LEC. 05. MOISTURE EXTRACTION PATTERN OF CROPS- SOIL MOISTURE STRESS - PLANT WATER STRESS -EFFECTS ON CROP GROWTH

Water as a Plant Component

The factors influencing the water relations of plants, and thus their growth and yield responses, may be grouped into the following

I. Soil factors – soil moisture content, texture, structure, density, salinity, fertility, aeration, temperature and drainage.

II. Plant factors – type of crop, density and depth of rooting, rate of root growth, aerodynamic roughness of the crop, drought tolerance and varietal effects.

III. Weather factors – sunshine, temperature, humidity, wind and rainfall.

IV. Miscellaneous factors – soil volume and plant spacing, soil fertility, and crop and soil management

The metabolic activity of cells and plants is closely related to their water content. Growth of plants is controlled by the rates of cell division and enlargement and by the supply of organic and inorganic compounds required for the synthesis of new protoplasm and cell walls. A decreasing water content is accompanied by a loss of cell turgor* and wilting, cessation of cell enlargement, closure of stomata reduction of photosynthesis and interference with many basic metabolic processes. Eventually, continued dehydration causes disorganization of the protoplasm and death of most organisms. The relation of water content to physiological processes is shown strikingly in seeds, where respiration and other physiological activities increase manifold as the water content increases. In photosynthesis, water is as important a reagent as carbondioixde. An essential function of water in plants is as the solvent in which gases, minerals, and other solutes enter plant cells and move from cell to cell and tissue to tissue within the plant. The permeability of most cell walls and membranes to water results in a continuous liquid phase extending throughout the plant in which translocation of solutes occurs. Water is a reactant or reagent in many physiological processes including photosynthesis and hydrolytic processes such as the hydrolysis of starch to sugar. Water is essential to maintain sufficient turgidity for growth of cells and maintenance of the form and position of leaves and new shoots.

The total quantity of water required for the essential physiological functions of the plant is usually less than five per cent of all the water absorbed. Most of the water entering the plant is lost in transpiration, directly contributing little to its growth. However, failure to replace the water lost by transpiration results in the loss of turgidity, cessation of growth, and eventual death of the plant from dehydration.

The following are the main areas of water-plant relationship: (1) water absorption, (2) water conduction and translocation, and (3) water loss or transpiration.

In determining the importance of water in crop productivity we have to understand clearly all the three processes – absorption, translocation and transpiration. We will have to analyse the effect of these processes on plant growth and crop yield in order to recognize the steps which are needed to regulate and modify the cropping systems with a view to obtain the maximum water use efficiency.

Amount of water in plants: The amounts of water varies in different plant parts. The apical portions of the root and stem contain 90 per cent or more water. Leaves and young fruits are other organs which are rich in water. When the organs mature, their water content decreases. The woods of large trees may contain about 50-60 per cent moisture whereas the stems of wheat, barley and sorghum contain about 60-70 per cent water which at harvest time may decline to 5-10 per cent. Freshly harvested grains of most crops contain 10-15 pr cent of water. Indeed, it is the moisture content of these grains which determines their storage life, viability and germinability.

Absorption of water in soil-plant-atmosphere system. The root system is extremely variable in different crop plants. The variability exists in rooting depth, root length and horizontal distribution of roots. These are further influenced by environmental factors and the genetic constitution. Nevertheless, both the properties of soil and the roots determine the water uptake by roots. The roots of cereals, apparently, occupy more surface area of the soil than other crops. For example, it has been shown that cereal roots extend to 200-4000 cm/cm^2 of soil surface area as against 15-200 cm/cm^2 for non-graminaceous plants.

It is desirable to consider water absorption in the total soil-plant-atmosphere system instead of the roots alone. In this system, one can partition the system in such a manner so that the involvement of different plant parts is taken into account. The flow rate of water in this system is given by the following equation:

$$\text{Flow rate} = \frac{\Psi_{soil} - \Psi_{root\ surface}}{r_{soil}} = \frac{\Psi_{root\ surface} - \Psi_{xylem}}{r_{root}}$$

$$= \frac{\Psi_{xylem} - \Psi_{leaf}}{r_{xylam}} = \frac{\Psi_{leaf} - \Psi_{air}}{r_{leaf} + r_{rleaf}}$$

in which, Ψ is the water potential at various sites of the system and r is the corresponding resistance.

Water absorption by roots is dependent on the supply of water at the root surface. The two main phenomena concerned with this are the movement of water to the root surface and the growth of roots into the soil mass. As the soil dries out from a saturated state, the rate of water movement in the soil decreases rapidly. The water movement in the soil drier than field capacity controls the distance in the soil from which roots can extract water. Thus, under the conditions where the water extracted by roots is not frequently replaced by rain or irrigation, it is important that the root system must expand continuously or else have already occupied a large enough volume of soil to provide the plant with sufficient water to replace the transpiration losses. Hence, all the factors which affect root growth or the occupation by roots of a large enough soil volume, will also affect the absorption of water by plants.

The actual entry of water into the roots is affected by the extent of the absorbing zone of the roots, the permeability of the root cortex to water movement and the water potential at the root surface. The movement of water through the root and conducting elements of the laves xylem to the leaves is initiated and largely controlled by the transpiration from the leaves in response to the water potential gradient extending from the soil water, through the plant to the atmosphere. The water moves from the xylem strands of the leaf across the mesophyll tissue and through the cell walls bordering the sub-stomatal cavities where the liquid vapourizes and diffuses out of the leaves through the stomatal openings. Transpiration, though an energy-controlled process, is modified by the soil, plant and atmospheric factors which govern the potential gradients in the various parts of the water path to the leaf surface.

Moisture stress and plant response

As mentioned previously, plant-water relations consist of a group of interrelated and interdependent processes. Thus, the internal water balance or degree of turgidity of a plant depends on the relative rates of water absorption and water loss, and is affected by the complex of atmospheric, soil and plant factors that modify the rates of absorption and transpiration.

Water moves in response to a potential gradient. When the plant roots are in equilibrium with the soil water potential, and the soil water potential gradients are near zero, a base level of leaf turgor or plant water potential is reached. Under the conditions of low evaporation demand during the night and early morning (prior to sunrise) the values of water potential are often at or near this level. An increase in the rate of transpiration, coincident with the increase in evaporation, during the day, causes a decrease in the turgor pressure of the upper leaves and the development of water potential gradients through the plant from the evaporating surface of the leaves to the absorbing surface of the roots. Conditions are often such that the rate of water loss exceeds the rate of water absorption, causing an internal water deficit to develop in the plant. It is this internal water deficit, through its influence on many of the physiological processes in the plant that is directly responsible for the growth and yield of a crop under the prevailing conditions.

The yield of a crop is the integrated result of a number of physiological processes. Water stress can after photosynthesis and respiration. It can also affect growth and reproduction. Reduction in leaf area, cell size and inter-cellular volume are common under water stress. Dehydration of protoplasm may be responsible for decreasing several physiological processes. Water stress produces important changes in carbohydrate and nitrogen metabolism of plants. Water stress at certain critical stages of plant growth causes more injury than at other stages. For example, irrigation at the crown root initiation stage has been shown to be essential for increased yield of wheat crop.

Moisture extraction pattern

The moisture extraction pattern reveals about how the moisture is extracted and how much quantity is extracted at different depth level in the root zone. The moisture extraction patter shows the relative amount of moisture extracted from different depths within the crop root zone.

The moisture extraction pattern of plant growing in a uniform soil without a restrictive layer and with adequate supply of available soil moisture throughout the zone is shown in figure.

It is seen from the figure that about 40% of the total moisture is extracted form the first quarter of the root zone, 30% form second quarter, 20% from the third quarter and 10% from last further quarter.

This indicates that in most of the crops the effective root zone will be available in the 1st quarter and it does not mean that the last quarter will not need any water. Hence soil moisture measurements at different depths in the root zone has to be taken.

a) To estimate the soil moisture status and
b) To work out the irrigation quantity to be applied

Rooting characteristics and moisture extraction pattern

The root system is extremely variable in different crop plants.

The variability exists in rooting depth, root length and horizontal distribution of roots. These are further influenced by environmental factors and the genetic constitution.

The roots of cereals apparently occupy more surface area of the soil then other crops. For example, it has been proved that cereals' roots extend to 200-400 cm m^2 of soil surface area as against 15-200 cm m^2 for most graminaceous plants.

The amount of soil moisture that is available to the plant is determined by the moisture characteristics of the soil depth and the density of the roots. The moisture characteristics of soil like FC and PWP cannot be altered so easily and greater possibilities lie in changing the rooting characteristics of plants system to go deeper and denser and more proliferation to tap water from deeper layers of soil as well as from the larger surface area.

Plants vary genetically in their rooting characteristics (Figure) Vegetable crops like onion, potato, carrot etc., have very sparse rooting system and unable to use all the soil water in the root.

Rice, Grasses, sorghum, maize, sugarcane have very fibrous dense root system which can extract much water from soil. Millets, groundnut, grams are moderately deep rooted.

Maize, sorghum, lucerne, cotton and perennial plants have deep root system and can utilize effectively the moisture stored in root zone as well as in the unexploited deeper zones. Crops which have dense and deep root system like cotton, sorghum, red gram tolerate high reduction of soil water content. Shallow rooted crops like rice, potato, tomato tolerate low level of soil water reduction. Moderately deep rooted crops like millets, groundnut, grams tolerate medium level of soil water reduction.

The root growth of the crop plants is affected by

1. Genetic nature
2. High water table
3. Shallow nature of soil and permeability of soil layer
4. Soil fertility
5. Salt status of soil

Effective root zone depth

It is depth in which active root proliferation occurs and where maximum water absorption is taking place. It is not necessary that entire root depth should be effective.