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3. Concept and Approaches of Irrigation Scheduling

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Abstract:

Efficient water management is imperative for sustainable agriculture, especially in the face of increasing water scarcity and climate variability. Irrigation scheduling and crop water requirements are crucial components of modern agricultural practices, vital for ensuring food security and sustainable water resource management. Crop water requirements encompass the amount of water essential for optimal crop growth and development. Different factors like climate, type of crops and different growth stages of crop influence these requirements. Accurate estimation of these needs is essential to prevent over-irrigation or under-irrigation, both of which can lead to reduced yields and environmental concerns. The purpose of irrigation scheduling is to apply water at right time and strategically to meet crop demands efficiently. Various methods and technologies including soil moisture sensors, data of weather and evapotranspiration models, are employed to determine when and how much amount of water should be applied. Precision irrigation scheduling not only conserves water but also minimizes energy and labour costs while maximizing crop productivity. So, the critical concepts and approaches of irrigation scheduling and crop water requirements offer a comprehensive overview of the principles, methods and technologies essential for optimizing water use in agriculture, and also addresses global challenges such as water scarcity, climate change, and food production demands. By optimizing water use and adopting efficient irrigation strategies, agriculture can become more resilient, productive, and environmentally responsible, ultimately contributing to a more sustainable future.

Keywords:

Climate Change, Food Security, Irrigation Scheduling, Water requirement.

3.1 Introduction:

Crop water requirement is essential concept in agriculture that plays an important role in ensuring optimal growth and yield of crops while conserving water resources. Irrigation is vital for agriculture and food production as nature is not always able to supply water by processes like rainfall. Irrigation scheduling is the practice of timing and applying irrigation water in a way that meets the crop's water requirements without wastage (Gu et al., 2020). The prime goal is to provide the right amount of water at the right time to optimize crop growth and conserve water resources.

These practices are particularly vital in addressing the challenges caused by climate change, increasing water scarcity and demand to feed an increasing global population. Water movement is from higher potential energy to lower potential energy whether it is in soil, plant or any other environment. According to (Rekwar *et al.,* 2022) this is the fundamental principle that controls the movement of water across the entire water flow path in the Soil-Plant-Atmosphere Continuum (SPAC). Generally, water moves from roots to leaves by a process called transpiration, the loss of water vapour from the plant's stomata (tiny openings on leaves). After water evaporation from the leaves, a negative pressure gradient is developed in the xylem, which pulls water upward from the roots through a process known as the "transpiration pull" (Kathpalia *et al.,* 2018). It does not involve any energy loss by plant. Thus, it is called passive absorption. Active absorption occurs under conditions where transpiration is little. Then plants absorb water by spending energy owing to reduction of water potential in xylem mostly by accumulation of solutes in the xylem. More than 90% of total water absorption by plant is through Passive absorption (Mengel *et al.*, 2001).

3.2 Concept of Water Requirements of Crops:

The water requirement of a crop refers to the amount of water needed for its normal growth and yield, regardless of its source, whether it comes from precipitation, irrigation, or a combination of both (Evans *et al.,* 2008). It is the amount of water required to raise a successful crop from sowing to harvest. This water is primarily used to fulfil the demands of three essential processes: evaporation (E), transpiration (T), and the metabolic needs of the plants, collectively called as consumptive use (CU).

$$\boldsymbol{Consumptive\ Use}\ (\boldsymbol{CU}) = \boldsymbol{Evaporation}(\boldsymbol{E}) + \boldsymbol{Transpiration}(\boldsymbol{T}) + \boldsymbol{Plant's\ metabolic\ use}\ (< \mathbf{1}\%)$$

Since the water used for the plant's metabolic activities is minimal, accounting for ≤ 1% of the total water inside the plant, we can practically equate evaporation (E) and transpiration (T) to CU. Practically, it is often challenging to separately determine evaporation and transpiration, so they are estimated together as evapotranspiration (ET).

It is always not possible to exactly apply the required quantity of water for bringing the root zone to field capacity. The total water requirement (WR) counts the losses that occur during irrigation water application in the field, such as seepage, runoff and percolation (collectively called as application loss) as well as the water needed for specific operations like land preparation, pre-sowing irrigation, transplantation, leaching of excess salts and so on (collectively called as water needed for special operations) (Ali et al., 2010). In this context, WR can be expressed as the sum of consumptive use (CU), application losses, and the water required in these special operations:

$$\boldsymbol{WR = CU + application\,losses + water\,needed\,for\,special\,operations}.$$

It is important to note that WR represents a demand for water, and the supply can come from various sources, including irrigation water, effective rainfall (ER), and contributions from the soil profile including from a shallow water table (S). Therefore, the total water requirement (WR) can be calculated as the sum of irrigation requirement (IR), effective rainfall (ER) and contributions of the soil profile:

$$\boldsymbol{WR = IR + ER + S}$$

Irrigation Requirement (IR): It refers to the volume of water supplied to a field, in addition to rainfall and soil profile contribution, to satisfy the water requirements of crops for ideal growth. Or, it is the amount of water applied artificially for recharging the crop's root zone when no other sources of water supply i.e. rainfall or profile contribution is not available or limiting to the plant for its growth and development. It can be expressed as:

$$\boldsymbol{IR = WR - (ER + S)}$$

a) Net Irrigation Requirement (NIR): It is the actual amount of irrigation water required to make the status of soil moisture of the root zone to the field capacity (FC) or to meet the consumptive use requirement of a crop.

$$\mathbf{NIR = Root\ zone\ water\ need\ (Rw)} = \sum_{i=1}^{n} \frac{(FC - \theta)}{100} * BD * d$$

Where,

NIR= Net irrigation requirement to be applied at each irrigation (mm)

n= Number of soil layers considered in root zone depth

FC= Gravimetric moisture percentage at field capacity in i^{th} layer

θ= Gravimetric moisture percentage just before irrigation in i^{th} layer

BD= Soil bulk density in i^{th} soil layer (g/cm^3)

d= Depth of i^{th} soil layer (cm)

b). Gross Irrigation Requirement (GIR): It refers the total amount of irrigation water needed including losses during application. Conveyance and application loss accounts for about 30-35% of total water supply in earthen irrigation channel.

$$GIR = Net\ IR + Conveyance\ loss + Application\ loss$$

$$= \frac{NIR}{Ea} \times 100 = \frac{Net\ irrigation\ requiremet}{Irrigarion\ application\ efficiency(\%)} \times 100$$

Effective rainfall (ER): It is the part of the rainfall that is available for the consumptive use (CU) of plant. The fate of rainfall may be last as infiltration and stored in the root zone for plant utilization, runoff, deep percolation, interception by climate or plant and even evaporation (Bodner et al., 2015). The amount or proportion of ER depends on intensity and duration of rain, soil moisture holding capacity, infiltration rate of the soil initial soil moisture content.

ER = Precipitation (P) - Water losses (Runoff + Evaporation + Deep drainage)

Precipitation (P) = Rainfall – Interception by atmosphere & plant foliage

ER can be measured by evapotranspiration /precipitation method ratio method, soil moisture changes, water balance methods.

3.2.1 Factors Responsible for Crop Water Requirements:

A. **Crop factors:** Diverse traits among crop varieties, such as their growth duration, rooting characteristics and canopy structures exert a significant impact on their water needs (Wasson et al., 2012). The longer a crop takes to mature, the greater its water demand becomes. Generally, crops with deep-rooted systems draw more water from deeper soil layers. Moreover, crops with higher leaf areas experience higher rates of evapotranspiration (ET), while taller crops intercept more solar radiation, resulting in increased ET compared to shorter crops.
B. **Soil Factors:** The evaporation occurring at the soil surface depends on several soil attributes such as hydraulic conductivity, reflectivity and thermal properties. Coarse textured soils tend to exhibit higher hydraulic conductivity, particularly when soil moisture levels are high, leading to increased evaporation rates from such soils (Li et al., 2022). Soil containing a larger proportion of aggregates with a diameter more than 1.0 mm limits the upward movement of water, consequently reducing evaporation. Additionally, the presence of ridges and furrows minimizes evaporation losses. Dark-coloured soils absorb more heat, resulting in elevated surface evaporation rates (Brady et al., 2008).

C. Climatic Factors: Evapotranspiration is influenced by solar radiation, relative humidity, temperature, and wind speed. Elevated temperatures, increased wind speed, and higher solar radiation levels all result in greater water requirements for crops (Hatfield et al., 2011). Conversely, higher humidity levels reduce ET. In particular, the presence of hot, dry winds surrounding irrigated crops (known as advection) can further increase ET. Smaller fields can be significantly affected by their surroundings, with wind patterns often causing a net horizontal movement of heat into or out of the field, especially when the field is not situated within a large, uniform region (Taha et al., 1991). This phenomenon, referred to as advection, holds particular significance in arid areas where small irrigated fields are typically bordered by dryland. In such cases, warm incoming air can convey sensible heat (energy used to heat the air) down to the crops. The process of extracting sensible heat from warm air passing over a field and converting it into the latent heat of evaporation is known as the "**oasis effect**." Warm air moving through vegetation has been termed the "**clothesline effect**." In arid regions, it's common to observe poor plant growth near the windward edge of a field, where the penetration of warm, dry winds contributes energy to ET.

D. Management Practices: Any crop management practice aimed at enhancing crop growth and yield invariably increases the water requirement of crop. Timely weeding and the application of mulch serve to minimize ET. Frequent irrigation significantly augments the crop's water needs.

3.2.2 Process of Determination of Crop Water Requirements:

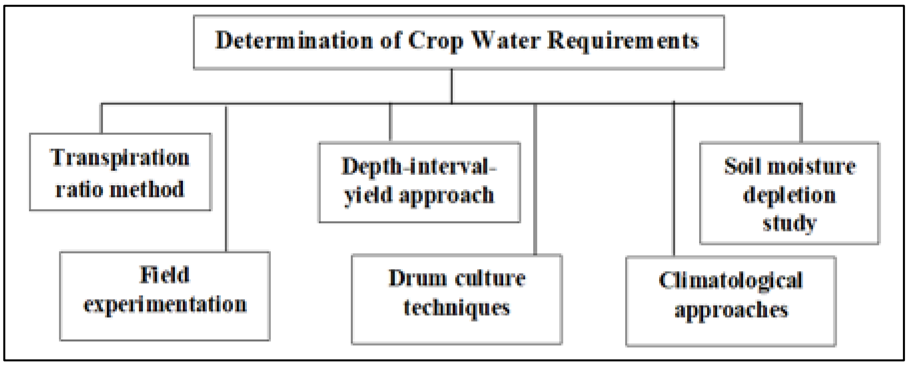

Figure 3.1: Determination of Crop Water Requirement

A. Transpiration Ratio Method: The transpiration ratio is the quantity of water transpired by a crop during the production of a unit amount of dry matter (Jones, 2004). Despite its use in the past, this method has several limitations. The transpiration ratio in green house condition can vary significantly from what occurs in field condition. As a result, it is not very useful for determining irrigation scheduling.

B. Depth-Interval-Yield Approach: Irrigations are planned with varying the water depth and the time intervals between irrigation sessions (Labbé et al., 2000). The crop's water requirement is determined by calculating the total water used to achieve the highest yield. While this provides some insight into the crop's water needs, it is not a dependable estimate due to the variations in climate experienced during different seasons.

C. Soil Moisture Depletion Studies: The Consumptive use (CU) is calculated by assessing alterations in soil moisture within the root zone at regular intervals throughout the crop season. This method is typically applied in those soils which are not affected by groundwater fluctuation as the water table lies sufficiently deep to impact soil moisture within the root zone.

$$CU = \sum_{i=1}^{n} \frac{(\theta 1 - \theta 2)}{100} * BD * d$$

Where, n = Number of soil layers considered in root zone depth

$\theta 1$= soil moisture percentage at first sampling in i^{th} layer

$\theta 2$ = soil moisture percentage at second sampling in i^{th} layer

BD= Soil bulk density in i^{th} soil layer (g/cm^3)

d= Depth of i^{th} soil layer (cm)

D. Climatological Approaches: The prevailing climate predominantly influences the rate of evapotranspiration. Water requirements can be obtained by adding application losses and water needed for special operations to the estimated ET crop (Seibert et al., 2010).

E. Drum Culture Technique for Lowland Rice: Dastane et al., (1966) proposed the drum culture technique. it can be used to assess the various factors contributing to water losses in lowland rice fields, including percolation, evaporation, transpiration, and ineffective rainfall. This technique involves the use of four metallic drums, each measuring 50*50 cm in diameter and 120 cm in height. Two of these drums have bottoms (referred to as A and B), while the other two do not (referred to as C and D). These drums are installed in the rice field, leaving 20 cm of their height above the soil surface. The drums with bottoms (A and B) are placed by excavating the soil layer by layer and filling the drums with the excavated soil in the same order. The drums without bottoms (C and D) are embedded by excavating the soil outside the drums. Rice seedlings are transplanted into drums A, C, and D, as well as in the field surrounding these drums. But in drum B, rice seedlings are also transplanted without any root system. These rootless plants in drum B are replaced on a weekly basis with plants of the same age and size from a bulk crop surrounding the drums, with their roots cut off. These plants without roots in drum B provide shade to the soil, similar to the plants in the other three drums. The level of water in both the field and the drums is maintained at the same level (5 cm). The water level of the drums is monitored daily, and any losses because of percolation and evapotranspiration (ET) are replenished. Any excess rainfall (ineffective rainfall) is collected in a sealed jar buried in the field and connected to drum D. It is vital to note that crop water requirements can vary significantly from one region to another due to factors such as agro-climatic conditions and management practices.

- Percolation = difference in water depth between drums C and A
- Evaporation = daily loss in drum B
- Evapotranspiration = daily loss in drum A
- Transpiration = difference in water depth between drums A and B
- Effective rainfall = total rainfall received - ineffective rainfall collected in the jar from drum D.

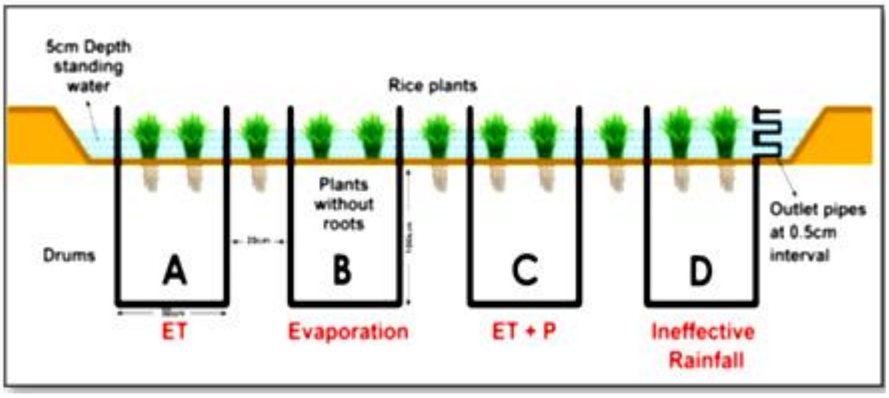

Figure 3.2: Drum Culture Technique for Assessing Water Balance Components in Low-Land Rice

F. Field Experimentation: The measurement of irrigation water usage, effective rainfall, and contributions from soil moisture within the profile are required to estimate water requirement (WR). The calculation of seasonal water needs is determined by combining these individual components.

$$\textbf{WR (mm) = IR + ER} + \sum_{i=1}^{n} \frac{(\theta 1-\theta 2)}{100} * BD * d$$

Where, WR = Water requirement of Crop (mm)

IR = Irrigation water applied (mm)

ER = Effective rainfall During the season (mm)

n= Number of soil layers considered in root zone depth

$\theta 1$= soil moisture percentage at the start of season in the i^{th} layer

$\theta 2$= soil moisture percentage at the end of season in the i^{th} layer

BD= Soil bulk density in i^{th} soil layer (g/cm^3)

d= Depth of i^{th} soil layer (cm)

Table 3.1: Water Requirements (WR) of Some Important Crops

Crops	WR (mm)	Crops	WR (mm)
Rice	900-2500	Potato	500-700
Wheat	450-600	Sorghum	450-650
Maize	500-800	Onion	350-550
Groundnut	500-700	Pea	350-500
Cotton	700-1300	Tomato	600-800
Soybean	450-700	Bean	300-500
Tobacco	400-600	Sugarcane	1500-2500

3.3 Concept and Approaches of Irrigation Scheduling:

The term "Irrigation Scheduling" implies when to irrigate a crop i.e. timing of irrigation, how much to irrigate a crop i.e. quantity of irrigation water and how to irrigate a crop i.e. method of irrigation. Irrigation scheduling helps to conserve water resources, facilitate the judicious use of water and enhance water productivity as well as crop yield (Ewaid et al., 2019).

Criteria/Approaches for Scheduling Irrigation:

As our understanding of the soil-plant-atmosphere system has progressed, numerous guidelines for planning irrigation have emerged and are currently being employed by researchers and farmers. Criteria suitable for irrigation scheduling may vary with different factors like soils, plants, climatic and management practices. These criteria can generally be grouped into three main categories.

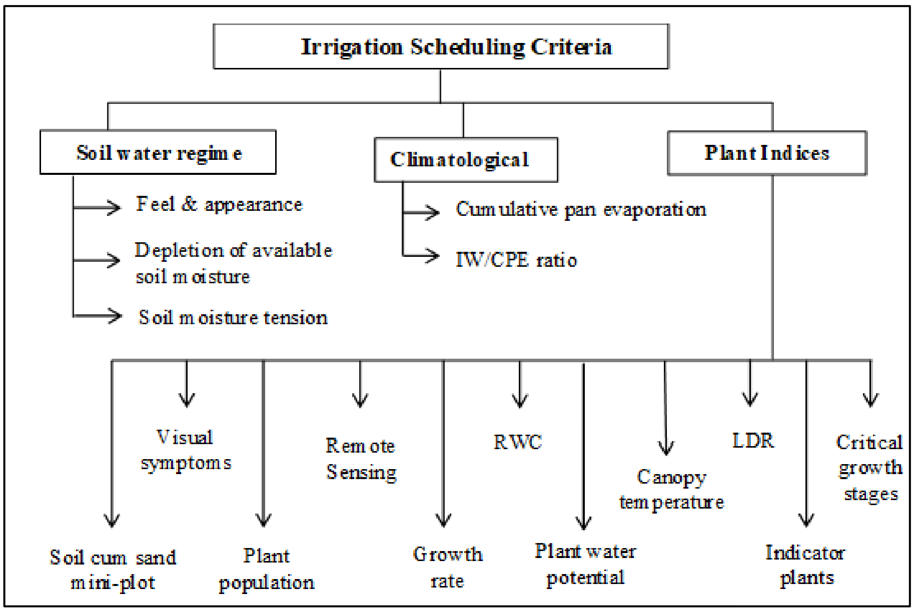

Figure 3.3: Criteria/Approaches for Scheduling Irrigation

3.3.1 Soil Water Regime Approach:

a. Feel and Appearance Method: This is the simplest method for judging the content of crop field's moisture. Farmers usually take moist soil from plant root zone and make it to a ball shape on squeezing. If the ball does not break easily on releasing the pressure, it indicates the moisture content nearer to field capacity or 100% available water i.e. moist soil. If the ball breaks easily on releasing the pressure, that indicates the moisture content less than 75% i.e. relatively dry soil. If the ball does not form, it indicates that the soil is dry and moisture content is less than 50%. Farmers usually provide irrigation at 25% depletion of available soil moisture (Michael et al., 2009)**.**

Table 3.2: Guidelines For Judging Soil Moisture by Feel & Appearance of Soil

Available soil moisture range	Course texture (loamy sand)	Moderately coarse (sandy loam)	Medium texture (loamy and silt loam)	Fine texture (clay loam and silty clay loam)
100% (field capacity)	Squeezing soil leaves a wet handprint, but no free water	Similar observation	Similar observation	Similar observation
75-100%	Soil clumps slightly and can form a weak ball when squeezed	Forms a fragile ball, easily breakable, do not slick	Creates a ball, highly flexible, slicks smoothly when handled	Easily ribbons between fingers with a smooth sensation
50-75%	Seems dry, doesn't compress into a ball under pressure	Tends to ball up under pressure but rarely sticks together	Shapes a somewhat plastic ball, occasionally becomes slightly slick under pressure	Shapes a ball, extends into ribbons between thumb and forefinger
25-50%	As previously mentioned, but requires very firm squeezing to form a ball	Seems dry and only forms a ball with strong squeezing	Somewhat crumbly but remains intact under pressure	Somewhat flexible; forms a ball when pressed
0-25%	Dry, loose, individual grains flow through fingers easily	Dry, loose, flow through fingers easily	Very dry, sometimes lightly crusted, but easily crumbles into powder	Hard, baked, cracked, may have loose surface crumbs

b. Available Soil Moisture Depletion Approach: Assessing the root zone's soil moisture serves as a valuable basis for planning irrigation. When the soil moisture within a specific depth of the root zone reaches a certain level of depletion (which varies on the crop), it should be replenished through irrigation (Chandrasekaran, 2010). For crops such as maize and wheat, it is sufficient to schedule irrigation when the available soil moisture is depleted by 25-30 per cent. However, for more drought-resistant crops like pearl millet, sorghum, finger millet, cotton etc. scheduling irrigation at 50-60 % depletion of available soil moisture is adequate. Irrigation water can be applied at a predetermined soil water tension at a specified depth as it is considered that response of plant to irrigation is better correlated with soil water suction than with soil water content. While measuring soil water content or soil moisture tension may not be readily accessible to farmers, they often estimate soil moisture content through feel and appearance method and visual observations and schedule irrigation accordingly (Howell et al., 2012).

c. Soil Moisture Tension Method: Soil water potential is the energy difference between pure water at its reference state and soil water (Pal, 2016). The pressure at which water is attracted by solid surfaces (soil matrix) is sometimes referred to as *suction* or *tension*. This tension is measured by field tensiometers, or Irrometers, which are designed with a water-filled tube closed at the bottom by a porous ceramic cup and at the top with an airtight seal. Once installed at the appropriate depth within the soil's root zone, the water in the tensiometer seeps through the ceramic cup into the soil until the water potential inside the tensiometer is equal to the matric water potential of the soil. As water exits the tensiometer, a vacuum form just beneath the top seal, which is measurable with either a vacuum gauge or an electronic transducer. When the soil is saturated by rainfall or irrigation, water enters the tensiometer through the ceramic tip, reducing the vacuum or tension shown by the gauge. Tensiometers are programmed to trigger irrigation when critical soil moisture tensions specific to certain crops are reached, such as 0.3 bar for potatoes, 0.5 bar for wheat, and 0.7 bar for sugarcane at a 30 cm root zone depth. The devices function effectively within a range from 0 to -85 kPa. However, when soil moisture decreases beyond -80 to -85 kPa, tensiometers become unreliable as air starts entering through the ceramic cup, nullifying the vacuum. This is why tensiometers are commonly used in coarse-textured soils for irrigating orchards and vegetables, which tend to hold moisture at lower tensions, but are not suitable for clayey soils (Das, 2004). For automated irrigation systems, a solenoid switch can be connected to a field tensiometer to control the irrigation system based on soil moisture needs.

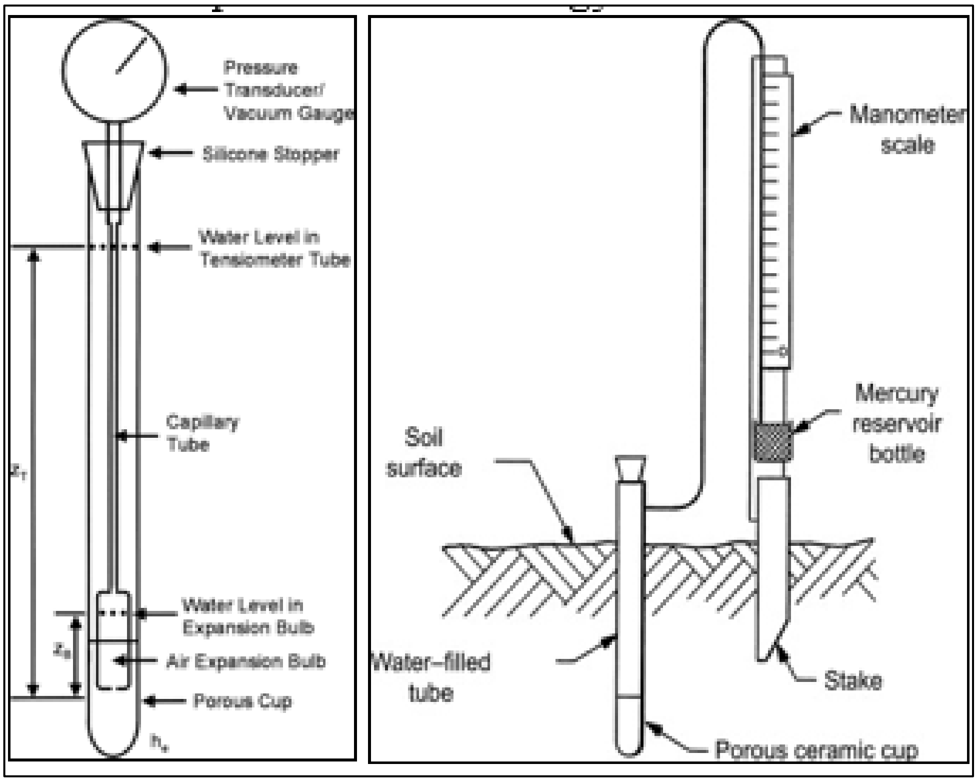

Figure 3.4: Gauge Type Tensiometer (Left) And Mercury Manometer Type Tensiometer (Right)

3.3.2 Climatological Approach:

The climatological approach to irrigation scheduling involves using climate data and weather patterns to determine when and how much irrigation is needed for crops. This approach takes into account various climatic factors that can influence soil moisture levels, such as temperature, humidity, rainfall, and evapotranspiration rates (Reddy et al., 2019). Evapotranspiration is primarily influenced by the prevailing climate conditions. The calculation of water loss through evapotranspiration relies on climatic data, and irrigation is planned when evapotranspiration reaches a specific threshold. The amount of given irrigation is either equal to ET or fraction of ET. Various techniques within the climatological approach include the can evaporimeter method and the IW/CPE ratio method.

A. Pan Evaporimeter Method:

Small one litre cans with dimensions of 14.3 cm in height and 10 cm in diameter are used to monitor the evaporation of cultivated area. These cans are painted white and then covered with a mesh of 6/20 size. An indicator pointer is fixed at 1.5 cm below the top edge. When water is given for irrigation to the crops for reaching at field capacity, the can is filled with water up to the level indicated by the pointer and placed at the same height as the crops. The evaporation rate from the can directly correlates with the crop's evapotranspiration. Irrigation is scheduled based on the water level of the container decreases to a predetermined point (equal to the amount of water to be applied at each irrigation), the container is then again refilled to the designated pointer level.

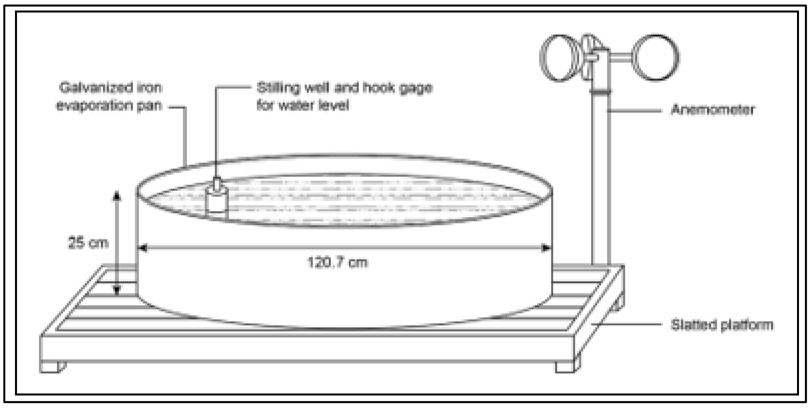

Figure 3.5: (USWB) Class-A open pan evaporimeter

B. IW/CPE Ratio Approach:

Here, a specified amount of irrigation water (IW) is given when the cumulative pan evaporation (CPE) reaches a predetermined threshold. The IW/CPE defines a ratio of the amount of irrigation water (IW) to cumulative pan evaporation (CPE) from a USWB Class A pan. A ratio of 1.0 in IW/CPE signifies scheduling irrigation with water equal to the amount lost through evaporation.

During each irrigation session the volume of water applied varies between 4 and 6 cm, with 5 cm being the most commonly used amount. When irrigation is scheduled at an IW/CPE ratio of 1.0 with 5 cm of irrigation water, it signifies that 5 cm of irrigation water is dispensed when the cumulative pan evaporation reaches 5 cm.

Typically, irrigation is planned using a ratio of 0.75 to 0.8 with 5 cm of irrigation water. A smaller ratio suggests longer irrigation intervals, while a larger ratio indicates more frequent irrigations i.e. more no of irrigation within crop growing period.

In this method, irrigation can be planned based on a constant level of Crop Water Requirement (CPE) by adjusting the quantity of irrigation water applied. For instance, the IW/CPE ratio for pulses and potato are 0.4-0.5 and 1.25-1.5, respectively (Aggarwal et al., 1983).

3.3.3 Plant Indices:

A. Canopy Temperature by Infrared Thermometry: Canopy temperature is assessed using an infrared thermometer, which concurrently measures both canopy temperature (T_c) and air temperature (T_a) and also presents as T_c-T_a values. These T_c-T_a values serve as valuable indicators for irrigation scheduling. When transpiration is operating normally, the canopy temperature tends to be lesser than the air temperature because of its cooling effect.

Negative T_c-T_a values signify that plants possess an ample water supply. Conversely, when T_c-T_a values are zero or positive that indicates stress, which means that irrigation becomes necessary. Stress-degree days (SDD), which is very advantageous for scheduling irrigation, are accumulated in a similar manner to the concept of growing-degree days.

$$\mathbf{SDD = \sum (T_c\text{-}T_a)}$$

The measurement of canopy temperature is typically conducted at mid-day by infrared thermometer when air temperature reaches its peak. It's crucial to note that the greatest reduction in yield occurs when the cumulative SDD count exceeds 10 to 15 units between successive irrigations (Surendran et al.,2015)

B. Critical Growth Stage Approach: In every crop, certain growth phases exist where inadequate moisture can result in irreversible yield reductions; these specific phases are termed as the critical period or the moisture-sensitive period. When there is an ample supply of irrigation water, irrigation is planned whenever the soil's moisture level drops to a critical point, typically around 25 to 50 % of the available soil moisture.

In situations where water is limited, irrigation is strategically timed to coincide with the moisture-sensitive stages while irrigation is skipped during non-sensitive stages (Reddy et al., 2018). For cereals, the critical moisture-sensitive stages include panicle initiation and flowering stages. In the case of pulses, the most crucial moisture-sensitive stages are flowering and pod development.

Table 3.3: Some moisture sensitive stages of important crops have been enlisted in the following table-

Crops	Moisture Sensitive Period
Rice	Panicle initiation and flowering stages
Wheat	Crown root initiation, jointing, milking
Maize	Silking, tasseling
Groundnut	Rapid flowering, pegging, early pod formation
Cotton	Flowering and ball formation
Soybean	Flowering and Seed formation
Pulses (Greengram, Blackgram, Redgram)	Flowering and pod formation

C. Indicator Plants: The use of indicator plants in irrigation scheduling involves selecting specific plant species or varieties that are highly sensitive to changes in soil moisture levels. These indicator plants are strategically placed within a crop field and serve as early warning systems for the need to irrigate.

For example, sunflower is well known to be used as an indicator plant in the onion field.

D. Remote Sensing Data: In regions where extensive monoculture farming is practiced, irrigation scheduling can be facilitated using remote sensing information.

The reflection of solar radiation by well-hydrated plants varies from that of stressed plants. This concept can be applied to determine the optimal timing for irrigation.

E. Plant Water Potential or Pressure Chamber Method: The pressure chamber is a tool used to assess the water tension within a plant's water-conducting xylem tissue (Zimmermann et al., 2002). In a nutshell, the pressure chamber method involves cutting a leaf and its connected stem (petiole) from the plant, safeguarding it against water loss, and placing the leaf inside a pressure chamber with a portion of the cut petiole exposed outside. Pressure is gradually increased within the chamber until water becomes visible at the cut end of the petiole.

The tension within the xylem is believed to correspond to the pressure in the chamber when water first appears, and it is considered a measure of the plant's physiological "dryness", referred to as the plant water potential (MPa). Commercial pressure chambers are readily available and are utilized to determine the timing of irrigations in various crops like cotton, grapes, and tree crops.

The essential levels of plant water potential for cotton, where decreases in yield are anticipated, ranged from 1.2 to 1.25 MPa across the entire growth cycle. In contrast, for sunflowers, these levels were 1.0, 1.2, and 1.4 MPa during the vegetative stage, pollination, and seed formation phases, respectively.

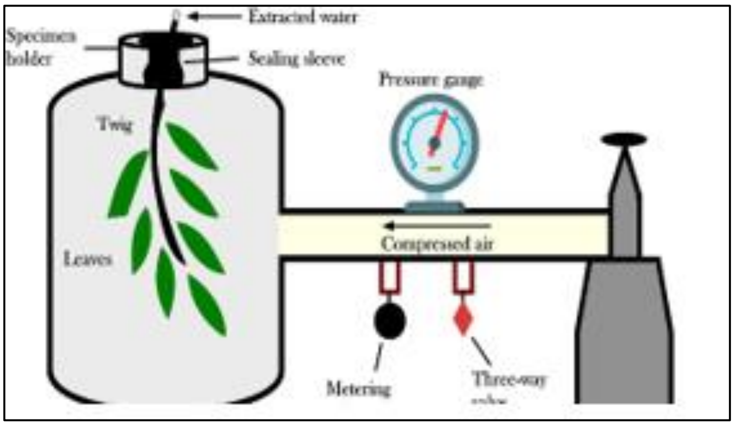

Figure 3.6: Pressure Chamber Tool for Plant Water Potential Measurement

G. Relative Water Content: Weatherly introduced this concept in 1950, revolves around the measurement of the actual moisture content within a leaf or plant sample in comparison to its moisture level when fully saturated or turgid. This measurement depends on the gap between the atmospheric evaporative demand and the rate at which the roots absorb water.

$$\textbf{RWC} = \frac{Fresh\ Weight - Dry\ Weight}{Turgid\ Weight - Dry\ Weight} = \frac{Actual\ Water\ Content}{Water\ Content\ at\ Saturation}$$

A high value of Relative Water Content (RWC) indicates the water content in plant is sufficiently good. In normal condition RWC ranges between 85-90% whereas in drought stress condition it falls below 30%. For cotton and sesame, the critical RWC thresholds, below which growth reduction is started, were determined to be 72% and 75% respectively. When the plant reaches these RWC values, it signifies the need for irrigation. However, it's primary drawback is that this method can be labour-intensive and time-consuming.

H. Plant Visual Symptoms: Visual symptoms such as the drooping, curling, and rolling of plant parts are commonly employed by farmers to determine when to irrigate their crops (Green, 2011). Additionally, changes in the colour of the foliage, particularly in beans, serve as indicators for irrigation timing. However, it's necessary to notice that these methods often mean the crop has already experienced water shortage and its impact on the final yield before exhibiting wilting or noticeable alterations in foliage colour (Savva et al., 2002).

Profile Modification or Soil-Cum-Sand Mini-Plot Technique or Micro-Plot Technique: This technique, also referred to as the soil-sand mixture mini-plot method lies on the principle of reducing the water-holding capacity intentionally of soil within the root zone of a mini-plot by incorporating sand into it. In these mini-plots with sand mixed into the soil, plants exhibit signs of moisture stress earlier compared to plants in the surrounding area (Rashid et al., 2004). Typically, a 1.0 m^2 area is selected within the field, and then a pit with1.0 m depth is dug in 15 cm layers.

I. Each soil layer is blended with 5 percent sand by volume, and the pit is refilled in the same layer sequence as it was excavated, with each layer compacted to attain the same bulk density as the surrounding area. Based on the wilting symptoms of the plants kept in the mini-plot irrigation is given to the entire crop field.

J. Showing High Seed Rate and Increased Plant Stand: A designated plot of approximately 1 m^2 area, preferably situated in an elevated location, is planted with the same crop, maintaining a plant population approximately four times greater than that found in the surrounding area (Critchley et al., 2013). This increased plant density in this elevated plot results in the crop showing signs of wilting earlier than the crop in the rest of the field, thereby suggesting the appropriate timing for irrigation scheduling.

K. Reduced Growth Rate: A decrease in the growth rate of vulnerable plant parts can serve as an indicator for when crops require irrigation (Cassaniti et al.,2012). For instance, in the case of orange trees, irrigation is given when the growth rate of fruit circumference drops below 0.2 to 0.3 mm/day. Additionally, because the elongation of stems in crops such as sugarcane, tomato, and cotton are closely linked to water stress, this characteristic can be employed as a reliable indicator for determining when irrigation is necessary.

L. Stomatal Resistance or Leaf Diffusion Resistance (LDR): Stomatal resistance (unit sec/cm) is measured by Porometer which measures the time required of water vapour to move 1cm from stomata surface to atmosphere. A high LDR signifies lower water content, stomatal closure, reduce transpiration rate and also right time for giving irrigation.

3.4 Conclusion:

Concepts of irrigation scheduling is of paramount importance in modern agriculture. As the global population continues to grow and climate change brings about unpredictable weather patterns, efficient water management in agriculture becomes essential for food security and sustainable farming practices. Precision irrigation, based on accurate knowledge about crop water requirements, is crucial for optimizing water use efficiency. By applying right amount of water at the right time to the crops, we can maximize yields while minimizing water wastage.

Different crops have varying water requirements at different growth stages. Understanding these needs and adjusting irrigation schedules accordingly is critical. Modern technology, including remote sensing, weather forecasting, and soil moisture monitoring, has revolutionized irrigation scheduling. Farmers can now make data-driven decisions to optimize their irrigation practices, reducing costs and conserving water. Sustainable agriculture practices should be at the forefront of irrigation scheduling. Over-irrigation not only wastes water but can also lead to soil degradation and water pollution. Balancing the needs of crops with environmental stewardship is essential. Climate change is altering traditional patterns of weather and increasing the risk of occurring of extreme weather events like droughts and floods. Adaptation strategies must be integrated into irrigation scheduling to ensure crop resilience. Proper irrigation scheduling can have significant economic benefits.

It can reduce operational costs, improve crop quality, and increase overall farm profitability. As global water resources become scarcer, responsible water management in agriculture is crucial. Irrigation scheduling should take into account local water availability and prioritize efficient use to mitigate water scarcity issues. Training and educating farmers about modern irrigation techniques and scheduling methods are essential for widespread adoption. Government agencies, NGOs, and agricultural extension services play a vital role in disseminating knowledge. Crop water requirements and irrigation scheduling are integral components of sustainable agriculture.

By embracing advanced technology, adopting precise techniques, and promoting responsible water management, we can ensure that agriculture remains resilient in the face of a changing climate while safeguarding our precious water resources for future generations. Through precision, technological innovation, and a commitment to responsible water management, farmers can fulfil the growing global demand for food while safeguarding our precious resources of water. This topic serves as a reminder that in the face of a changing climate and increasing water scarcity concerns, the integration of science and sustainability is essential to secure a prosperous future for agriculture.

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