depletion rate for a known value of ET (which depends on various factors, mainly climate); it is possible to find out the irrigation interval.

Some of the operational soil moisture ranges of some common crops are given below:

Rice:
This crop is grown both in lowland and upland conditions and throughout the year in some parts of the country. For lowland rice, the practice of keeping the soil saturated or upto shallow submergence of about 50mm throughout the growing period has been found to be the most beneficial practice for obtaining maximum yields. When water resources are limited, the land must be submerged atleast during critical stages of growth. The major portion of the water applied to the rice crop, about 50-75% is lost through deep percolation which varies with the texture of the soil. Since the soil is kept constantly submerged for rice growth, all the pores are completely filled with water through it is in a state of continuous downward movement. The total water required by the rice plant is about 1.0 to 1.5m for heavy soils and soils with high water table; 1.5 to 2.0m for medium soils and 2.0 to 2.5 for light soils with deep water table.

Wheat:
The optimum soil moisture range for tall wheats is from the field capacity to 50% of availability. The dwarf wheats need more wetness, and the optimum moisture range is from 100 to 60 percent availability. The active root zone of the crops varies from 0.5 to 0.75m depending upon the soil type. The total water requirement for wheat plants vary from 0.25m to 0.4 m in northern India to about 0.5m to 0.6m in Central India.

Barley:
This crop is similar to wheat in its growing habits, but can withstand more droughts because of the deeper and well spread root system. The active root zone of Barley extends between 0.6m to 0.75m on different soil types. The optimum soil moisture ranges from the field capacity to 40% of availability.

Maize:
The crop is grown almost all over the country. The optimum soil moisture range is from 100 to 60% of availability in the maximum root zone depth which extends from 0.4 to 0.6 on different soil types. The actual irrigation requirement of the crop varies with the amount of rainfall. In north India, 0.1m and 0.15m is required to establish the crop before the onset of monsoon. In the south, it is found that normal rain fall is sufficient to grow the crop in the monsoon season where as 0.3m of water is required during water.

Cotton:
The optimum range of soil moisture for cotton crop is from the field capacity to 20% of available water. He root zone varies upto about 0.75m. The total water requirement is about 0.4m to 0.5m.

Sugarcane:
The optimum soil moisture for sugarcane is about 100 to 50 percent of water availability in the maximum root zone, which extends to about 0.5m to 0.75m in depth. The total water depth requirement for sugarcane varies from about 1.4m to 1.5m in Bihar; 2.2m – 2.4m in Karnataka; and 2.0 – 2.3m in Madhya Pradesh.

3.2.9 Importance of water in plant growth

During the life cycle of a plant water, among other essential elements like air and fertilizers, plays a vital role, some of the important ones being:

- Water maintains the turgidity of the plant cells, thus keeping the plant erect. Water accounts for the largest part of the body weight of an actively growing plant and it constitutes 85 to 90 percent of the body weight of young plants and 20 to 50 percent of older or mature plants.

- Water provides both oxygen and hydrogen required for carbohydrate synthesis during the photosynthesis process.

- Water acts as a solvent of plant nutrients and helps in the uptake of nutrients from soil.

- Food manufactured in the green parts of a plant gets distributed throughout the plant body as a solution in water.

- Transpiration is a vital process in plants and does so at a maximum rate (called the potential evapo transpiration rate) when water is available in adequate amount. If soil moisture is not sufficient, then the transpiration rate is curtailed, seriously affecting plant growth and yield.

- Leaves get heated up with solar radiation and plants help to dissipate the heat by transpiration, which itself uses plant water.

3.2.10 Irrigation water quality

In irrigation agriculture, the quality of water used for irrigation should receive adequate attention. Irrigation water, regardless of its source, always contains some soluble salts in it. Apart from the total concentration of the dissolved salts, the concentration of some of the individual salts, and especially those which are most harmful to crops, is important in determining the suitability of water for irrigation. The constituents usually determined by analyzing irrigation water are the electrical conductivity for the total dissolved salts, soluble sodium percentage, sodium absorption ratio, boron content, PH, cations such as calcium, magnesium, sodium, potassium and anions such as carbonates, bicarbonates, sulphates, chlorides and nitrates.

Water from rivers which flow over salt effected areas or in the deltaic regions has a greater concentration of salts sometimes as high as 7500 ppm or even more. The quality of tank or lake water depends mainly on the soil salinity in the water shed areas and the aridity of the region. The quality of ground water resources, that is, from shallow or deep wells, is generally poor under the situations of

- high aridity
- high water table and water logged conditions
- in the vicinity of sea water

on the basis of suitability of water for irrigation, the water may be classified under three categories, which are shown in the following table:

Class	Electrical Conductivity (micro-ohm/cm)	Total Dissolved Solids (ppm)	Exchangeable sodium (percentage)	Chloride (ppm)	Sulphates (ppm)	Boron (ppm)	Remarks
I	0-1000	0-700	0-60	0-142	0-192	0-0.5	Excellent to good for irrigation
II	1000-3000	700-2000	60-75	142-355	192-480	0.5-2.0	Good to injurious; suitable only with permeable soils and moderate teaching. Harmful to more sensitive crops.
III	>3000	>2000	>75	>355	>480	>2.0	Unfit for irrigation

3.2.11 Important Definitions

1. Root Zone: The soil root zone is the area of the soil around the plant that comes in contact with the plant root (Figure 4).

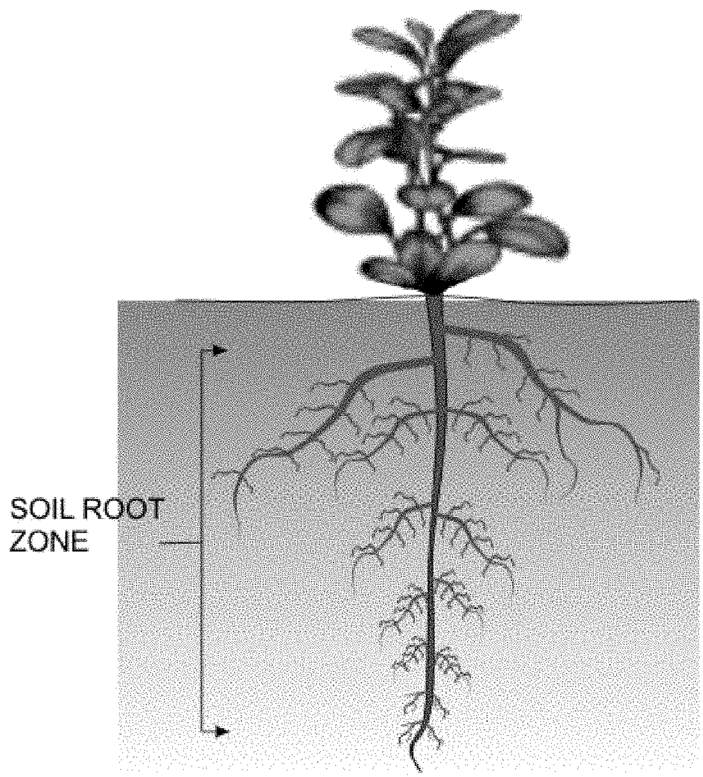

FIGURE 4 **Definition of soil root zone**

2. Soil Moisture tension: In soils partially saturated with water there is moisture tension, which is equal in magnitude but opposite in sign to the soil water pressure. Moisture tension is equal to the pressure that must be applied to the soil water to bring it to a hydraulic equilibrium, through a porous permeable wall or membrane, with a pool of water of the same composition.

3. Wilts: Wilting is drooping of plants. Plants bend or hang downwards through tiredness or weakness due to lack of water.

3.2.12 Bibliography

- Majumdar, D K (2000) *Irrigation Water Management* by, Prentice Hall of India.