Course – Water Management in Horticultural crops, 2(1+1)
B.Sc. (Horticulture)IstYear IIndSemester
College of Horticulture, Chhindwara
Course Teacher- Dr. Shikha Sharma
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Topic - Cimatological approach – atmospheric demand – factors affecting ET– in scheduling irrigation

- ✓ Attempts have been made from time to time to use meteorological parameters, which are the major factors demanding atmospheric moisture, for estimating the evapotranspiration and consumptive use for controlling irrigation.
- ✓ For this purpose, empirical formulae using different meteorological parameters have been developed.
- ✓ Penman (1948), Thornthwaite (1948), Blaney–Criddle (1950) and Christiansen (1968) developed formulae for estimating potential evapotranspiration and then used the estimated evapotranspiration for scheduling irrigation by water budget method.
- ✓ The daily evapotranspiration loss is deducted from the soil water reserve in root zone soil after irrigation and a balance is worked out.
- ✓ When the balance show that the soil water is depleted to a predetermined level, say, the lower level of optimum soil water regime, irrigation is applied to replenish the water lost through evapotranspiration.
- ✓ The adoption of empirical formulae for irrigation control demands the knowledge of water holding capacity of soil and a continuous record of rainfall and other meteorological parameters.
- ✓ This approach of scheduling irrigation to crops is complicated for an ordinary farmer.

Frequency and interval of irrigation

- ✓ The terms, frequency of irrigation and interval of irrigation are closely related and are often interchangeable.
- ✓ With higher frequency of irrigation, the interval between two irrigations decreases in a given period, while with lower frequency the interval between two irrigations increases.
- ✓ The term, interval of irrigation indicates the time gap, usually expressed in days, between two subsequent irrigations.
- ✓ The total amount of water required by a crop for producing an optimum yield is termed as delta of water and it is synonymous with water requirement of crop.
- ✓ Immediately after irrigation when the soil is wet, evapotranspiration occurs at a potential rate.
- ✓ It starts declining some days after irrigation as the surface soil dries up. Dry and loose soil surface helps to reduce evaporation.
- ✓ Since soil water declines progressively owing to continuous evapotranspiration, the rate of evapotranspiration also declines progressively with the advance of time after irrigation.
- ✓ Therefore, the longer is the interval between irrigations, the greater is the saving of water. Besides, a longer interval between two irrigations cuts down the number of irrigations during the growing season.

- ✓ Care should, however, be taken not to cause any water stress beyond a certain limit by making the irrigation interval unduly long unless compelled to do so for reasons of water scarcity.
- ✓ Irrigation is usually advised at the lowest limit of the optimum water regime, as already stated earlier.
- ✓ The interval between two irrigations should normally be the time taken by crops to reduce the soil water from field capacity to the lowest level of optimum soil water regime.

Factors affecting frequency of irrigation

The factors which affect the ET have been dealt in the earlier schedule :

- **Climatic factors:** Radiation, precipitation, relative humidity, temperature and wind.
- **Soil factors**
- **Cultural factor**.

  The effect on affecting the frequency of irrigation is briefly explained hereunder. The two main consideration namely, water need of crops and the availability of irrigation water decide the irrigation frequency. Once these two are known, the frequency of irrigation is influenced mainly by climate, soil characteristics, crop characteristics and management practices.

i. Climate

- ✓ Climate is responsible for causing variations in consumptive use rate and frequency of irrigation.
- ✓ High temperature, low humidity, high wind velocity and greater solar radiation in a place emphasize the need to irrigate crops more frequently as evapotranspiration takes place at a higher rate due to greater evaporative demand of the atmosphere.
- ✓ This is particularly evident in arid regions and during summer season.
- ✓ On the other hand, higher rainfall and greater relative humidity during the rainy season reduce the irrigation requirement of crops and irrigations may be applied at longer interval, if it becomes necessary.

ii. Soil characteristics

- ✓ Water retentive capacity of soil is considered as the most important soil factor deciding the frequency and interval of irrigation.
- ✓ A soil with greater water retentive capacity serves as a bigger water reservoir for crops and can supply water for longer duration.
- ✓ Consequently, frequency of irrigation is lower and interval of irrigation is longer.
- ✓ On the other hand, the frequency is higher in porous sandy soils with coarse texture, poor structure and low organic matter content.
- ✓ Retention of greater amount of available water is considered more important than total quantity of water retained by a soil.
- ✓ Depth of soil is another factor that influences the frequency of irrigation.
- ✓ A shallow soil cannot hold enough water to meet the crop demand for a longer period. Necessarily, frequent irrigations are required with smaller depth of water each time.
- ✓ Irrigations at longer interval is applied to deep soil that has a greater water storage capacity.
- ✓ Such a soil can supply water for longer duration particularly when the rootsystem is quite deep and extensive.

iii. Crop characteristics

- ✓ Crops vary in their consumptive use of water, sensitivity to water stress, water extraction capacity and optimum water regime.
- ✓ Frequency of irrigation thus varies with crops.
- ✓ Crops like vegetables, onion and sugar beet that require a higher level of water to be maintained in the soil need frequent irrigations than other field crops.
- ✓ Many crops have varieties that are either sensitive or tolerant to drought conditions. Varieties sensitive to drought conditions require frequent irrigations compared to tolerant varieties.
- ✓ Rooting characteristics of crops such as shallow or deep, fibrous or tapering, vertically or laterally extensive root systems decide the frequency of irrigation.
- ✓ When the root system is shallow and fibrous, crops are not able to utilize water from deeper soil layers and are frequently irrigated with smaller depth of water to wet only the upper soil layers.
- ✓ Crops with deeper and extensive root system command a greater depth of soil and water reserve and require irrigations at longer interval.
- ✓ Sometimes, they may get water from water table which is not deep enough.
- ✓ Shallower water table reduces the irrigation requirements and help to increase the interval between irrigations.
- ✓ Besides, the concentration and relative proportion of the root mass in different soil layers decides the water extraction capacity.
- ✓ They represent the extraction capacity of crops from different depths of soils. Irrigation frequency varies with stages of crop growth.
- ✓ The consumptive use rate, sensitivity to water stress and rooting characteristics of crops change at different stages.
- ✓ A crop when young and delicate needs frequent irrigations.
- ✓ Subsequently, the consumptive use rate gradually increases and at the same time the root system also develops. Irrigations can then be applied at longer interval, as roots are able to draw water from greater volume of soils.
- ✓ When a crop approaches maturity, the demand for water greatly declines because of steep fall in consumptive use rate.

iv. Management practices

- ✓ Soil water conservation practices such as artificial or soil mulching and crop cultural practices like weeding and hoeing help to reduce the evaporation loss and conserve more soil water for crops use.
- ✓ Thus, there is a reduction in irrigation requirement of crops. Method of irrigation, depth of water applied each time and the water distribution efficiency influence the frequency of irrigation.

v. Irrigation period

- ✓ Irrigation period is the time, usually expressed in days, that can be allowed for applying one irrigation to a given design crop area during the peak consumptive use period of the crop.
- ✓ It is a function of the peak-period consumptive use rate. It is considered for designing the irrigation system capacity and equipment.
- ✓ The irrigation system must be so designed that the irrigation period is not greater than the irrigation interval.
- ✓

Climatological approach using irrigation water depth and evaporation relationship Evaporimeter

- ✓ Evaporimeters like United States Class-A open Pan Evaporimeter, Sunken Screen Open Pan Evaporimeter and atmometer may be used for irrigation control.
- ✓ They are employed to measure the evaporation loss, which is used to determine the consumptive use by crops by multiplying the evaporation values with crop coefficient values.
- ✓ The coefficient varies from 0.6 to 0.8 for most crops at their different stages. Irrigation is applied when crops consume the available soil water to certain limit, calculated on the basis of consumptive use rate as determined by evaporimeters.
- ✓ Sunken screen evaporimeter value can be used from the period of 25 per cent ground coverage by crops till their maturity.
- ✓ The values of pan evaporation for this purpose are found crops at their different growth stages under different soil and climatic conditions.

Depth of irrigation

- ✓ Depth of irrigation is a function of the water retentive capacity of and extent of soil water depletion at the time of irrigation.
- ✓ It refers to the depth to which the applied water would cover an area.
- ✓ The net depth of irrigation is decided by the amount of water required to bring the soil water content just b capacity in the root zone soil.
- ✓ The water content of soil just before irrigation must be known to calculate the net depth of water required to be applied. It is calculated by the following formula,

$$D = \sum_{i=l}^{n} F_{ci} - M_{bi} / 100 * a_{si} \times d_i$$

Where,

D= net depth of water to be applied or net irrigation, cm

F_{ci} = field capacity of the I-th layer of soil before irrigation to field

M_{bi} = water content of the i-th layer of soil just before irrigation, per cent by weight

a_{si} = apparent specific gravity of i-th layer of soil, g/cm^3

d_i= depth of i-th layer of soil in the root zone, cm

n = number of soil layers in the root zone d

- ✓ Usually, the soil zone that accounts for 90 per cent of the root mass needs to be wetted by irrigation when the crop is fully grown, but for an actively growing crop the soil little below the actively growing roots should be made moist.
- ✓ The depth of irrigation required for different soil types when soil water is depleted to 50 per cent availability are given in the following table.

Irrigation depths required for different soils at 50 Per cent Soil Water Depletion

Soil class	Depth of irrigation in millimeters per metre depth of soil
Sandy soil	40
Sandy loam soil	60
Loam soil	80
Clay loam soil	100
Clay soil	125

The concept of IW/CPE ratio in scheduling irrigation

Irrigation water/Cumulative pan evaporation ratio (IW/CPE ratio)

- ✓ The use of IW/CPE ratio is suggested as a practical basis of scheduling irrigation.
- ✓ The approach is based on the close and direct relationship of crop evapotranspiration with pan evaporation.
- ✓ When irrigation is applied, water is lost from the soil through evapotranspiration in the same way as the evaporation occurs from an open pan evaporimeter.
- ✓ It is ratio of the amount of irrigation water (IW) applied to cumulative pan evaporation (CPE). The pan evaporation values are added up every day till it is equal to certain ratio of the amount of water applied as irrigation.
- ✓ The ratio for various crops is determined experimentally by estimating the evapotranspiration by lysimeter studies.
- ✓ The IW/CPE ratios for various crops at different agro climatic conditions in India have been determined under ICAR Coordinated Project for Research on Water Management.

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Topic -Irrigation Scheduling – Different approaches

The artificial application of water in the field to fulfill moisture deficiet in root zone is known as irrigation.

Proper irrigation management demands application of water at the time of actual need of the crop with just enough water to wet the effective root zone soil. The principal aim is to obtain maximum crop yield by making the most efficient and economic use of water.

What is the Time of Irrigation

Time of irrigation is usually governed by two major conditions

(1) **water requirement/need of crops**: Water need of crops is, however the prime consideration to decide the time of irrigation.

(2) **Availability of irrigation water**: Irrigation water is often in short supply in most locations and therefore demands a careful and economic use. Economic use of water helps to bring more areas under protective irrigation and leads to greater crop production in areas of limited water supply. In areas where water is scarce, farmers are not able to apply normal irrigation to crops and are forced to skip some irrigation.

What are the Criteria for scheduling irrigation

- The optimum scheduling of irrigation should be based on crop needs to avoid both over and under-irrigation and to ensure high water use efficiency.
- A thorough understanding of the soil-water - atmosphere relationship.
- Irrigation needs of crops are decided by the evaporative demand of the atmosphere, soil water status and plant characteristics.

  Therefore the criteria for scheduling irrigation, as attempted from time to time, may be grouped into three categories:

  (1) plant criteria (2) soil water status (3)meteorological criteria.

1. **Plant Criteria:**
   - Plants show up certain characteristic changes in their constitution, appearance and growth behavior with changes in available soil water and atmospheric conditions.
   - Different plant criteria considered to schedule irrigation are presented below:-

1.1. Plant appearance
1.2. Plant water potential and water content
1.3 Plant growth
1.4. Critical crop stages of water need
1.5. Indicator plant
1.6. Stomatal aperture and Leaf diffusion resistance
1.7. Plant temperature

1.1. Plant appearance

With water stress, some characteristic changes usually occur in the general appearances of plants.

- ✓ Changes in the normal colour of plant
- ✓ distortions of plants such as wilting or drooping of plants
- ✓ Curling or rolling of leaves.

Some crops like leafy vegetables are very sensitive to soil-water changes and develop scarcity symptoms easily, while others do not.

Changes in colour appear first in the lower leaves.

For eg.Water stress is also shown by temporary wilting of plants, as with sugar beet during the hottest part of the day.

Fruit plants do not easily show up water stress by changes in appearance until serious retardation in growth takes place.

However an experienced orchardist can detect early signs of stress by the appearance of the foliage especially during the period of peak transpiration demand. Young leaves are the most sensitive part in this regard.

This technique is however quite simple and rapid, but suffers from many deficiencies.

Changes in colour may be misleading since nutritional disorder, insect damage, disease attack and varietal character cause variable changes in foliage colour.

1.2. Plant water potential and water content

- ✓ Some crops show strong correlation between the water content of leaf or leaf sheath and the available soil water.
- ✓ The relative leaf water content (RLWC) and leaf water potential change with variations in soil water availability or owing to lag between water absorption by plants and evaporative demand of the atmosphere.
- ✓ Adverse physiological and growth phenomena specific to plant species have been reported with fall in the RLWC and water potential below certain critical limits.
- ✓ As mentioned in the 3rd schedule a drop of 8-10% moisture(-5 to -6 bars of leaf water potential) causes a mild stress and crop is to be irrigated before the critical RLWC is reached.
- ✓ The RLWC and leaf water potential (LWP) values for the individual crops and their stages are to be standardized for scheduling irrigation. However, sophisticated equipment, intricate measuring devices, high cost and lack of proper standardization of instruments determine the use of this technique on a large scale.

1.3. Plant growth

- ✓ Cell elongation is considered as the growth process that suffers first with water stress in plant.
- ✓ Subsequently, retardation in growth of height or internodal length.
- ✓ Timing of irrigation can be set as and when the normal growth rate is observed to decline.
- ✓ This is, however, possible in places where a continuous measurement of plant growth is maintained.
- ✓ This technique offers many difficulties owing to unavailability and high costs of equipment.
- ✓ The serious objection to this approach of scheduling irrigation is that the plants suffer before they show any retardation in growth processes.

1.4. Critical crop stages of water need

- ✓ Irrigation scheduling may be decided based on stages of growth more conveniently in crops in which the physiological stages are distinct to locate the critical periods of water need.
- ✓ Scheduling of irrigation based on these critical stages is most convenient .
- ✓ Farmers who may need, at the most, some guidance or education initially.
- ✓ However, it may be a little difficult in crops where stages are not so well defined.

1.5. Indicator plant

- ✓ There are some plants sensitive to soil-water variations.
- ✓ They may be used for detecting the water stress in crops that do not show symptoms of water stress easily or exhibit the same when they have already suffered seriously.
- ✓ Sunflower plants are often used as indicator plants in onion crop.
- ✓ An indicator plant for irrigation should be such that it shows the water stress before the crop has suffered from it.
- ✓ When an indictor plant is grown in a crop field, care should be taken not to shade the plant by crop plants.

1.6. Stomatal aperture and Leaf diffusion resistance

- ✓ Opening of stomata in plants is regulated by soil water availability.
- ✓ Stomata remain fully open when the supply of water is adequate, whereas they start closing with scarcity of water in soils to restrict the transpiration.
- ✓ Water deficit in plants is directly related to availability of soil water and that may be used for scheduling irrigation in crops.
- ✓ A close relationship exists between leaf diffusion resistance (LDR) and plant water stress.
- ✓ LDR is a sensitive index of internal water balance in the mild to moderate stress range and holds a promise for scheduling irrigation.

1.7. Plant temperature

- ✓ Solar radiation received on earth heats up leaf tissues besides causing evapotranspiration and heating up the ambient air.
- ✓ With water deficit in plant the temperature of leaf tissues rises.
- ✓ Many investigations have shown that leaf or canopy temperature is a sensitive index of plant water status.

2. Criteria based on soil water status

- ✓ Scheduling irrigation based on soil water content is the most accurate and dependable method.
- ✓ Determination of available soil water is rather more important than estimating the total water content of soils.
- ✓ For the purpose, information on the optimum water regime of crops and the available water holding capacity of soils is essential.
- ✓ Irrigation is applied when the soil water content reaches the lowest point of optimum soil water regime.
- ✓ The optimum water regime for a crop in a place is determined experimentally by correlating yield with the water contents of soils.
- ✓ Various methods are used to determine the soil water status and farmers may choose any of the methods according to their needs, accuracy wanted and facilities available for estimating soil water.

- ✓ The criteria based on soil water status attempted or used to schedule irrigation to crops are discussed here.

2.1. Soil water content

- ✓ Early attempts were made to schedule irrigation when the soil water content reached a certain value.
- ✓ The idea did not succeed since there existed a wide variation in the water content retained by the different classes of soils.
- ✓ However later a new concept of scheduling irrigation based on the lower limit of soil water content for potential evapotranspiration of crop was made.
- ✓ In this approach it was assumed that the growth of crop was likely to suffer below a level of soil water.
- ✓ This threshold limit could be decided for various crops, soil types and atmospheric evaporability.
- ✓ In the fruit crops, irrigation is more effective if applied before soil moisture becomes limiting. As a rule of thumb, water should be applied when 50% of the available water in the root zone has been depleted. If further depletion is allowed, the plants may be subjected to a level of stress that might cause an appreciable reduction in yield.

2.2. Depth-interval of irrigation

- ✓ Since the water retentive capacity of soils varies widely with soil types and soil physical conditions,
- ✓ The root zones of crops vary with types of crops and their rooting characteristics at different growth stages.
- ✓ The depth and interval of irrigation require modifications in different soils and at various crop growing periods.
- ✓ The drawback of this method is that an arbitrarily fixed depth or interval of irrigation has misleading effects on crop growth and yield.

2.3. Critical level of available soil water

- ✓ As stated earlier, the critical level of soil water denotes the level of available water below which the crop growth and yield decline drastically.
- ✓ It is the lowest level of the optimum soil water regime.
- ✓ This level once established experimentally for various crops in different soil types and soil conditions can be profitably used for scheduling irrigation.
- ✓ This approach has been widely suggested for adoption.
- ✓ A periodical determination of soil water content is made to know the time when the soil water is likely to reach the critical level.
- ✓ This criterion is synonymous with the concept of available soil water depletion for deciding the time of irrigation.
- ✓ The depth of irrigation however needs revision upwards every time with increasing vegetative growth and rooting depth of an actively growing crop.
- ✓ In fruit trees more than 80% of water is drawn from 0 – 90 cm layer and amount water to be added to fill only this depth of soil. But during summer the depth of soil to be taken for consideration extends up to 120cm.
- ✓ The critical ASM limit for crops like brinjal, chilli and cucumber is 50%; Tomato, onion, garlic and cabbage is 60% and cauliflower and leaf vegetables is 70%.

2.4. Soil water tension

- ✓ Many scientific workers have used this criterion for scheduling irrigation to crops in various parts of the world.
- ✓ Tensiometer techniques are used for irrigation.

- ✓ In many countries, the tensiometer has been considered as a useful device for scheduling irrigation to orchard and vegetable crops, particularly on coarse textured soils where most of the available water is held at low tensions.
- ✓ The use of tensiometer for controlling irrigation did not find much favour with common farmers since the device presents certain difficulties in its use.
- ✓ The tensiometer can be used only in the lower tensions up to 0.85 bars.
- ✓ It does not show the actual soil water content for direct calculation of the depth of irrigation to be applied.
- ✓ The water content is calibrated from the soil tension curve.
- ✓ Again, there exists a time lag in tension equilibrium between the porous cup and the surrounding soil that makes the tensiometer showing the energy status of soil water earlier to the existence of the actual soil water content.

2.5. Electrical resistance

- ✓ The concept of electrical resistance that varies inversely with the water content in soils was also tried to schedule irrigation.
- ✓ For this purpose, resistance blocks made of gypsum, nylon, nylon-resin etc, were used. Crops were irrigated when the electrical resistance reached a certain value.
- ✓ The value could be decided experimentally for various crops by using the resistance blocks. This method has however many limitations and did not become popular.
- ✓ The limitations are that resistance blocks cannot be used at low tension at which most of the available water is held by soils, difficulty in deciding the depth of irrigation as resistance blocks do not directly show the prevailing soil water content and the existence of a time-lag in tension-equilibrium between the porous block and the surrounding soil which causes showing up the energy status of soil water earlier.

3. Meteorological criteria: solar radiation, Ambient air temperature, wind velocity, relative humidity and precipitation.

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Topic -Climatological approach for estimating water requirement. Use of pan evaporimeter, Pan Factor

It is necessary to conduct field experiments for precise data on crop water requirements. In view of the difficulties associated with direct measurement of crop water requirements, some methodologies have been developed to predict the water requirements, primarily, based on climatological factors.

The FAO group of scientists screened 31 empirical formulae for predicting the ET and recommended four for use under different climatic conditions.

1. Blaney – Criddle method
2. Radiation method
3. Modified Penman method
4. Pan evaporation method

Three major steps involved in the estimation of ET are

- ✓ Estimation of PET or reference evapotranspiration (ET_o)
- ✓ Determination of crop coefficient (k_c)
- ✓ Making adjustments to location specific crop environment

The choice of prediction method for the determination of ET_o is primarily determined by the available climatic data.

1. Blaney-Criddle method

The original Blaney-Criddle prediction method for determining ET_o was modified to improve the accuracy.

ET_0=C [P (0.46T+8]

Where,

ET_o = reference evapotranspiration (mm day^{-1}) for the month considered

C = adjustment factor depending on RH_{min}, daytime wind velocity and ratio of actual sunshine hours to maximum possible sunshine hours.

T=mean daily temperature (^oC) for the month under consideration

P=mean daily percentage of total annual daytime hrs.

- ✓ The ETo may be computed with any one of the empirical formulae proposed by Blaney – Criddle, modified Penman, radiation and pan evaporation methods using mean climatic data for the period desired.
- ✓ To find out the crop ET (ET crop) the ETo values calibrated by the relationship called crop coefficient (Kc).
- ✓

2. Radiation method

The crop evapotranspiration is estimated by the formula

$ET_o = C\ (W.Rs)$

Where,

C=the adjustment factor made graphically on W.Rs using estimated values of RH mean and day time wind velocity

W = the temperature and altitude dependent weightage factor

Rs = the solar radiation in equivalent evaporation (mm/day)

Rs can be measured directly by solar monitor with pyranometer sensor. It can also be obtained from measured sunshine duration records as

$Rs = (0.25+0.50\ n/n)\ RA$

Where,

R_A= the extra terrestrial radiation in equivalent evaporation in mm/day

n = actual measured bright sunshine hours

N= maximum possible sunshine hours

3. Penman formula

- ✓ Penman (1948) suggested a formula using the important climatic parameters such as solar radiation, temperature, vapour pressure and wind velocity to compute the evaporation from open free water surface.
- ✓ Estimates of crop ET are obtained by multiplying the estimated values of evaporation by crop coefficient.

3.1 modified penman method:

- ✓ Doorenbos and pruit (1975) proposed a modified penman method for estimating fairly accurately the reference crop ET and gave tables to facilitate the necessary equation.
- ✓ The penman method is quite satisfactory for both humid and arid regions under calm weather conditions.
- ✓ It has the advantage over other two methods as it uses many climatological parameters for the estimate off crop ET.
- ✓ Drawbacks are that the method requires many climatological parameters that may not be available in many meteorological stations and the computation procedure is cumbersome.

4. Pan Evaporimeters

- ✓ Seasonal consumptive use of crop (CU) is determined by using (USWB) Class-A Pan Evaporimeter, sunken Screen Pan Evaporimeter or Piche Atmometer.
- ✓ The USWB class-A pan evaporimeter is however most widely used.

4.1. USWB Class-A pan evaporimeter

- ✓ The standard USWB Class-A pan evaporimeter is the most widely used evaporimeter in the world for finding evaporation from the free water surface.
- ✓ It consists of a 121.5 cm diameter and 25.4 cm deep pan made of 20 gauge galvanized iron sheet with a stilling well.
- ✓ A vertical pointer is provided in the stilling well to show the level of water maintained in the pan.
- ✓ The pan is painted white and is placed on a wooden frame so that air may circulate beneath the pan.
- ✓ Daily evaporation rate is given by the fall of water level in the stilling well during 24-hour period.

- ✓ Measurements of the fall of water level may be made at closer intervals to know the evaporation rate during different parts of a day. Water levels in the stilling well are measured by hook gauge.
- ✓ Adjustments are made to the evaporation values if rain occurs during a period of measurement.
- ✓ The rainfall is measured by standard rain gauge.
- ✓ Evaporation loss may also be computed from the measured quantity of water added to bring the water level to the tip of the pointer in the stilling well.
- ✓ The amount of water added is divided by the surface areas of pan and stilling well to gether to find out the depth of water added which is taken as the daily evaporation rate.
- ✓ After measuring the fall in water level each time, water is added to the pan to bring back the water level to the original position of pointer tip level.
- ✓ As the rate of evaporation from pan evaporimeter is higher than that over a large free water surface, the pan evaporation value is multiplied by 0.7 to obtain the evaporation rate over the large free water surface (E_o).
- ✓ The relationship between actual evaporation and pan evaporation rates may be presented as,

$$Eo = Kp \cdot Epan \text{ or, } Kp = Eo/Epan$$

Where,

K_p = Pan evaporation coefficient (a commonly used value of 0.7)

E_{pan} = Evaporation value from pan evaporimeter

4.2. Sunken screen pan evaporimeter

- ✓ Sharma and Dastane (1968) developed the sunken screen pan evaporimeter that provides evaporation values more close to crop ET values than the USWB Class-A pan evaporimeter.
- ✓ The crop coefficient values in a sunken screen pan evaporimeter was found to be 0.95 to 1.05 in New Delhi, while that in a USWB Class-A pan evaporimeter varied from 0.5 to 1.3 for different crops in different locations.
- ✓ However, this device requires extensive evaluation under varying climatic and crop conditions.
- ✓ The evaporimeter consists of a 60 cm diameter and 45 cm deep pan made of 20 gauge galvanized iron sheet and stilling well of 15 cm diameter and 45 cm depth attached to the pan with a tube.
- ✓ The pan and the well are painted white and screened at the top with 6/20-mesh wire net.
- ✓ The stilling well has a pointer inside at the centre.
- ✓ The pan with the well is buried in the soil with 10 cm edge over the soil surface.
- ✓ The fall of water level in the well during 24-hour period is taken as the measure of the evaporation rate per day.
- ✓ Further, evaporation rate may be computed from the measured quantity of water added daily to bring the water level to the pointer tip level after each measurement.
- ✓ Tip of the pointer should be at level with the soil surface while installing the evaporimeter.
- ✓ The pan is located in the field with no obstruction to wind movement over the pan.

4.3. Piche atmometer

- ✓ Piche atmometer is sometimes used to measure the evaporation rate.

- ✓ It consists of a graduated tube 1.5 cm in diameter and 30 cm long with one end open and a flat horizontal disc of drier paper placed to the open end.
- ✓ The tube is filled with water and then the drier paper placed to the open end.
- ✓ The tune is filled with water and then the drier paper is placed in position and held to the tube by a metallic device.
- ✓ Atmometer is laid in an inverted position for evaporation measurement in the field. Water from the tube wets the paper slowly and evaporates from the paper.
- ✓ The loss of water is read on the graduated tube that gives the measure of evaporation.
- ✓ The rate of evaporation from atmometer is usually higher than that obtained from USWB Class-A pan evaporimeter and is poorly correlated with the crop ET.
- ✓ It tends to overestimate the wind effect and grossly underestimate the radiation effect.
- ✓ The evaporating surface of the unit isoften subjected to contamination by dust, oil and other foreign materials interfering with the evaporation process.

Crop factor-Factor for different growth stages

Kc values of crops

- ✓ Crop coefficient is the ratio between crop ET and potential ET.
- ✓ Crop coefficient depends on soil cover, soil moisture and crop height.
- ✓ At early stage crop covers only a fraction of soil and covers as it matures.
- ✓ The rate at which plants grow and cover the soil depends on the crop.
- ✓ In the early stage main component of ET is evaporation, while under fully covered condition transpiration is the main component.
- ✓ ET of a crop depends on plant height and leaf area index.
- ✓ Tall plants with high LAI transpire more water than short plants with low LAI.
- ✓ The relationship between ETo and ETc is expressed as

$$ETc = ETo \times Kc$$

- ✓ ETc is also known as maximum evapotranspiration ET (max).
- ✓ Kc value is inbuilt with crop and soil characteristics and management practices and varies with in the crop duration.

For a precise estimate duration of (annual) crop is divided into four stages:

(i) **Seedling stage** which represents germination and early growth when the soil surface is hardly covered by the crop and the ground cover is less than 10 per cent

(ii) **Active vegetation stage** form the end of initial stage to attainment of effective full ground cover which is less than 80 percent coverage

(ii) **Reproductive stage** from attainment of full ground cover to first sign of maturity as indicated by discolouration of leaves ,leaf falling etc.

(iii) **Maturity stage** from reproductive stage to full maturity.

- ✓ Crop coefficients vary with relative humidity and wind velocity.
- ✓ Strong winds and low RH cause more transpiration.
- ✓ In brief Kc values vary with crop development stage of the crop
- ✓ and to some extent with wind speed and RH.

- ✓ For most of the crops, Kc value increases from a low value at the time of emergence to a maximum value during the period when the crop reaches flowering and declines as the crop approaches maturity.

Crop coefficients for different growth stages

- ✓ Crop coefficient (Kc) value varies with the development stage of the crop.
- ✓ For most crops the value for total growing period is between 0.85 and 0.9 with the exception of higher value for banana, coffee and cocoa and lower value for citrus, grape, sisal and pineapple.
- ✓ In general, Kc is higher in hot, windy and dry climates than in cool, calm and humid climates.
- ✓ The values vary among crops due differences in reflectivity, crop height and roughness, degree of ground cover and canopy resistance to transpiration.
- ✓ In the case of annual crops , kc typically increase from a low value at seedling emergence to a maximum when the crop reaches full ground cover, continues at that value during the stage of full activity and declines as the crop matures.

Course – Water Management in Horticultural crops, 2(1+1)
B.Sc. (Horticulture)I[st]Year II[nd]Semester
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Topic 1 -Soil Moisture Constants

• Water contents under certain standard conditions are referred to as soil moisture constants.

1. **Saturation capacity:**
   Saturation capacity refers to the condition of soil at which all the macro and micro pores are filled with water and the soil is at maximum water retention capacity.
2. **Field capacity**:
   - At field capacity, the soil moisture tension depending on the soil texture ranges from 0.10 to 0.33 bars (or −10 to −33 kPa).
   - field capacity is considered as the upper limit of available soil moisture or Field capacity is the amount of soil moisture or water content held in soil after excess water has drained away and the rate of downward movement has materially decreased, which usually takes place within 2-3 days after a rain or irrigation in pervious soils of uniform structure and texture.
   - The physical definition of field capacity (expressed symbolically as θ_{fc} "the bulk zvater content retained in soil at -33 J/kg (or -0.33 bar) of hydraulic head or suction pressure".
   - Field capacity (FC) is the amount of water that a soil can hold against drainage by gravity.
   - This usually occurs between 1/10 atm. (coarse soils) and 1/3 atm (heavy soil).

Physical Classification of Water

1. Gravitational water: Water held between 0.0 to 0.33 bars (0 to −33 kPa) soil moisture tension, free and in excess of field capacity, which moves rapidly down towards the water table under the influence of gravity is termed as gravitational water.

2. Capillary water: As the name suggests capillary water is held in the pores of capillary size i.e., micro pores around the soil particles by adhesion (attraction of water molecules for soil particles), cohesion (attraction between water molecules) and surface tension phenomena. It includes available form of liquid water extracted by growing plants and is held between field capacity (0.33 bars or −33 kPa) and hygroscopic coefficient (31 bars or −3100 kPa).

3. Hygroscopic water: The water held tightly in thin films of 4 – 5 milli microns thickness on the surface of soil colloidal particles at 31 bars tension (−3100 kPa) and above is termed as hygroscopic water

Types of water movement • Generally three types of water movement within the soil are recognized –saturated flow, unsaturated flow and water vapour flow.

1. Saturated water movement: The condition of the soil when all the macro and micro pores are filled with water the soil is said to be at saturation, and any water flow under this soil condition is referred to as saturated flow.

2. Unsaturated water movement: The soil is said to be under unsaturated condition when the soil macro pores are mostly filled with air and the micro pores (capillary pores) with water and some air, and any water movement or flow taking place under this soil condition is referred to as unsaturated flow.

Water absorption by plants

Mechanism of Absorption of Water: In higher plants water is absorbed through root hairs which are in contact with soil water and form a root hair zone a little behind the root tips. Mechanism of water absorption is of two types:

1. Active Absorption of Water: In this process the root cells play active role in the absorption of water and metabolic energy released through respiration is consumed.

2. Passive Absorption of Water: It is mainly due to transpiration, the root cells do not play active role and remain passive.

Topic-2 . Available and Unavailable water

- The water held by soil between field capacity and wilting point and at a tension between 0.33 and 15 atm is available to plants and is termed as available water.
- It comprises the greater part of capillary water.
- Availability of water to plants is more in the upper range of available water that is, at field capacity or near to it.
- It decreases sharply as the water content approaches the wilting point.
- It means that at field capacity the available water is 100 % whereas at PWP the available water is 0%.
- The range of available water that can be stored in soil and be available for growing crops is known as available soil water/moisture.
- It is the difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point referred to as the available water or moisture.
- Readily available water (RAW) is that portion of available water which the crop uses without affecting its evapotranspiration and growth. This portion is often indicated as a fraction of available water which is dependent primarily on the type of crop and evaporative demand.
- Many shallow rooted crops, such as most vegetables, require high moisture levels for acceptable yields. Deeper rooted crops will generally tolerate higher depletions.
- The water readily available to plants is the difference between water content at field capacity (θ_{fc}) and permanent wilting point (θ_{pwp})

$$\theta_a = \theta_{fc} - \theta_{pwp}$$

Unavailable water

- There are two situations at which soil water is not available to most plants.
- When the soil water content falls below the permanent wilting point and is held at a tension of 15 atmosphere and above.
- When the soil water is above the field capacity and is held at a tension between 0 and 1/3 atmosphere.

- Water in the former situation is held tenaciously by soil, while that in the latter situation moves downward under gravity. Water under both the situations, is termed as unavailable water.

Topic 3. - Plant characteristics

Soil – Plant and Plant – Water Relations

- To design a successful irrigation system, it is essential to know the plant rooting characteristics, effective root zone depth, moisture extraction pattern and moisture sensitive periods of crops.

Rooting characteristic of plants:

- The purpose of irrigation is to provide adequate soil moisture in the immediate vicinity of the plant roots.
- All plants do not have the similar rooting pattern i.e., root penetration and proliferation. Some plants have relatively shallow root system (for example annual crops), while others develop several meters under favorable conditions (for example tree crops).

Root characteristics

- Root systems in the field are seldom uniform with depth.
- In a shallow soil, roots may be confined to a thin layer of soil irrespective of their usual
- pattern.
- Similarly, high water table limits normal root growth. Crops with extensive and dense roots can
- utilize soil moisture more effectively and lower residual soil moisture than crops with sparse and shallow roots.
- Rooting depth of annual field crops on deep well drained soils range from 0.30 to 2.0 m.
- In general, the root zone depth of crops on clayey soils is reduced by 2.5 to 35 per cent
- and on sandy soils increased by 2.5 to 35 per cent.

Table1. Rooting depths (m) of annual crops on deep well drained soils.

- Onion 0.3 - 0.5
- Chillies 0.6 – 0.9
- Maize 1.0 – 1.6
- Cabbage 0.4 - 0.5
- Peas 0.6 – 1.0
- Soybean 1.0 – 1.5
- Cauliflower 0.3 - 0.5
- Tomato 0.7 – 1.5
- Potatoes 0.4 – 0.6

- The soil depth from which the crop extracts most of the water needed to meet its
- evapo-transpiration requirements is known as effective root zone depth (table 1.).
- It is also called as design moisture extraction depth, the soil depth used to determine irrigation water requirements for design.
- It is the soil depth in which optimum available soil moisture level must be maintained for high productivity of crops.
- If two or more crops with different rooting characteristics are to be grown together, the design depth should be that of the crop having the shallower root system.

Soil properties influencing root development

1. Hard pan: Root penetration is seriously affected by presence of a hard pan or compacted layer in the soil profile. Thus roots cannot penetrate a hard layer except through cracks.

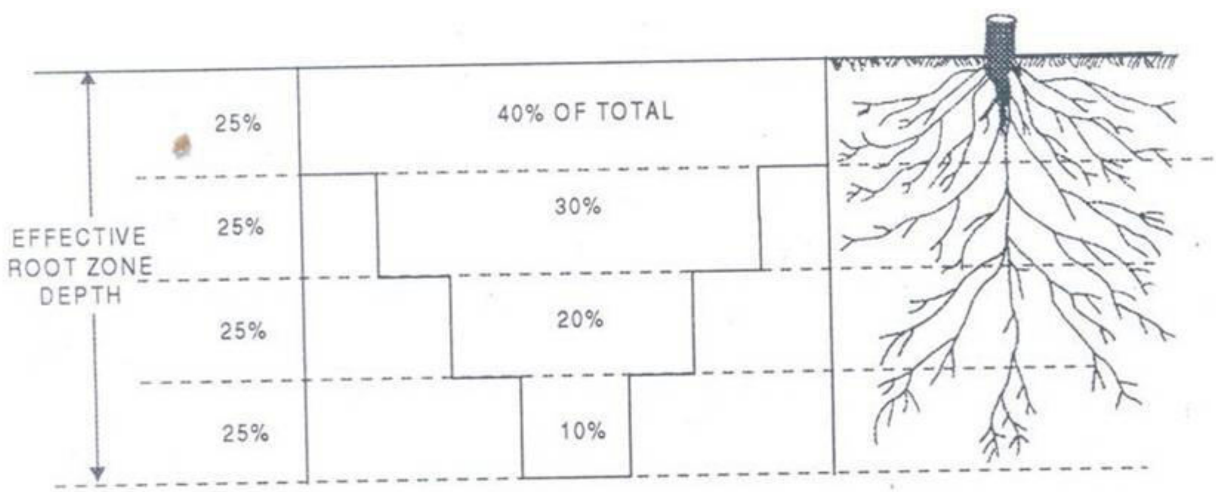
2. Soil moisture: Since roots cannot grow in soil that is depleted in moisture down to and below the permanent wilting point, a layer of dry soil below the surface in the profile can restrict root penetration.

3. Water table: A high water table limits root growth, and a rising water table may kill roots that have previously grown below the new water level. 4. Toxic substances: Presence of toxic substances in the sub-soil also limits root growth and development. Saline layers or patches in the soil profile therefore inhibit or prevent root penetration and proliferation.

Topic 4. -Moisture extraction pattern

- For most plants, concentration of absorbing roots is greatest in upper part of the root zone and near the base of plants.
- Extraction of water is most rapid in the zone of greatest root concentration and under favorable environmental conditions Usual moisture extraction pattern show that about 40 per cent of the extracted moisture comes from upper quarter of the root zone, 30 per cent from second quarter, 20 per cent from third quarter and 10 per cent from fourth bottom quarter.
- This general pattern of extraction slightly varies with irrigation frequency.
- With higher the frequency of irrigation, the moisture extraction is greater from first quarter of the root zone than the others.
- Low frequency irrigation leading to depleting soil moisture results in more moisture extraction from lower quarter of the root zone soil depth.

Fig.1 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
- 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 m2 of soil surface area as against 15-200 cm m2 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.

Topic 5.- Water requirement of horticultural crops and Lysimeter studies

- The estimation of the water requirement (WR) of crops is one of the basic needs for crop planning on a farm and for the planning of any irrigation project.
- Water is mainly needed to meet the demands of evapo transpiration (ET) and the metabolic activities of plant, both together known as consumptive use (C or U). Since the water used in the metabolic activities of the plant are negligible, ET is practically considered equal to Cu.

Water requirement defined

- Water requirement may be defined as the quantity of water, regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place.
- Water requirement, includes the losses due to ET (or CU) plus the losses during the application of irrigation water and the quantity of water required for special operations such as land preparation. It may be formulated as follows:

  WR= ET or CU + application losses + special needs.

Based on the sources of water supply to meet the water requirement, numerically it is represented as, WR=IR+ER+S *i. e.,* Irrigation water (IR), effective rainfall (ER) and soil profile contribution (S).

Classification of consumptive use of water

- **Daily consumptive use**: The amount of water consumptively used during 24 hour period is called the daily consumptive use.

- **Peak period consumptive use:** The average daily consumptive use during a few days (usually 6 to 10 days) of the highest consumptive use in a season is called the peak period consumptive use.

- **Seasonal consumptive use:** The amount of water consumptively used by a crop during the entire growing season or crop period is called the seasonal consumptive use.

Classification of ET

Potential evapo-transpiration (PET):

- The term denotes the highest rate of evapotranspiration (ET) by a short and actively growing crop or vegetation with abundant foliage completely shading the ground surface and abundant soil water supply under a given climate.
- It integrates the evaporating demand of the atmosphere and refers to the maximum water loss from the crop field.

Reference crop evapo-transpiration (ETo):

- The term is used to express the rate of evapo-transpiration from an extended surface of 8-15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water.
- The ET is corrected for day and night weather conditions to ETo (adjusted reference crop ET) by multiplying with the adjustment factor.

Actual crop evapo-transpiration (ET crop):

- Refers to the rate of evapotranspiration by a particular crop in a given period under prevailing soil, water and atmospheric conditions. It involves the use of a crop factor called, crop co-efficient while computing it from reference crop ET (ETo) estimated by different empirical formulae or evaporation rates from evaporimeters.
- The ET crop varies under different soil, water and atmospheric conditions and at different stages of crop growth, geographical location and season of the year.

Factors affecting ET

1. **Climatic factors:** Radiation, precipitation, relative humidity, temperature and wind.
2. **Soil factors:** Soil factors such as texture, hydraulic conductivity, water holding capacity, crop residues on the soil surface, colour and rough surface of the soil affects the ET.
3. **Plant factors:** Plant morphology, crop, variety, crop geometry, extent of plant cover, stomatal density, duration of the crop, rooting characteristics, growth phase, crop growing season,etc.
4. **Cultural practices:**
   - Weed control is necessary to reduce the water loss through transpiration by weeds.
   - Fertilizer application increases the ET and CU by producing greater biomass and developing a deeper and extensive root system.
   - However, the CU does not vary widely between well-fertilized and under - fertilized crops.
   - Mulching reduces the ET by reducing the evaporation from the bare soil, reflecting the solar radiation and reducing the weed infestation.
   - Mulching has a greater effect in reducing the ET when the crop cover is relatively small.

Estimation of water requirement for horticultural crops

Annuals and biennials

- The vegetable crops are mostly annuals and their duration extends from two to five months or a single season.
- Some may be biennial and the season may get extended. Thevegetable crops are sensitive to water stress.
- The water requirement is normally expressed for the entire period of the crop in the field. The crop water requirements are worked out for this period.
- The requirement could be estimated by all the methods.

Perennial

- Fruit crops are mostly perennials.

- When an orchard is first established, transpiration is very low because of the small crop canopy. Most water lost from the soil is by evapotranspiration from among the trees.
- With the increase in years the trees grow and a large canopy is established. The water is expressed for one year or daily basis.
- The water requirement of perennial crop through lysimeter is not a practical proposition. Hence other methods may be used to assess the water requirements.

Methods of estimating evapo-transpiration

Various methods are employed to estimate the crop ET or CU. The methods may be grouped into (i) direct methods, (ii) empirical methods and (iii) pan evaporimeter method

I. Direct Methods

Direct methods are the water balance or hydrologic methods and include

(1) lysimeter, (2) field experimentation, (3) soil water depletion, and (4) inflow-outflow methods. They give reliable values, but require elaborate installations and precise measurements.

(2) They are however costly, laborious and time consuming.

1. Lysimeter method

- The lysimeter method is very important in measurement of not only the ET but also the various components of water balance.
- A lysimeter is a device by which an experimental soil located in a container is provided with hydrologic separation from the surrounding soil.
- The method involves growing crops in lysimeters installed in crop fields to provide the crop environment and measuring the water balance during the crop growing period.
- Measurements of different components for water balance studies such as water added to lysimeters through precipitation and irrigations, change in soil water storage, and water lost through evaporation, transpiration, run-off and deep percolation are made.
- This can be expressed as,

$$\mathbf{ET = P + IRn + \_SW - (R+PW)}$$

Where,

P=precipitation, cm

IR n = net irrigation requirement of crop, cm

SW = soil water contribution (the difference between soil water contents at sowing and at harvest of crop in cm)

R = surface runoff, cm

PW = deep percolation, cm

or

$$\mathbf{CU \text{ or } ET = ER + IRn + \_SW}$$

Where,

ER = effective precipitation, cm

ER = P- (R+PW) = effective rainfall, cm

- Increase with the development of canopy, the evaporation from the adjacent soil surface gradually decreases, while the transpiration and the resultant ET increase.
- Crop density influences the ET in the same way as the crop cover influences the ET.

- The plant population and other crop management practices that affect the net radiation at the soil surface, change the ET unless the soil surface and plants get constant water supply.
- With lower plant population, the ET is low.
- Plant height increases ET by greater interception of advective heat.
- Root spread governs the ET to the extent roots encounter water in the soil profile, when the soil water is limiting in upper part of the soil.
- This is quite important particularly in arid and semi-arid areas where deep-rooted crops have higher ET than shallow rooted ones.

- Lysimeters are installed in fields with a fairly large guarded area having the same crop as in the lysimeter.
- The guarded areas are irrigated whenever the lysimeter crop is irrigated.
- The soil is placed in the lysimeters as close to *in-situ* condition as possible.
- Both the weighing and nonweighing type lysimeters are used for measurement of ET.
- When very short period (daily or hourly) estimates are wanted, the weighing type lysimeter is installed.
- In weighing type lysimeters, the container is placed inside a tank containing some suitable liquids (water or $ZnCl2$ solution) so that the lysimeter container remains floating to ease the weighing.
- An overhead portable balance may be used for weighing. The changes in the buoyancy or in the hydraulic load are calibrated to estimate the loss in weight of the lysimeter owing to evapotranspiration.
- The loss in weight gives the measure of the evapotranspiration. A deduction is made for any loss due to deep percolation.
- Estimates of consumptive use by nonweighing type lysimeters are made following the soil water depletion method as discussed later in this chapter.
- Soil water measurements may be made by neutron scattering meter or gravimetric method. The former is preferred.
- Determination of soil water content by gravimetric method requires replicated soil sampling. The change in soil water content is worked out by using equation.

2. Field experimentation method

- Field experiments with treatments having varying levels of irrigation are carried out to estimate the seasonal consumptive use of irrigated crops.
- The water table should be at a considerable depth (at least 3 metres deep for field crops). Measurements of water supplied to the crop through effective rainfall and irrigation and changes in the soil water reserve during the growing season are made.
- The water thus supplied to the crop under treatments of varying levels of irrigation is correlated with the yields obtained.
- The quantity of water used to produce the yield that appears most profitable is taken as the CU.

3. Soil water depletion method

Consumptive use of crops may be determined by soil water depletion studies on a fairly uniform soil.

- Water table should be deep enough (at least 3 m deep) so that it does not influence the soil water fluctuations in the root zone.
- Soil water content in different layers of the root zone are measured just before and after irrigation or rainfall (immediately, as early as soil sampling is possible after irrigation) and during the period between two successive irrigations as frequently as possible depending on the degree of accuracy desired.
- Frequent soil water measurements give more accurate information.
- The soil water depletion during any short period is considered as the consumptive use (CU) and is obtained by summing up soil water depletion or losses of soil water during the different periods of measurements in the growing season.

4. Inflow-outflow methods

- The inflow – out flow method is applied for estimating the yearly CU over large area. It is also called water balance method. It may be formulated as follows.

$$\mathbf{CU= P+I= GW - R}$$

Where,

CU = Yearly consumptive use over a large area, hectare metres

P= Yearly precipitation, hectare meters

GW= Change in ground water storage, hectare metres

R=Yearly outflow from the area, hectare metres

The change in soil water storage in the profile is not included as it is considered negligible. It is assumed that the subsurface inflow into the area is the same as the subsurface outflow.

Topic 6.- Plant – water relations
Plant-water potential- Climatological approach

1. Plant-water potential- Climatological approach

- Energy status of water in plant cells is determined by three major factors *viz*., turgor pressure (p) imbibitional pressure (m) and solute or osmotic pressure (s).
- Pressures arising both from gravitational forces and intercellular pressure can be included in the turgor pressure term.
- Total potential of water in plants can be expressed as indicated below:

$$\Psi= \psi_p + \psi_m + \psi_s$$

Where, ψ=total water potential

Ψ_p= turgor potential (equivalent to pressure potential in soils)

Ψ_m= imbibitional potential (equivalent to matric potential in soils) and

Ψ_s=solute or osmotic potential.

1.1. Relative Water Content

- Relative water content (RWC) is the ratio of actual water content to water content at saturation (fully turgid) and is generally expressed as percentage.
- Actual water content is obtained by subtracting dry weight (DW) of the sample from the fresh weight (FW).
- Water content at saturation is the difference between saturation weight or turgid weight (TW) and dry weight.
- Major areas of water-plant relationships in irrigation water management are:

- Water absorption
- Water loss or transpiration.

1.2. Water absorption by plants

- Plants absorb water from soil through roots, rain and water sprays through foliage.
- Young roots offer largely the water absorbing surface in actively growing annual plants, while they offer relatively a small fraction of the total absorbing in old perennial plants and trees.
-
- A young growing root tip consists of a root cap, a zone of maximum meristematic activity, region of rapid cell elongation and a region of quick cell differentiation and maturation.
- A rapid absorption of water occurs through younger part of the root immediately basal to the region.
- It is usually the area where root hairs grow extensively;
- Root hairs are thin walled protuberances of the epidermal cells.
- They present relatively large absorbing surface.
- The xylem elements develop to conduct water up the plantsystem.
- Suberization of cell walls reduces the permeability to water.
- But a considerable volume of water is absorbed, though slowly, through suberized roots in older plants.
- The role of such roots in water absorption is very important as they comprise the largest portion of a root system in older plants and trees and offer relatively large water absorbing surface.

1.3. Water absorption processes

- Water absorption by plants occurs by two processes namely active absorption and passive absorption.
- In active absorption plants play an active part.
- In passive absorption water is absorbed mechanically through roots without plants playing an active role .
- plants present simply the absorbing surfaces.

1.4. Factors affecting water absorption

Water absorption by plants is influenced by atmospheric, soil and plant factors.

1.5. Water conduction

- Water is conducted from the root surface to leaf surface through the plant body.
- The difference of ψ air and ψ root surface results in the ascent of water.
- The transpiration from leaf surface sets up imbibitional forces in the mesophyll cells that are transmitted through the hydrodynamic systems in the plant to the root surface.
- Water moves in liquid form from the soil to leaf cells through root cells and the conductive system of xylem.
- It moves in vapour form from leaf cells to the air through intercellular spaces in the leaf and stomatal openings.
- The xylem functions in water conductivity.
- The water conduction is based on the cohesion theory.

2. Transpiration

- Transpiration is the process by which plants loss water in vapour form into the air through their aerial parts, mainly leaves.
- It involves nearly 99 per cent of the volume of water absorbed by young plants.

- Usually about 95 per cent of the water absorbed is transpired and only about 5 per cent is used by the plant for metabolic purpose and making the body weight.
- About 90 to 95 per cent of transpiration occurs during the day time and 5 to 10 percent during the night time.
- Pineapple which is a Crassulacean acid metabolism (CAM) plant is the exception in which most of the stomata remain open during the night time and the major transpiration takes place at night.
- Transpiration rate in the morning is less. It increases with the increase in temperature during the day time and reaches the maximum at around 2 pm local time.
- Transpiration is usually expressed by transpiration ratio or transpiration coefficient that refers to the volume of water transpired by a plant to produce a unit quantity of dry matter.
- The factors affecting absorption also affect transpiration, besides the chemical and cultural factors.

3. Water and plant process

- Plant processes starting from germination to maturity of fruits or grains is affected by the water supply.
- They are germination, seedling emergence, root development, shoot growth and photosynthesis.

3.1. Causes of moisture stress in plants

- Water content in the plants decreases due to soil, plant and environmental factors.
- The main reason being the extent of transpiration which is affected by leaf size and composition, size and distribution of stomata on leaf, atmospheric humidity, temperature, wind velocity and day length.
- The term moisture stress is generally applied to the stomata opening and transpiration increases with time until they close due to high temperature.
- Loss of water from the leaf extends to the cell walls, from cell walls to protoplasm, from it to vacuole and gradually to the roots through xylem.
- In turn water ascends to the site of transpiration in this path.
- Along the path the water has to confront resistances and the steady state of flow gets imbalanced and transpiration loss cannot be met by absorption.
- This leads to wilting of leaves.
- High atmospheric temperature due to intense sun and increased transpiration causes closure of stomata and wilting of leaves even if soil moisture content is not limiting (ψm very high).
- This deficit is made up during night due to decreased transpiration.
- In plants, moisture content decreases either due to increased transpiration or reduction in absorption or both.
- On the contrary, if the atmosphere is humid and dew cover is substantial the plants may not show wilting sign even if soil moisture content is low.
- Roots are more sensitive to decrease in soil water potential than the leaves.
- Thus moisture in the plant is governed by soil moisture potential and atmospheric conditions.