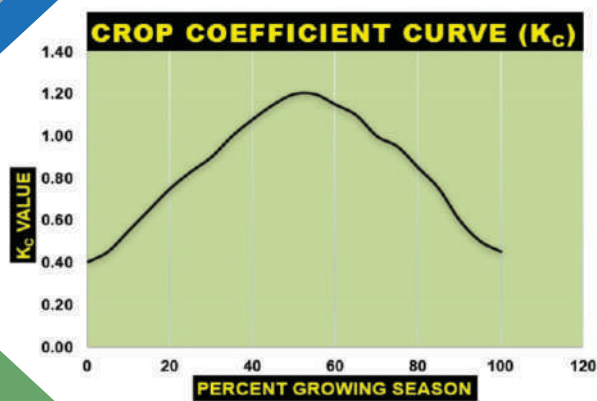


GOVERNMENT OF THE PUNJAB
AGRICULTURE DEPARTMENT

MANUAL

ESTIMATION OF CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING UNDER HEIS



Directorate General Agriculture (Water Management)
Punjab, Lahore



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GOVERNMENT OF THE PUNJAB**

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PREFACE

This is, indeed, highly gratifying to observe that high efficiency irrigation systems (HEISs) have established their worth among the farming community in the Punjab and their acceptance is accelerating on day to day basis. The benefits of these HEISs have been experienced pragmatically by the beneficiaries and their interviews reveal that substantial savings in water, fertilizers, pesticides especially the weedicides, energy and labour have been realized on most of the farms. As a result, extensive installation of drip and sprinkler irrigation systems under the PIP is in progress which, indeed, is helping in combating the shortage of irrigation water in the country on one hand and is proving effective in bringing the yield levels of crops of the country at par with the world standards on the other. Their effectiveness, however, largely depends upon accurate scheduling of irrigation through the HEIS and a definite improvement in their efficiency may be accrued through proper monitoring of the schedules both with respect to their preparation as well as their implementation.

Since HEISs are relatively new intervention in Pakistan, there is lack of relevant printed material regarding various operational aspects of the systems especially in relation to estimation of crop water requirement and preparation of fertigation/irrigation schedules. Perhaps, the most critical and the most lacking facet of these newly introduced systems is preparation of proper irrigation schedules for various crops being grown. In addition, the training of project staff and the operators of the systems regarding these schedules for their understanding and implementation in the field appears to be a missing link. A fair analysis of the factors leading to such gaps reflects that lack of technical material on the subject is the primary reason.

This effort in the form of a manual is expected to serve the purpose. Elucidation of the basis of CWR estimation and provision of solved examples for preparation of irrigation schedules for a number of crops have facilitated to give an in depth orientation to the reader about the subjects. Detailed information have been provided regarding reference evapotranspiration, crop growth stage coefficient and crop evapotranspiration. A calculation sheet has been given to manually calculate the CWR. In addition, CROPWAT 8.0, the FAO software has also been duly explained with solved examples for its extensive use.

This manual will not only enable to properly estimate the crop water requirement of the desired crop but will also facilitate to check and monitor the irrigation schedules supplied on the sites by the SSCs for their authenticity and accuracy. In addition, it will also enable the project staff especially the HEIS teams to prepare and provide the irrigation schedules at the farms/sites for any crop.

1. INTRODUCTION

Improvement in crop production cannot be ascertained without adoption of advanced management practices. If all the inputs required for improved yields are managed on the basis of latest economic principles and focus is made on taking up the entire agricultural enterprise on commercial footings, it may be confidently envisaged that a production level at par with the international standards may be achieved without any qualm and apprehension. Handsome research has been carried out regarding each input and clues have been determined which have brought significant developments in the area of desired objectives. Irrigation is one of the major inputs which like other ones, has attracted considerable attention of the researchers. Resultantly, highly effective and comprehensive aspects of this input have been unveiled especially with reference to soil-plant-water-atmosphere relationships.

To get maximum output per unit of available irrigation water for a country like Pakistan, it is essential to improve the efficiency of the prevailing irrigation methods through adoption of high efficiency irrigation systems on one hand and adoption of latest techniques of irrigation scheduling on the other to save each drop of water from wastage. It is, indeed, a highly wise step on the part of the government that projects aiming at execution of pressurized irrigation systems have been launched through which it is possible to hit up to 95% irrigation efficiency. An equally important aspect for efficient irrigation is to apply measured quantity of water to the crops which is just sufficient to gain good yields but not in excess of the required amount. This necessitates that water requirement of various crops is calculated so accurately and precisely that the chances of over irrigation are automatically minimized.

An advanced method of irrigation must ensure that there is neither over irrigation which brings the soil often to saturation point completely eliminating the oxygen from the root zone nor under irrigation which often renders the soil moisture down to a level where ionic absorption of nutrients is impeded. Both of these physiological stresses adversely affect the plant growth and drag it to a position where in the reduction in yield below its potential becomes a natural end result. High Efficiency Irrigation Systems, especially the drip irrigation, have made this breakthrough and have proven to be the ideal methods.

Adoption of improved Irrigation scheduling techniques, which encompass both aspects of measured irrigation i.e. when to apply irrigation and how much water to apply, may play the requisite role. Out of three ways of irrigation scheduling i.e. soil based, plant based and weather based, the weather based methods have proven most promising in assessment of the real crop water needs as the consumptive use of water/evapotranspiration primarily depends upon climatic parameters. These include temperature, humidity, wind velocity and radiation. Accordingly, if the data pertaining to these parameters is available, it is easy to assess the amount of water consumed in evapotranspiration of a crop which in other words is termed as crop water requirement (CWR).

In addition to protecting the plants from any physiological stress, these help in ample saving of energy, economize labor, facilitate optimum application of nutrients and significantly reduce the incidence of weeds infestation. These have, virtually, made it possible to apply correct amount of water to the plants at exact time. Accordingly, the crop does not face any shortage of water or air or nutrients throughout its period of growth and this helps in hitting the potential both in yield as well as quality of production.

This is, however, to be kept in view that the efficiency of HEISs depends primarily upon appropriate irrigation scheduling. If the time of application of water does not synchronize with the crop water requirement in exact accordance, certainly the efficiency of the system will go to adverse. In case the application time is higher than the requirement, both irrigation water and the energy will be wasted and in case the irrigation has been scheduled for a time span lesser than the requirement, it will result in reduction of the yield and wastage of resources. It is, therefore, highly important that after installation of the HEISs, not only the accurate irrigation schedules are prepared but the same are implemented with extreme care also so that the desired and expected benefits of these systems may be accrued in letter and spirit.

Irrigation Scheduling deals with application of irrigation water to a crop at the right time in the right amount (and in case of drip irrigation system at right place). In other words, it focuses upon when to irrigate a crop and how much water to apply during successive irrigations. The significance of this parameter of crop production is revealed from the fact that full potential of any crop cannot be hit unless scheduling of irrigation water is made in such a way that the crop never faces its shortage throughout its period of growth. Under conditions of low water availability, not only the absorption or ionic uptake of nutrients is held back but many other physiological processes in the plant cells get impeded also which ultimately lead to low yields. Contrarily, over irrigation proves detrimental in a number of ways as it blocks the availability of oxygen to the roots, it leads to leaching of valuable nutrients down to the zone below root level and results in wastage of water as well as energy.

It, therefore, becomes vital that irrigation of a crop is managed in such a way that an optimum moisture level is maintained in the root zone to effectively fulfill the needs of the plants throughout the period of their demand and this is possible only through proper irrigation scheduling.

2. CROP WATER REQUIREMENT

Water requirement of a crop (CWR) may be defined as the “amount of water required by a crop to reach its maturity.” FAO (1984) defined crop water requirements as “the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment”. Another group of experts has defined it as “The quantity of water required by a crop or diversified pattern of crop in a given period of time for its normal growth under field conditions at a place”.

The crop evapotranspiration is denoted as ET_c and the crop water requirement is expressed as CWR. Empirically the values of both ET_c and the CWR are the same, the difference being between the facts that ET_c reflects the amount of water lost through evapotranspiration as a result of atmospheric demand (plus other losses) whereas CWR reflects the amount of water required to compensate for that loss through available resources.

The water consumed in plant synthesis plus water intercepted by various aerial plant parts and then lost through evaporation should be taken into account but as this quantity proves negligible, it may be ignored. Moreover, the water needed for special operations will be taken into account only if applicable. Thus major constituent of the crop water requirement is the water consumed by the crop through Evapotranspiration. CWR is normally expressed as depth of water in millimetres, (mm) or centimetres (cm) for a unit of land.

CWR is calculated as under:

$$CWR = \text{Crop Area} * ETo * Kc * \text{Percent Wetted Area} / Ei \text{ or } Eu$$

Where

ETo is Reference Evapotranspiration for a particular unit of time, Kc is Crop Coefficient for particular stage of crop, Percent wetted area is the fraction of the soil wetted after irrigation. It is considered as 1 in surface irrigation whereas 0.33 – 0.66 under drip irrigation, Ei is Irrigation efficiency under surface irrigation and Eu is Emission uniformity under drip irrigation.

The concepts given above are briefly introduced hereafter and have been discussed in detail in the chapters to come.

The **Reference Evapotranspiration (ETo)** has been defined as the rate of evapotranspiration from a reference surface of hypothetical grass cover with specific characteristics and not short of water. Since water is considered to be abundantly available at the reference evapotranspiring surface, soil factors need not to be taken into account. Accordingly, assessment of the magnitude of only the climatic factors is enough to ascertain the value of ETo . In other words, ETo reflects the evaporative power of the atmosphere at a particular location in a particular day, week or month

of the year irrespective of the crop factor and is normally expressed in mm/day. It is important to design the system for its peak requirement although the same will be operated to fetch the required amount of water as per middle stage of the crop only for few days. Designing at peak ETo value is important to avoid any risk of stress to the crop at that stage.

As for as the **crop factor** is concerned, the evapotranspiration of a common crop is normally much less compared to the reference grass when it is at its initial or development stage, it gradually increases as the crop reaches its maximum leaf area where it surpasses the reference value and again decreases when crop reaches its senescence/maturity stage. These ratios have been determined experimentally and are referred as **Crop Coefficient** values denoted as Kc. The value of Kc of the reference crop has been fixed as 1 and the difference of a required crop compared to the reference crop is assessed in the light of their growth stages. These are expressed commonly in terms of decimals of 1 if lower and 1 plus (decimals) if higher than the reference value.

The value of evapotranspiration of the crop is calculated as under:

$$ET_c = ET_o * K_c$$

Where ET_c is Crop Evapotranspiration in mm/day, ET_o is Reference Crop Evapotranspiration in mm/day and K_c is Crop Coefficient.

The above mentioned approach is termed as **Single Crop Coefficient Approach**. It is a general purpose approach and can be used to calculate the ET_c of all the crops under various systems of irrigation with fair dependability. This approach covers effects of evaporation and transpiration on joint basis. As a matter of fact, the difference of evapotranspiration between a cropped surface and reference grass surface can be calculated more accurately if the effects of both the factors i.e. crop transpiration and soil evaporation are assessed on separate basis. In such a case, the value of K_c is derived from two coefficients: one- basal crop coefficient denoted as K_{cb} to determine the value of plant transpiration component and two- soil water evaporation coefficient denoted as K_e to determine the part of evaporation from the soil surface. This approach is referred as **Dual Crop Coefficient Approach**. In this case $K_c = K_{cb} + K_e$. Accordingly, equation referred above gets transformed to:

$$ET_c = ET_o * (K_{cb} + K_e)$$

For Drip Irrigation Systems, dual crop coefficient approach has been considered as more appropriate.

Percent wetted area: An important aspect of drip irrigation is that a grower does not need to irrigate the whole surface of the soil. Drip irrigation systems normally wet only a portion of the soil area and soil volume. No single correct or proper minimum value for percentage of wetted area

(Pw) has been established. Research has revealed that significant production was achieved when only a relatively small portion of the soil volume received water; maximum production would be achieved with considerably less than full wetting. Therefore, while preparing a design for drip irrigation of widely spaced crops, it would be justified to consider that not less than 33% and as much as two-thirds of the potential horizontal cross-sectional area of the root system i.e. 67% are the appropriate values of percent wetted area. However, when growing crops with rows and drip lines spaced <1.8 m apart, the wetted area can approach 100%. The percent wetted area (Pw) is the average horizontal area wetted in the top 6 to 12 inches (0.15 to 0.30 m) of the root zone as a percentage of the total crop area.

Reference evapotranspiration multiplied by a crop coefficient based on estimated percentage canopy coverage might be the most appropriate approach for maximising water-use efficiency and crop productivity and for scheduling the drip-irrigation. This approach has been widely used by growers of many crops in the western United States. The amount of irrigation water to apply to the root-zone by drip irrigation is dependent on the criteria chosen, for example the percentage of wetted area or canopy cover. It is the area especially in case of orchards which is shaded due to the canopy cover when sun is overhead. Experience has revealed that a crop can grow successfully even if the wetted zone is restricted to a fraction of the soil volume. It should, however be ensured that supply of moisture and nutrients in the partial volume is sufficient to satisfy full crop needs. In drip or micro-sprinkler method of irrigation entire volume of the potential root-zone is never wetted and still the response of the crop is better than the conventional practice.

Percentage of wetted area depends upon the stage of growth of trees. It is assumed that the area covered by the roots is almost equal to the area covered by the canopy of the tree. With widely spaced crops and orchards, ET_c will be reduced because evaporation takes place only from the area which becomes wet at the top surface of the soil. In case of young orchards with almost 30 percent ground cover growing especially on light, sandy soils requiring frequent irrigations, a reduction in ET_c of up to possibly 60 percent has been experienced. For surface irrigation, percent wetted area is treated as 100% whereas for drip irrigation it varies from 33% to 66% of the plant root zone area. The width of the horizontal area wetted in the top 0.15–0.30 m of the crop root-zone is divided by the total planted area.

The percentage of canopy cover may be determined by measuring the average plant width in a row (i.e. shaded width) and dividing that value by the bed width i.e. row space.

Calculation of the percent wetted area P_w may be made through the following formula:

If emitter spacing is less than 0.8 of the wetted width along the lateral, then

$$P_w = 100 \{ N_p * S_e * w / S_p * S_r * P_d \}$$

Where N_p is the number of emitters per plant, S_e is the spacing of emitters along the lateral, w is the wetted width along the lateral, S_p is spacing of plants along a row, S_r is spacing between the rows and P_d is the fraction (in decimal) of area shaded.

If the spacing between emitters along the lateral is equal to or greater than $0.8w$, then

$$P_w = 100 \{ 0.8 * N_p * w^2 / S_p * S_r * P_d \}$$

The following equation may be used to calculate the irrigation water requirement.

$$I = E_p * K * P$$

where I is the irrigation water requirement applied (mm), E_p is cumulative pan evaporation (mm) measured in a Class A Pan during the irrigation interval or more accurately the E_{To} (it can be expressed as $E_{To} = E_p * K_p$) value, K is proportion of E_p as per crop stage (it can be expressed as K_c) and P is a coefficient comprising plant coverage (P_c) or wetted area (P_w).

The percentage of wetted area can be used as a multiplier to reduce the total water applied under drip irrigation. The use of an appropriate percentage of wetted area will bring notable change in both the system design and the efficiency of drip irrigation. Experiments have revealed that using percentage of canopy cover as the basis for calculation of the amount of irrigation water for drip-irrigated crops resulted in less total water usage and greater crop productivity. It has, however, been indicated that for practical purposes the initial value of percentage of canopy cover has been set at 35% from planting until canopy cover exceeded 35%, after which it was set to the measured value and then fixing it to 67% till harvest.

3. EVAPOTRANSPIRATION

3.1. DEFINITION

The water consumed by the crop can be divided into three components:

- a) Water entering in to the roots and being consumed in building of plant tissues.
- b) Water passing through leaves and entering into atmosphere also referred as “Transpiration”.
- c) Water evaporating from the soil surface adjacent to plants, water surface of irrigated fields or from the leaf surface after rainfall etc. also referred as “Evaporation”.

Since the amount of water becoming part of the plant tissue is quite negligible compared to the rest of the two components, the above mentioned components b and c are together termed as Evapotranspiration and are also referred as Consumptive Use.

3.2. RELATED CONCEPTS

3.2.1. Evaporation

Evaporation is the process through which the water is converted to vapour form and gets removed from the evaporating surfaces such as all types of water bodies, irrigated fields and wet soils. The process is driven through the energy being received by the water from solar radiation and to certain extent from the ambient temperature of the air. The vapours developing because of energy leave the evaporating surface on account of difference between the vapour pressure at that surface and the pressure in the atmosphere.

As the evaporation continues, the atmosphere surrounding the evaporating surface gets saturated and the evaporation process slows down to the extent that it may even stop if the saturated air does not get replaced by the comparatively drier air of the atmosphere. Accordingly, it has been observed that solar radiation, air temperature, humidity level of the air and wind speed affect the rate of evaporation.

When evaporation is taking place from the soil surface, the degree of shading by the crop canopy negatively affects its rate. Moreover, limitation in amount of water available at the evaporating surface also tends to reduce the evaporation process. It is, therefore, derived that evaporation process depends purely on meteorological factors

3.2.2. Transpiration

It is the process through which the liquid water of the plant tissues transfers to the atmosphere. The process takes place through stomatal openings of the leaves. Vaporization occurs in the intercellular spaces of the leaves and the vapours exchange to the atmosphere via stomata.

Similar to evaporation, transpiration is also affected by meteorological factors such as radiation energy, air temperature, level of humidity and wind speed. In addition, the degree of soil water contents, ability of the soil to conduct water to the roots, crop characteristics, stage of growth of crop and management practices also influence the rate of transpiration.

3.2.3. Evapotranspiration (ET)

Evapotranspiration includes evaporation of liquid or solid water (ice/snow) from soil and plant surfaces plus transpiration of water through plant tissues expressed as the latent heat of transfer per unit area or its equivalent depth of water per unit area. At the beginning stage of the crop, the main factor determining the rate of evaporation is solar radiation. Thus almost 100% of evapotranspiration comes from evaporation. As the crop develops with increase in foliage, crop canopy progressively shades more and more of the ground area resulting in gradual decrease in rate of evaporation and gradual increase in rate of transpiration. This reaches an extent that almost 90% of evapotranspiration constitutes of transpiration only.

The rate of evapotranspiration is normally expressed in terms of millimetres (mm) per unit time which may be an hour, a day, a decade or a month. It may, however, be taken on the basis of entire crop season or a year.

3.2.4. Reference Crop Evapotranspiration

It is defined as the Evapotranspiration rate from a reference surface, not short of water and is denoted as ET_0 . The reference surface is a hypothetical grass reference crop with specific characteristics. This definition is now the standard definition by FAO. The other denominations such as potential Evapotranspiration and other definitions of ET_0 being based on alfalfa or any other crop have been strongly discouraged.

It reflects evaporative demand of the atmosphere independently of crop type, crop development stage, and management practices. Moreover, since as per definition, the crop should not be short of water, soil factors also do not affect Evapotranspiration. The only group of factors effecting ET_0 is climatic parameters, thus it can be computed through weather data.

Because ET_0 is linked to a specific surface, it provides a reference to which Evapotranspiration from other surface can be related and accordingly it eliminates the need to define a separate ET level for each crop and stage of growth. Evapotranspiration of the crop it can be calculated on daily, weekly, decadal or monthly basis.

3.3. FACTORS AFFECTING EVAPOTRANSPIRATION

The rate of evapotranspiration depends upon four groups of factors given hereunder:

3.3.1. Climatic Parameters

These include solar radiation, atmospheric temperature, wind velocity and air humidity. First three have direct proportion, whereas, air humidity has inverse proportion.

3.3.2. Crop Characteristics

These include type of crop itself, varietal peculiarities, growth pattern and stage of growth. It has been revealed that size of canopy cover, leaves orientation to sunlight, leaves resistances to transpiration, roughness of leaves surface and number and nature of stomata apertures also influence the amount of water being evapotranspired.

3.3.3. Environmental Aspects

Percentage of ground cover, presence and extent of salinity & alkalinity, soil fertility status, nature/extent of pests and diseases, and any other factor affecting crop development.

3.3.4. Management Practices

These include cultivation practices, presence of hardpan, amount and type of fertilizers used for the crop, amount and frequency of irrigations, plant geometry/ density and level of pests control.

Accordingly, the experts have divided the conditions under which the evapotranspiration process is taking place into two categories i.e. one- Evapotranspiration under Standard Conditions where crops are being grown in large fields under non-limiting soil water and agronomic conditions and two- Evapotranspiration under Non-standard Conditions where crops are growing under a situation deviating from the standard one. On the basis of such differences, concepts of stress coefficients have been introduced for calculating the values of evapotranspiration for crops grown under non-standard conditions and it is denoted as $ET_{c\ adj.}$.

3.4. METHODS OF MEASUREMENT OF EVAPOTRANSPIRATION

Various methods have been devised to measure the evapotranspiration but none of them has proven itself popular and fit to the required standards of accuracy and applicability for either being site specific or cumbersome or because of high expertise involved for its users. These have been categorized under three groups:

1. Direct Methods
2. Pan Evaporimeter
3. Empirical Methods

3.4.1. Direct Methods

These methods include:

- Energy Balance Method
- Mass Transfer Method
- Water Vapour Gradients
- Lysimeter Method
- Field Experimentation Method
- Soil Water Depletion Method
- Inflow Outflow Method

These methods require a number of installations, very accurate measurements and considerable labour. Moreover, these are time consuming.

3.4.2. Pan Evaporimeter

3.4.2.1. Description

Pan Evaporimeter has earned wide spread popularity and has, therefore, been adopted world over by the concerned institutions.

Two types of pans have been in use. One is the standard US - Weather Bureau (USWB) Class A Pan Evaporimeter and the other is Sunken Colorado Screen Evaporimeter.

Out of both, the USWB Class A Pan has proven more practical.

This USWB Class A Pan, having diameter of 121.7 cm and a depth of 25 cm, is made of 22 gauge galvanized iron sheet (0.8mm). A stilling well is attached with the pan in the form of a small cylinder of about 10 cm in diameter and 20 cm deep having a small hole near the bottom to receive water from the pan. The readings of the water level are taken through pointer installed with the stilling well to take the readings of water level through a vertical point provided for the purpose.

The pan is painted white or with aluminium paint and is always mounted on a wooden platform which is fixed 15 cm above ground level so that the air can freely circulate beneath it. The pan must be placed accurately levelled.

It should be filled with water up to 5 cm below the rim. The water should be refilled once or twice every week and should not be let to go below a level of 7.5 cm from the rim to save it from being turbid. Covering the pan with screen should preferably be avoided. To keep the animals away from drinking or creating other disturbance, fencing of the pan area is advisable. The site should preferably be under grass up to 20M X 20M and open on all sides for free circulation of the air. If

a large cropped area exists already or the same is going to come under crop, the pan should be placed / located in the centre or on the leeward side of the same.



Figure 3.1: Evaporation Pan

Readings to note the amount of evaporation, should be taken daily at the fixed time preferably in the morning.

3.4.2.2. *Pan Coefficient- K_p*

Pan provides a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. There are, however, certain factors which have extra influence on the rate of evaporation of water from a pan. These are

1. Effect of solar radiation on the water in a shallow pan differs from that of a grass reference surface.
2. Absorption of heat by the pan continues its effect on evaporation even at night time compared to the natural crop which transpires normally only in the day time.
3. Characteristics of the air with respect to turbulence, temperature and humidity above the water surface differ from that of crop surface.

To overcome the influence of such factors, empirical derivation of a pan coefficient has been made which has brought the values of pan evaporation fairly close to the values of reference Evapotranspiration as reflected in Table 3.1.

Table-3.1. Pan Coefficient

Class A pan	Case A: Pan placed in short green cropped area				Case B: Pan placed in dry fallow area			
Wind Speed (m/sec)	Windward side distance of green crop (fetch) (m)	mean relative humidity			Windward side distance of dry fallow (fetch) (m)	mean relative humidity (%)		
		low <40	medium 40-70	high >70		low <40	medium 40-70	high >70
Light < 2	1	0.55	0.65	0.75	1	0.7	0.8	0.85
	10	0.65	0.75	0.85	10	0.6	0.7	0.8
	100	0.7	0.8	0.85	100	0.55	0.65	0.75
	1000	0.75	0.85	0.85	1000	0.5	0.6	0.7
Moderate 2-5	1	0.5	0.6	0.65	1	0.65	0.75	0.8
	10	0.6	0.7	0.75	10	0.55	0.65	0.7
	100	0.65	0.75	0.8	100	0.5	0.6	0.65
	1000	0.7	0.8	0.8	1000	0.45	0.55	0.6
Strong 5-8	1	0.45	0.5	0.6	1	0.6	0.65	0.7
	10	0.55	0.6	0.65	10	0.5	0.55	0.65
	100	0.6	0.65	0.7	100	0.45	0.5	0.6
	1000	0.65	0.7	0.75	1000	0.4	0.45	0.55
Very Strong >8	1	0.4	0.45	0.5	1	0.5	0.6	0.65
	10	0.45	0.55	0.6	10	0.45	0.5	0.55
	100	0.5	0.6	0.65	100	0.4	0.45	0.5
	1000	0.55	0.6	0.65	1000	0.35	0.4	0.45

Thus E_{To} is equal to $E_{pan} * K_p$

Where E_{To} = is reference Evapotranspiration in mm/day.

K_p is pan coefficient and E_{pan} is pan evaporation in mm/day.

The value of appropriate pan coefficient depends upon

- Pan type
- Ground cover of the station,
- Cover of the surroundings,
- Range of the wind speed
- Range of humidity level.

For example, larger the upwind buffer zone (fetch) more will be the equilibrium between the air moving over the pan and the buffer zone. Accordingly, selection of proper value of K_p becomes important.

3.4.2.3. *Solution of an example*

A pan is surrounded by irrigated crop, wind speed is 2 meter/second, relative humidity is 60% and fetch is 100 meters. Its K_p as reflected in table (1) above is 0.8. Find the value of ET.

See the reading of the pan. The reading is 7.5 mm for that day. The appropriate value of Evapotranspiration will be $7.5 \times 0.8 = 6.00$ mm for that day. If the evaporation of a week or 10 days is multiplied with this K_p , we can have reference Et of a week or 10 days' period.

3.4.3. Empirical Methods

The literature reveals that about 30 empirical and semi-empirical formulae have so far been developed to measure the Evapotranspiration rate in different localities. Those which earned good fame and have been more or less used by various experts and institutions are enlisted below:

- Blaney Criddle Method (1945)
- Thornth Waite Method (1948)
- Penman Method (1948)
- Jensen-Haize Method (1963)
- Hargreave Samani Method
- Turc Method
- Radiation Method
- Penman Modified Method (1975)

In recent years, the analysis of the performance of these methods revealed that the results of these methods differ in different localities of the world and some methods always give higher value of ETo compared to the others.

The major limitations are given here-below:

1. Relationships between various parameter are calibrated as per local value which have limited global application. Deviations were often found to exceed the permissible limits
2. Testing the accuracy of a method under new set of conditions proves time consuming, laborious and costly.
3. Penman method requires local calibration of the wind function.

4. Radiation method gives erratic values under arid conditions.
5. Pan evaporation method gets influence of microclimatic conditions and thus its performance becomes doubtful.

To overcome these weaknesses, FAO has formulated a standard and more consistent method in 1990 with the consultation of international experts, scientists and researchers and named it as **Penman-Monteith Method**. Calculations through this method provide values which have been found more consistent with actual consumptive use of the crops in a wide range of locations and climatic factor. The equation developed under Penman-Monteith Method is given in the next section.

3.4.3.1. Penman - Monteith Method

According to this method

$$ET_o = \frac{[0.408 \Delta (R_n - G) + \gamma 900 U_2 (e_s - e_a)] / T + 273}{\Delta + \gamma (1 + 0.34 U_2)}$$

Where;

1. Delta (Δ - rate of change) is slope of saturation vapour pressure curve with change in temperatures expressed in $\text{kPa}/^{\circ}\text{C}^{-1}$ and $(e_s - e_a)$ is the difference between saturation vapour pressure (e_s) and actual vapour pressure e_a expressed in kPa referred as vapour pressure deficit expressed in kPa.
2. R_n = Net radiation at the crop surface expressed MJ/M^{-2} per day
3. G = Soil heat flux density expressed in MJ/M^{-2} per day
4. γ = Psychrometric constant (its unit is $\text{kPa}/^{\circ}\text{C}^{-1}$). It reflects the function of altitude while recording the data regarding actual vapour pressure and saturation vapour pressure.
5. T is main daily air temperature in $^{\circ}\text{C}$ at 2 meters height from the ground.
6. U_2 is wind speed at 2 meter height expressed in meters per second (ms^{-1}).
7. Primarily, these are only six meteorological parameters which are required to be understood and recorded. In addition to the climatological data, the Penman-Monteith equation also demands to ascertain location of site with respect to altitude above sea level in meters and latitude of the location in terms of degrees north or south. These help in adjusting the weather parameters with reference to atmospheric pressure which is a function of elevation above mean sea level. This helps in computing the extra-terrestrial radiation (R_a) and daylight hours (N).

3.4.4. Data Available in Pakistan

FAO has developed worldwide data-base of mean monthly Agro climatic parameters which has been published in FAO, 1992 and FAO, 1993. Addition has been made by International Water Management Institute in the form of electronic databases for various parts of the World.

It is, however, to be kept in view that the actual long-term data available for a particular area through local observatories is more authentic to be used for desired subject calculations.

It is highly encouraging to note that National Agromet Centre of Pakistan Meteorological Department, Islamabad (www.pakmet.com.pk) is taking care of almost all the Agro climatologically data and comprehensive datum of each parameter is available as well as being regularly published in Agro meteorological Bulletin every month.

The values for ETo for various regions of Pakistan have been calculated /developed by certain institutions namely IWMI, Pakistan Agro-meteorological Directorate, Islamabad and FAO. IWMI has developed the values of ETo using Penman Monteith method and Agromet has developed the values using Blaney Criddle Method. The values published by these Institutions are given as Tables 3.2, 3.3 & 3.4 respectively.

Table-3.2. Values of ETo for Different Ecological Zones of Pakistan by IWMI

Sr. No.	Districts	Average Daily Reference Crop Evapotranspiration (mm)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Jacobabad	2.6	3.5	5.6	7.5	9.3	10.2	7.9	6.9	6.0	4.7	3.0	2.2
2	Hyderabad	2.8	3.7	5.1	6.9	8.6	7.9	6.2	5.6	6.1	4.9	3.3	2.8
3	Nawabshah	2.8	3.7	5.1	6.7	8.7	9.5	7.2	6.2	6.1	4.9	3.3	2.7
4	Larkana	2.4	3.4	5.3	7.0	9.0	9.8	7.4	6.4	6.1	4.4	3.1	2.3
5	Khanpur	2.0	3.0	4.5	6.0	7.2	8.0	6.6	6.2	5.2	4.0	2.6	1.9
6	Mianwali	1.4	2.0	3.3	4.6	6.2	6.5	5.6	5.0	4.6	3.1	1.8	1.2
7	Sargodha	1.7	2.5	4.0	5.6	7.2	7.6	6.1	5.3	5.1	3.8	2.3	1.7
8	Bahawalpur	1.8	2.8	4.1	5.5	6.8	7.7	6.2	6.0	5.3	3.9	2.5	1.7
9	Bahawalnagar	2.0	3.0	4.5	6.5	8.3	9.0	6.6	6.3	5.7	4.4	2.8	1.9
10	Jhang	1.6	2.5	3.9	5.5	7.2	7.8	6.5	5.8	5.0	3.6	2.2	1.5
11	Faisalabad	1.4	2.2	3.5	4.8	6.2	6.5	5.4	4.9	4.7	3.3	1.9	1.3
12	Multan	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.4	2.0	1.5

13	Peshawar	1.4	2.0	3.1	4.4	5.7	6.3	5.2	4.9	4.2	2.8	1.7	1.2
14	Sialkot	1.2	1.9	3.1	4.4	5.4	5.8	4.4	4.3	3.8	2.7	1.6	1.1
15	D I Khan	1.6	2.4	3.8	5.0	6.4	6.9	6.0	5.5	4.8	3.3	2.0	1.5
16	Jhelum	1.4	2.1	3.4	4.8	5.9	6.2	4.7	4.0	4.5	4.0	2.9	1.8
17	Lahore	1.4	2.2	3.6	5.0	6.3	6.5	5.2	4.7	4.5	3.2	1.8	1.3

Table-3.3. Values of Reference Crop Evapotranspiration (ET_o) in MM/Day by Agromet. Pakistan

Sr. No.	Districts	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Peshawar	1.8	2.3	4.4	4.4	6.5	7.6	7.7	5.2	5.6	4.1	2.8	1.3
2	D.I.Khan	1.9	2.6	4.0	5.4	6.7	6.7	6.2	5.3	5.8	4.5	3.1	2.1
3	Rawalpindi	1.7	1.7	3.0	4.9	6.3	7.1	6.7	4.9	5.4	4.0	2.7	1.7
4	Jhelum	2.0	2.6	3.9	5.3	6.4	7.6	4.7	4.3	5.6	5.2	3.6	1.4
5	Sargodha	2.0	2.6	4.0	5.4	6.7	7.7	6.1	5.3	5.7	5.3	3.7	1.4
6	Lahore	2.1	2.7	4.0	5.5	6.8	7.7	4.7	4.4	5.7	5.3	3.8	1.5
7	Faisalabad	2.0	2.6	3.9	5.4	6.7	7.7	6.1	5.3	5.7	4.5	3.1	2.0
8	Multan	2.1	2.7	4.2	5.6	7.0	7.9	7.3	6.8	5.9	4.8	3.3	2.3
9	Khanpur	2.3	3.0	4.3	5.7	7.3	7.8	7.3	6.7	5.8	5.5	4.0	2.9
10	Quetta	1.0	1.2	3.2	4.6	5.9	7.2	7.4	5.7	4.4	3.7	2.3	1.0
11	Rohri	2.6	3.3	4.5	6.0	7.3	7.9	6.4	6.7	5.9	5.8	4.3	2.7
12	Hyderabad	3.7	3.7	5.1	6.4	8.2	8.5	5.3	4.3	7.0	6.2	4.8	3.9

Table-3.4. Values of Eto for Different Ecological Zones of Pakistan by FAO

Zone	Districts	Average Daily Reference Crop Evapotranspiration (mm)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Zone I	Thatta, Badin, Hyderabad	3.6	4.5	6.6	8.6	11.5	10.9	9.1	8.1	8.0	6.6	4.5	3.7
Zone II	Hyderabad, Badin, Tharaparkr, Sanghar, Dadu, Khairpur, Larkana, Nawabshah, Sukkur, Rahim Yar Khan, Sibi and Shikarpur Thatta.	3.2	4.3	6.3	8.5	11.0	11.1	9.2	8.1	7.6	6.2	4.1	3.2
Zone III (a)	Tharparkar, Khairpur, Nawabshah, Sanghar, Rahim Yar Khan, Bahawalnagar.	3.1	4.2	6.2	8.5	10.8	11.2	9.3	8.3	7.6	6.0	4.1	3.1
(b)	Muzaffargarh, Mianwali, Sargodha, Bhakar, Khushab.	1.8	2.7	4.0	6.4	8.6	9.2	7.6	6.5	5.8	4.5	2.7	1.9
Zone IV (a)	Bahawalnagar, Rahim Yar Khan, Multan, Vehari, Muzaffargarh, Sahiwal, Okara, Kasur, Faisalabad, Jhang, Sheikhupura, Gujranwala, Sargodha, Gujrat, Bahawalpur,	1.7	2.6	4.0	6.1	7.7	8.6	7.1	6.3	5.7	4.3	2.6	1.8
(b)	Peshawar, Mardan.	1.7	2.3	3.2	4.5	7.3	8.4	7.4	6.3	5.0	3.9	2.6	1.8
Zone V	DI Khan, Bannu, Mianwali, Talagang, Attock, Jehlum, Gujrat, Gujranwala, Sialkot.Lahore,	1.8	2.8	3.8	5.9	7.8	8.5	6.7	5.8	5.2	4.1	2.8	1.8
Zone VI	Rawalpindi, Hazara, Mansehra. Abbotabad	1.8	3.1	4.0	6.5	8.9	10.1	7.1	5.7	5.3	4.3	3.2	2.1
Zone VII	Gilgit, Baltistan, Chitral, Dir, Swat, Malakand, Mohmend Agency, Khyber, Bajaur, Tribal Areas of Peshawar and Kohat.	0.8	1.1	2.0	3.1	4.2	5.1	5.1	4.7	3.8	2.5	1.4	0.8
Zone VIII	Kohat, Bannu, Kurram, North & South Waziristan, Zhob, Loralai, Kalat, Sibi, Quetta.,	1.6	2.3	3.5	4.7	6.3	7.3	7.2	6.5	5.5	4.1	2.6	1.7
Zone IX	Karachi, Dadu, Mekran, Kharan, Chaghi, Lasbella.	2.5	3.2	4.4	5.8	7.2	7.8	7.5	6.9	5.8	4.6	3.3	2.5
Zone X	DI Khan, DG Khan, Kacchi.	1.7	2.4	3.7	5.2	6.8	6.9	6.3	6.0	5.1	3.8	2.3	1.6

3.5. VALUES OF ET_o FOR ALL DISTRICTS OF PUNJAB

A reference table for ET_o values for use in the field was prepared during the NPIW project through HEISCON Office. These values were selected from the work done in this context by FAO, IIMI and Agromet (Pakistan) as referred above and it encompassed only the major regions of Pakistan. A difficulty was being faced by the system designers and field engineers in correlating the values for a number of districts of Punjab not clearly delineated in the said table.

To solve this problem, the data available in this context has been reviewed with due contemplation and a table has been prepared titled “Values of ET_o for All Districts of Punjab”. The deliberation made in this context by IIMI, where in the ET_o values of all the canal commands have been computed through concurrent data collected from the local meteorological stations and then processed with the help of Penman Monteith equation, has been utilised as the main reference. The district covering the highest percentage of a canal command has been designated with the value computed for that canal command.

In addition, weather data from few stations has been processed through CROPWAT 8.0 and the same has been presented in chapter 4 of this manuscript duly explaining the procedure of using this software for the purpose. Meteorological data of three stations namely Lahore, Multan and Mianwali has been processed to calculate ET_o values and then CWRs of salient crops of the area pertaining to that station have been computed through the FAO software.

These ET_o values have been presented in Table 3.5.

Table-3.5. Reference Evapotranspiration of All Districts of Punjab

Sr. No.	Districts	ET _o (mm)/Day											
		Months											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Attock	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
2	Bahawalnagar	1.9	2.9	4.3	6.0	7.6	8.3	6.4	6.1	5.5	4.2	2.6	1.8
3	Bahawalpur	1.8	2.8	4.1	5.5	6.8	7.7	6.2	6.0	5.3	3.9	2.5	1.7
4	Bhakkar	1.5	2.4	3.9	5.2	6.7	7.4	6.1	5.6	5.0	3.5	2.0	1.5
5	Chakwal	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
6	Chiniot	1.4	2.3	3.6	5.0	6.4	6.8	5.5	5.0	4.7	3.3	1.9	1.4
7	Dera Ghazi Khan	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
8	Faisalabad	1.4	2.2	3.6	4.9	6.2	6.5	5.3	4.8	4.6	3.3	1.9	1.3
9	Gujranwala	1.3	2.1	3.4	4.7	6.0	6.2	5.0	4.6	4.3	3.1	1.8	1.2
10	Gujrat	1.5	2.3	3.7	5.2	6.6	6.9	5.4	4.8	4.6	3.9	2.6	1.7
11	Hafizabad	1.4	2.3	3.6	5.0	6.4	6.8	5.5	5.0	4.7	3.3	1.9	1.4
12	Jhang	1.4	2.3	3.6	5.0	6.4	6.8	5.5	5.0	4.7	3.3	1.9	1.4
13	Jhelum	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
14	Kasur	1.3	2.1	3.5	4.8	6.0	6.3	4.9	4.6	4.3	3.1	1.8	1.2
15	Khanewal	1.5	2.4	3.9	5.1	6.4	7.1	5.8	5.4	4.9	3.4	1.9	1.4
16	Khushab	1.5	2.4	3.9	5.2	6.7	7.4	6.1	5.6	5.0	3.5	2.0	1.5
17	Lahore	1.3	2.3	3.6	5.3	6.2	6.2	5.4	4.8	4.4	3.2	2.1	1.4
18	Layyah	1.5	2.4	3.9	5.2	6.7	7.4	6.1	5.6	5.0	3.5	2.0	1.5
19	Lodhran	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
20	Mandi Bahauddin	1.5	2.3	3.7	5.2	6.6	6.9	5.4	4.8	4.6	3.9	2.6	1.7
21	Mianwali	1.4	1.9	2.9	4.3	5.7	6.2	5.8	5.1	4.7	3.4	2.1	1.4
22	Multan	1.4	2.1	3.2	4.8	6.1	7.0	6.1	5.9	5.1	3.4	2.1	1.4
23	Muzaffargarh	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
24	Norowal	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
25	Nankana Sahib	1.3	2.1	3.4	4.7	6.0	6.2	5.0	4.6	4.3	3.1	1.8	1.2
26	Okara	1.5	2.4	3.9	5.1	6.4	7.1	5.8	5.4	4.9	3.4	1.9	1.4
27	Pakpattan	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5
28	R. Y. Khan	1.9	2.9	4.3	5.7	7.0	7.8	6.4	6.1	5.3	4.0	2.5	1.8
29	Rajanpur	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5

30	Rawalpindi	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
31	Sahiwal	1.5	2.4	3.9	5.1	6.4	7.1	5.8	5.4	4.9	3.4	1.9	1.4
32	Sargodha	1.5	2.4	3.8	5.3	6.8	7.2	5.8	5.0	4.9	3.8	2.5	1.6
33	Sheikhupura	1.3	2.1	3.4	4.7	6.0	6.2	5.0	4.6	4.3	3.1	1.8	1.2
34	Sialkot	1.3	2.1	3.4	4.7	5.9	6.1	4.8	4.5	4.2	3.0	1.7	1.2
35	T T Singh	1.4	2.2	3.6	4.9	6.2	6.5	5.3	4.8	4.6	3.3	1.9	1.3
36	Vehari	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.5	2.0	1.5

4. CROP COEFFICIENT

4.1. DEFINITION

The Crop Coefficient (K_c) is the ratio of the Evapotranspiration rate of the crop (ET_c) to the Evapotranspiration rate of the reference green grass cover (ET_o) and it is calculated through dividing ET_c by ET_o . It is a coefficient expressing the difference between the Evapotranspiration from the surface of a crop and the evapotranspiration from reference grass surface. The K_c represents an integration of the effects of characteristics that differentiate the crop from the reference grass for which the value of K_c has been fixed as 1.

4.2. FACTORS AFFECTING COEFFICIENT VALUE

Because of the following factors, a common crop differs from the reference crop.

4.2.1. Crop Height

Crop height influences the aerodynamic resistance of the canopy and the turbulent transfer of vapours from the crop into the atmosphere.

4.2.2. Albedo

Albedo is the reflectance of radiation by the crop leaves and the soil surface. It influences the net radiation of the surface R_n which is a key factor and major source of energy exchange for the evaporation process. This itself is affected by the fraction of ground covered by vegetation and by the soil surface wetness being inversely proportional.

4.2.3. Canopy Resistance

The crop resists vapour transfers through (a) area of the leaves (b) number of stomata per leaf. (c) age and condition of leaves and (d) degree of stomatal control.

4.2.4. Evaporation from the Soil

Evaporation from the soil especially open to sunshine is a major source of difference by a crop compared to reference grass. Moreover, the value of evaporation from the soil is particularly significant when crop is at its initial stage and coverage of ground by the canopy is quite limited.

4.2.5. Health and Vigour of Crop

Undoubtedly, the value of K_c will be maximum when the crop is at its potential growth. In case the crop encounters certain limitations due to water shortage, poor crop density, high salinity and/ or pests attack etc. and growth is below standard, the value of K_c becomes low. Such crop is considered as non-standard crop and accordingly the values of K_c should be adjusted.

On over all bases, there are two factors which lead to variations in the values from crop to crop and these are:

4.2.6. Crop Type

The close spacing of plants, taller canopy heights and roughness because of difference in plant heights of many full grown agricultural crops lead to K_c values that are larger than 1 and may go by 15-20% higher for some of crops such as maize, sorghum and sugarcane. The characters of crop that affect are:

4.2.6.1. Stomata opening behaviour

In crops such as pineapple, the stomata are closed during the day. The coefficient value in the crops is, therefore, very small.

4.2.6.2. Number & position of stomata

In crops such as Citrus and many deciduous trees, the stomata are on lower side of the leaf as well as much less in number.

4.2.7. Crop Growth Stage

Value of Evapotranspiration changes as the crop changes its ground cover, height and leaf area. Accordingly, the K_c for that crop will vary. The growing period is divided into four growth stages:

- (i) initial
- (ii) crop development
- (iii) mid-season and
- (iv) late stage.

The same are graphically presented in fig 4.1.

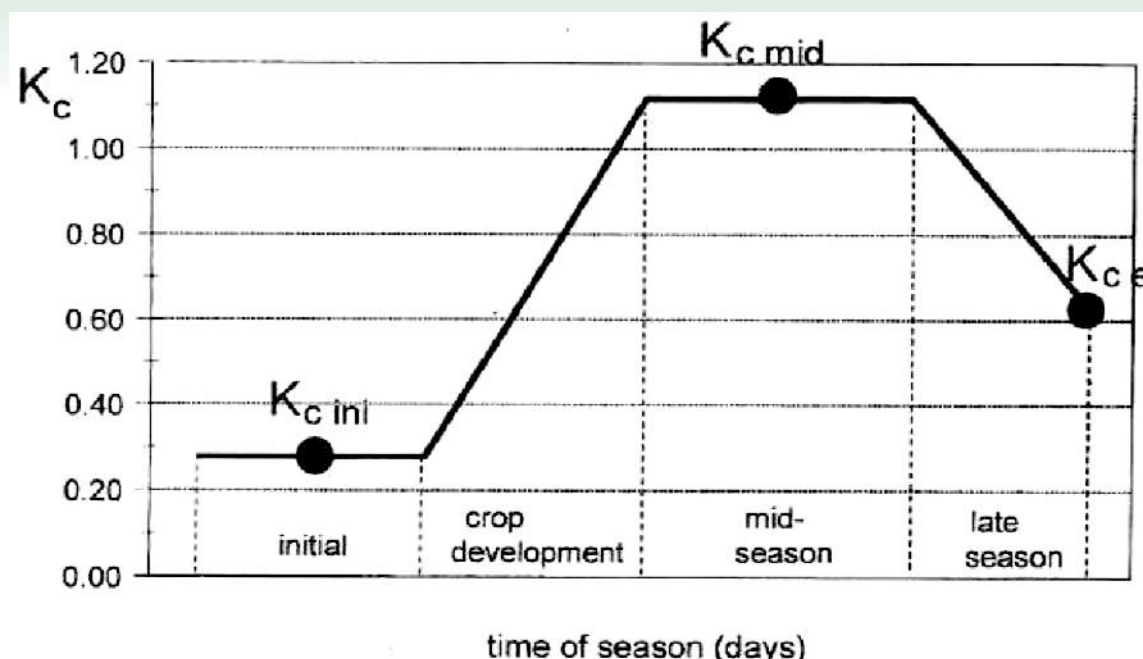


Figure- 4.1 Curve indicating Crop Growth Stages i.e. Initial, Crop Development, Mid-season and Late season

4.2.7.1. Initial Stage

This stage runs from planting date to approximately 10% ground cover which in turn depends upon kind of crop, variety, the planting date and the climate. For perennial crops, the “planting date” is replaced by the “green update” i.e. when the initiation of new leaves occurs.

During initial stage, leaf area of the crops is quite small and soil evaporation constitutes the major part of Evapotranspiration. The value of K_c , therefore, is quite low. It is, however, high when the soil is wet.

4.2.7.2. Crop Development Stage

This stages runs from 10% ground cover to effective full cover which occurs at initiation of flowering. In row crops such as beans, sugar beets, potatoes and corn, effective cover is defined as the time when leaves of adjacent rows begin to intermingle and the soil is almost completely shaded or when the plants gain their full size. For some crops, at this stage, fraction of the ground surface covered by vegetation (f_c) reaches a value of 0.7 to 0.8.

Another criterion to judge the occurrence of full cover is to have an estimate of leaf area Index (LAI). LAI is defined as the average total area of leaves (one side) per unit area of ground surface. When LAI reaches a value of 3, the plant is considered to have reached the stage of full cover.

By this stage of growth of plants, evaporation gradually becomes almost constant and transpiration becomes the major phenomena.

4.2.7.3. *Mid-Season Stage*

This stage runs from effective full cover to the start of maturity. The start of maturity is often reflected by:

- i. Beginning of aging.
- ii. Yellowing or senescence of leaves.
- iii. Leaf drop.
- iv. Browning of fruit.

At this stage, the K_c reaches its maximum value, and remains almost constant for most of the growing season. Moreover, this stage is the longest one for perennials and annual crops whereas it may be short for vegetables harvested fresh and green.

4.2.7.4. *Late Season Stage*

The late season stage runs from the start of maturity to harvest or full senescence. The K_c of this stage is denoted as $K_{c\text{ end}}$. Because of aging of the crop, stomatal conductance becomes less efficient and thus K_c values are reduced.

4.3. SINGLE AND DUAL CROP COEFFICIENT APPROACHES

The difference between the values of evaporation and the values of transpiration can be combined into one single coefficient, or it can be split into two describing separately the differences in evaporation and transpiration between both surfaces. The selection of the approach depends on the purpose of the calculation, the accuracy required, the climatic data available and the time step with which the calculations are executed.

4.3.1. Single Crop Coefficient Approach

In the single crop coefficient approach, the effect of crop transpiration and soil evaporation are combined into a single K_c coefficient. The coefficient integrates differences in the soil evaporation and crop transpiration rate between the crop and the grass reference surface. Since soil evaporation may fluctuate daily as a result of rainfall or irrigation, the single crop coefficient expresses only the time-averaged effects of crop evapotranspiration.

As the single K_c coefficient averages soil evaporation and transpiration, the approach is used to compute E_{tc} for weekly or longer time periods, although calculations may proceed on daily basis. The single K_c is used for planning studies and irrigation system design where the averaged effects of soil wetting are more relevant. This proves more suitable for surface irrigation and sprinkler systems where the time interval between successive irrigation is of several days, often ten days or more.

4.3.1.1. Crop coefficient curves

Through presenting the period of growing season of a crop on x axis and values of crop coefficient on y axis and then plotting the weekly values of crop coefficient on the graph, it is quite easy to develop a curve which will represent the changes occurring at various stages of the crop growth as per their ratio of E_{tc} to E_{To} . Through this curve, the value of K_c factor of any stage can be interpolated and hence the value of E_{tc} for a desired period of the crop can be calculated.

4.3.1.2. Single crop coefficient curve

The single crop coefficient curve is shown in Figure 4.2. Shortly after the initiation of new leaves for perennials, the value for K_c is small, often less than 0.4. The K_c begins to increase from the initial K_c value, $K_{c\text{ initial}}$ at the beginning of rapid plant development and reaches a maximum value, $K_{c\text{ mid}}$, at the time of maximum or near maximum plant development. During the late season period, as leaves begin to age and senesce due to natural or cultural practices, the K_c begins to decrease until it reaches a lower value at the end of the growing period equal to $K_{c\text{ end}}$.

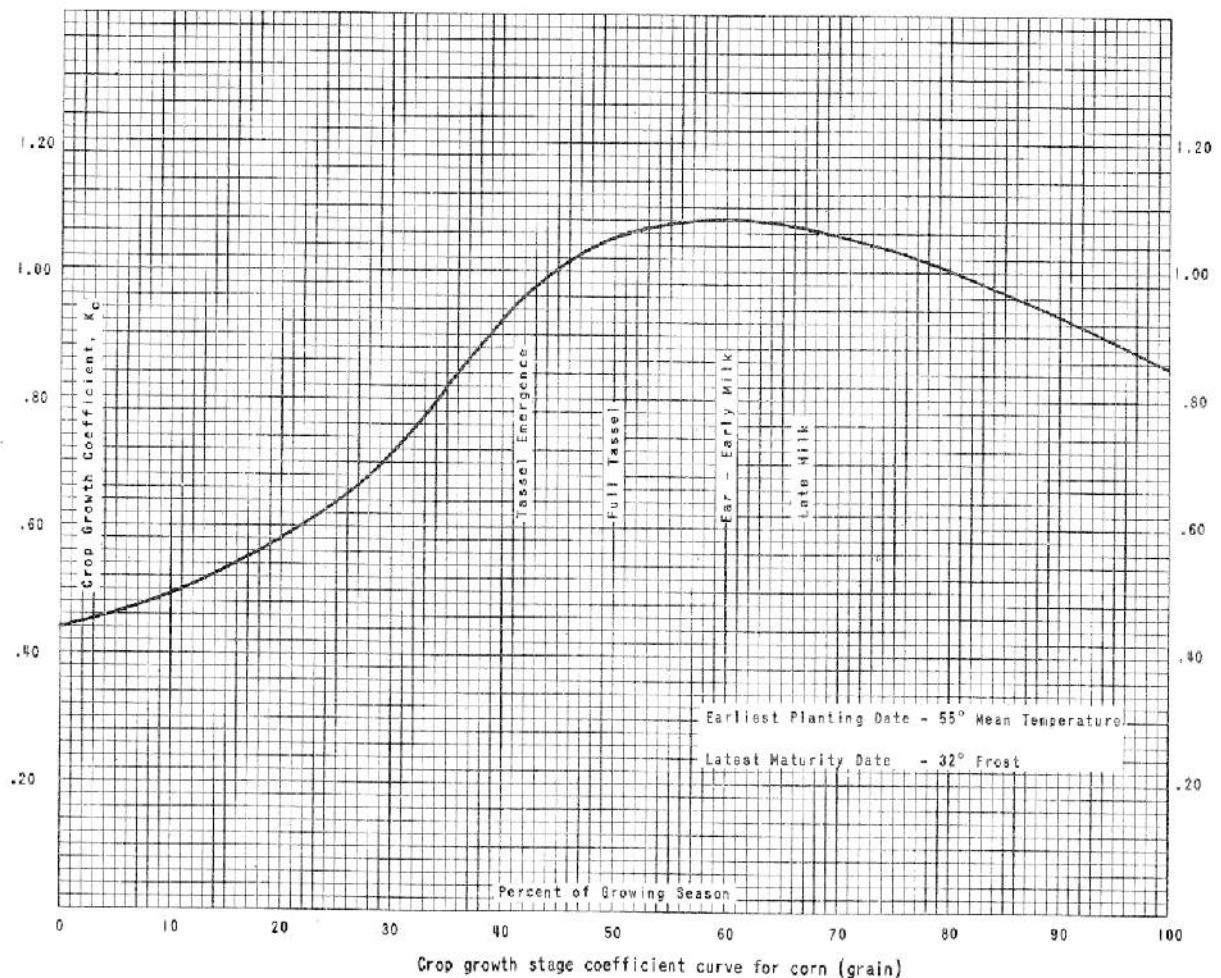


Fig 4.2 Generalized Crop Coefficient Curve with Single Crop Coefficient Approach

4.3.1.3. *Values of K_c for agronomic crops, vegetables and orchards*

The peak K_c values of most of the miscellaneous crops have been given in Table 4.1. Duration of important growth stages of important agronomic crops along with corresponding values of K_c have been given in Table 4.2. The same for vegetable crop are given in Table 4.3 & for Fruit crops in Table 4.4. The values are based on the findings of regional research stations being coordinated & supervised by FAO.

Table-4.1. Values of Crop Coefficient of Mid-Season Stage (Kc mid) of Miscellaneous Crops

Sr. No.	Agronomic Crop	Kc mid	Sr. No.	Vegetables	Kc mid	Sr. No.	Forages	Kc mid	Sr. No.	Orchards	Kc mid
1	Barley	1.15	1	Ash gourd	1.0	1	Alfalfa (Lucerne)	1.2	1a	Almonds without Ground Cover	0.9
2	Beans (Dry)	1.15	2	Bitter gourd	1.2	2	Bermuda Grass	1.0	1b	Almonds with Ground Cover	1.1
3	Canola	1.15	3	Beans (green)	1.05	3	Berseem	1.15	2a	Apple without GC	0.9
4	Caster Beans	1.15	4	Beats (Table)	1.05	4	Clovers (general)	1.15	2b	Apple with GC	1.2
5	Chickpea (Grams)	1.05	5	Bingil	1.05	5	Guar	1.10	3a	Apricots without GC	0.9
6	Cluster bean (Guar)	1.15	6	Cabbage	1.05	6	Maize	1.15	3b	Apricots with GC	1.15
7	Cotton	1.25	7	Capsicum	1.05	7	Millet	1.0	4a	Banana 1st year	1.1
8	Flax	1.1	8	Carrot	1.05	8	Oats	1.15	4b	Banana 2nd year	1.2
9	Groundnut	1.15	9	Cauliflower	1.05	9	Ryegrass	1.05	5	Ber	1.1
10	Jute	1.1	10	Chillies	0.75	10	Sorghum	1.10	6	Berries	1.05
11	Maize	1.2	11	Cucumber	1.0	11	Sudan grass	1.15	7	Chiku	1.1
12	Millets	1.0	12	Egg Plant	1.05				8a	Citrus without GC	0.65
13	Oats	1.15	13	Garlic	1.0				8b	Citrus with GC	0.85
14	Rapeseed	1.0	14	Garma	1.05	Sr. No.	Pulses	Kc mid	9a	Cherries without GC	0.95
15	Rice	1.2	15	Ladyfinger	1.0	1	Arhar	1.15	9b	Cherries with GC	1.2
16	Safflower	1.0	16	Lettuce	1.0	2	Beans dry	1.15	10	Dates	0.95
17	San-hemp	1.2	17	Long melon	1.0	3	Chickpea (Gram)	1.0	11	Fig	1.0
18	Sesame	1.1	18	Mint	1.15	4	Lobia	1.05	12	Grapes	0.95
19	Sorghum	1.1	19	Muskmelon	1.05	5	Mash Beans	1.15	13	Guava	1.1
20	Soybeans	1.15	20	Onion (dry)	1.05	6	Mung Beans	1.15	14	Litchi	1.05
21	Sugarcane	1.3	21	Onion (Green)	1.0	7	Lentil	1.10	15	Mango	0.65
22	Sugar Beats	1.2	22	Peas (Green)	1.15				16	Mulberry	1.0
23	Sunflower	1.2	23	Peas (Seed)	1.2				17	Oil Palm	1.0
24	Sweet Corn	1.15	24	Pepper	1.05				18	Olives with 60% GC	0.7
25	Toria	1.0	25	Potato	1.15				19a	Peaches without GC	0.9
26	Tobacco	1.2	26	Pumpkin	1.0				19b	Peaches with GC	1.15
27	Wheat	1.2	27	Radish	0.9				20	Pears	0.95
			28	Sarda	1.05				21a	Pine apple without GC	0.3

			29	Spinach	1.0				21b	Pine apple with GC	0.5
			30	Squash	0.95				22	Pistachio	1.10
			31	Sweet Melon	1.05				23	Plum	1.15
			32	Sweet Pepper	1.05				24	Pomegranate	0.75
			33	Sweet Potato	1.15				25	Strawberry	0.85
			34	Tomato	1.15				26a	Tea (without Shade)	1.0
			35	Turnip	1.10				26b	Tea (with Shade)	1.15
			36	Water melon	1.05				27	Walnut	1.1

Table-4.2. Duration of Growth Stages of Agronomic Crops and Corresponding Kc Values

Sr. No	Crop	Date of Sowing	Duration of Initial stage (Days)	Kc initial	Duration of Development stage (Days)	Kc Development*	Duration of Middle Stage (Days)	Kc Mid stage (Peak Value)	Duration of Late Stage (Days)	Kc Late stage	Total days	Date of Harvesting
1	Barley	Nov	15	0.3	25		50	1.15	30	1.0	120	April
2	Beans	Jun	15	0.4	25		35	1.05	20	0.95	95	Sep & Oct
3	Canola	Oct	25	0.35	45		70	1.15	40	1.0	180	Mar & April
4	Castor Beans	March	25	0.35	40		65	1.15	50	1.1	180	Sep & Oct
5	Cotton	April	30	0.5	50		60	1.25	55	0.9	195	Nov & Dec
6	Grams	October	20	0.4	30		45	1.05	20	1	115	Feb & Mar
7	Groundnut	March	25	0.5	35		45	1.15	25	0.85	130	July & Aug
8	Maize	Feb/July	20	0.5	30		40	1.2	20/25	0.9	115	May & Nov
9	Millets	Jun/July	15	0.4	25		40	1.0	25	0.9	105	October
10	Rapeseed	October	25	0.35	45		70	1.15	40	1.0	180	Mar & Apr
11	Rice	Jun/July	30	1.15	30		60	1.2	30	1.05	150	Nov & Dec
12	Safflower	Nov	25	0.5	40		65	1.0	30	0.8	160	April
13	Sesame	Jun/July	15	0.35	25		50	1.1	20	1.0	110	Oct & Nov
14	Sorghum	July	20	0.4	35		40	1.1	30	0.8	125	Nov & Dec
15	Soybeans	Feb July	20/20	0.4	25/35		50/60	1.15	15/20	0.8	110/130	June & Nov
16	Sugarcane	Feb Sep	30/35	0.5	60/65		180/200	1.3	60/90	0.8	330/390	Dec & Jan
17	Sugar Beets	October	30	0.5	45		90	1.2	15	0.9	180	April
18	Sunflower	Jan Feb	25	0.4	35		45	1.2	25	0.8	130	June
19	Sweet Corn	Feb July	20	0.3	30		40	1.15	20	1.1	110	June & Nov
20	Mustard	Oct	25	0.3	45		70	1.0	40	1.1	180	April
21	Tobacco	Oct	30	0.4	40		50	1.2	30	0.9	150	Mar & April
22	Wheat	Nov	15	0.4	25		50	1.2	30	0.7	120	April

* No single value may be indicated for Kc dev as it continuous changing throughout the development stage.

Table 4.3 Duration of Growth Stages and Kc Values of Vegetables Crops

Sr.No	Crop	Date of Sowing	Initial Stage		Development Stage*		Mid Stage (Peak Value)		Late Stage		Total Days	Date of Harvesting
			Duration	Kc	Duration	Kc	Duration	Kc	Duration	Kc		
1	Ash gourd	Oct & Feb	15	0.6	25		50	1	30	1	120	March
2	Bitter gourd	Mar Jun	30	0.6	40		50	1	30	1	150	Sep & Oct
3	Beans green	Oct	15	0.4	25		25	0.95	10	0.95	75	Jan
4	Beans dry	Mar	15	0.4	25		35	1.15	20	0.7	95	July
5	Bringle	Apr	30	0.6	50		60	1.05	40	0.9	180	Nov & Dec
6	Cabbage	Oct	30	0.4	40		65	1.05	30	1	165	Feb & Mar
7	Capsicum	Mar	25	0.5	35		45	1.05	25	0.9	130	July & Aug
8	Carrot	Oct	15	0.7	25		40	1.05	20	0.95	100	January
9	Cauliflower	Aug	15	0.7	25		40	1.05	20	0.95	100	December
10	Chillies	Feb	30	0.3	40		70	0.75	30	1	170	August
11	Cucumber	Feb / Mar	15	0.6	20		30	1	15	0.9	80	May/ Jun
12	Egg Plant	Nov	20	0.6	30		55	1.05	25	0.9	130	April
13	Garlic	Sep/ Oct	30	0.7	40		70	1	30	0.7	170	March/April
14	Ladyfinger	Feb / Mar	15	0.7	20		40	1	15	0.9	90	May/June
		Jun	15	0.7	20		40	1	15	0.9	90	September
15	Lettuce	Feb/Sep	25	0.7	35		30	1	10	0.95	100	Dec & Jan
16	Muskmelon	Mar	20	0.5	25		40	1.05	15	0.75	100	July/August
17	Onion dry	Oct	15	0.5	25		70	1.05	30	0.75	140	April
18	Onion (Gr)	Oct	15	0.5	25		60	1	--	--	100	February
19	Peas (Gr)	Sep/ Oct	20	0.5	25		35	1.15	--	--	80	Dec/Jan
20	Peas seed	Sep/ Oct	20	0.5	25		35	1.15	20	0.3	100	Jan/Feb
21	Potato	Sep/ Oct	25	0.5	30		35	1.15	30	0.75	1.20	Dec/Jan

22	Pumpkin	Feb	20	0.6	30		30	1	20	0.8	100	June/July
23	Radish	July Nov	10	0.7	15		20	0.9	5	0.85	50	Sep to Jan
24	Spinach	Mar June	20	0.7	30		40	1	10	0.95	100	July to Oct
25	Squash	Feb June	25	0.5	35		25	0.95	15	0.75	100	June & Oct
26	Tomato	Sep/ Oct	30	0.6	40		40	1.15	25	0.8	135	Feb/March
27	Turnip	Sep Nov	10	0.5	20		25	1.1	5	0.95	60	Nov to Jan
28	Water melon	Feb/ Mar	15	0.4	30		30	1	25	0.75	100	June/July

* No single value may be indicated for Kc dev as it continuous changing throughout the development stage.

Table- 4.4. Duration of Growth Stages and Kc Values of Fruit Crops

Sr.No.	Fruit Name	Duration of Initial Stage	Kc Initial	Duration of Dev. Stage	Kc Dev*.	Duration of Mid Stage	Kc Mid	Duration of Late Stage	Kc Late
1	Almond		0.4				0.9		0.65
2	Apple		0.45				0.95		0.7
3	Apricot		0.45				0.9		0.65
4	Banana		0.5				1.1		1
5	Ber						1.1		
6	Berries		0.3				1.05		0.5
7	Chiku						1.1		
8	Citrus		0.5				0.65-0.85		0.6-0.8
9	Cherries		0.45				0.95		0.7
10	Date Palm		0.9				0.95		0.95
11	Fig						1		
12	Grapes		0.3				0.95		0.45
13	Guava						1		
14	Lychee						1.05		
15	Mango						0.65		
16	Mulberry		0.4				1		1
17	Olives		0.6				0.7		0.7
18	Peaches		0.45				0.9		0.65
19	Pears		0.45				0.95		0.7
20	Plum		0.45				1.15		0.65
21	Pomegranate		0.5				0.75		0.75
22	Strawberry						0.85		

* No single value may be indicated for Kc dev as it continuous changing throughout the development stage.

4.3.2. Crop Growth Coefficient Curves of Important Crops

As already explained, crop growth stage coefficient curves for some representative crops covering cotton, sugarcane, maize, wheat, citrus and peas are shown in figures 4.3 – 4.8 as follows.

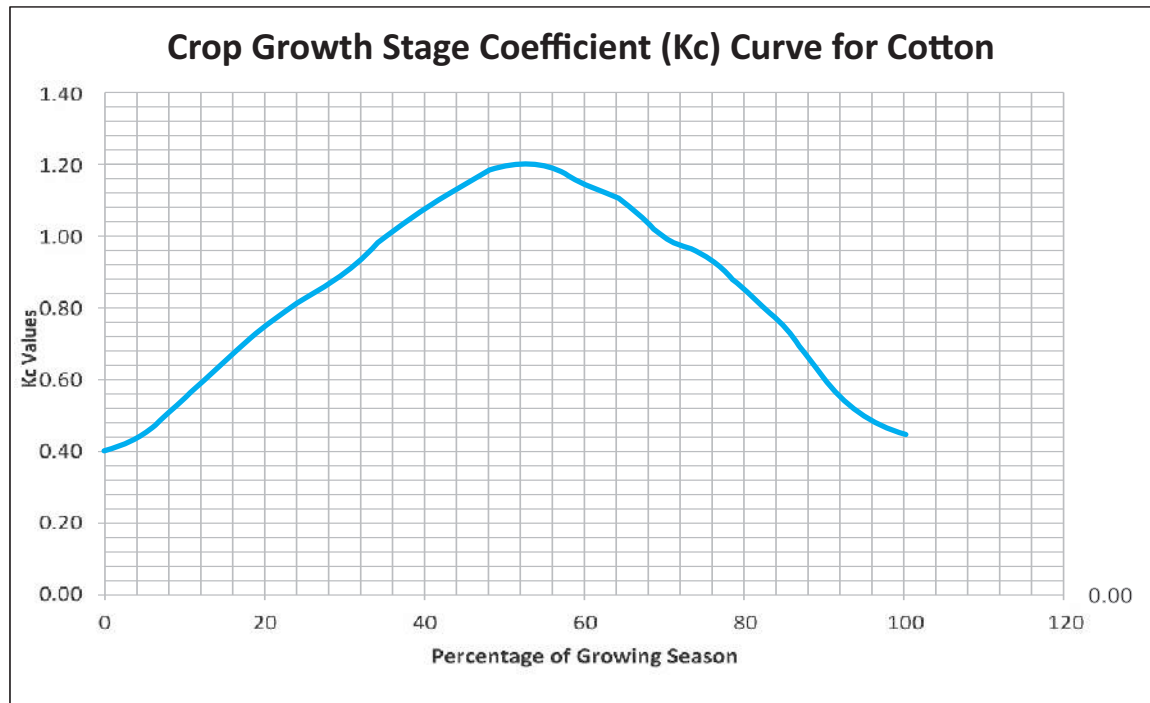


Figure - 4.3 Crop Growth Stage Coefficient (Kc) Curve for Cotton

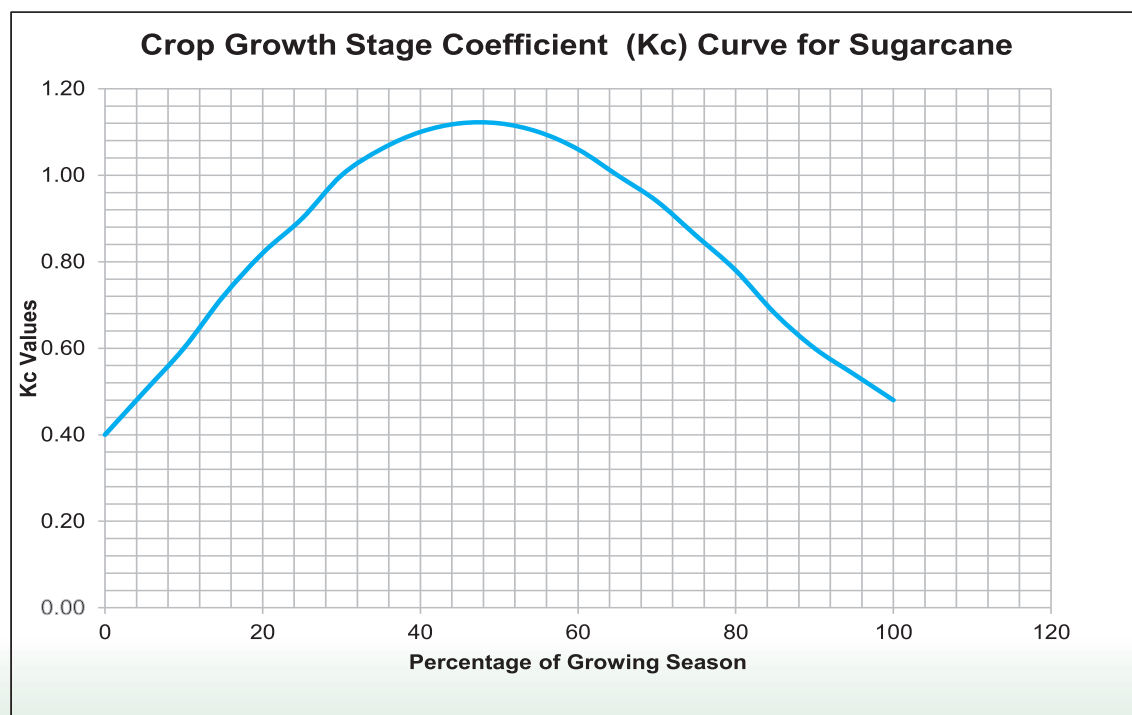


Figure - 4.4 Crop Growth Stage Coefficient (Kc) Curve for Sugarcane

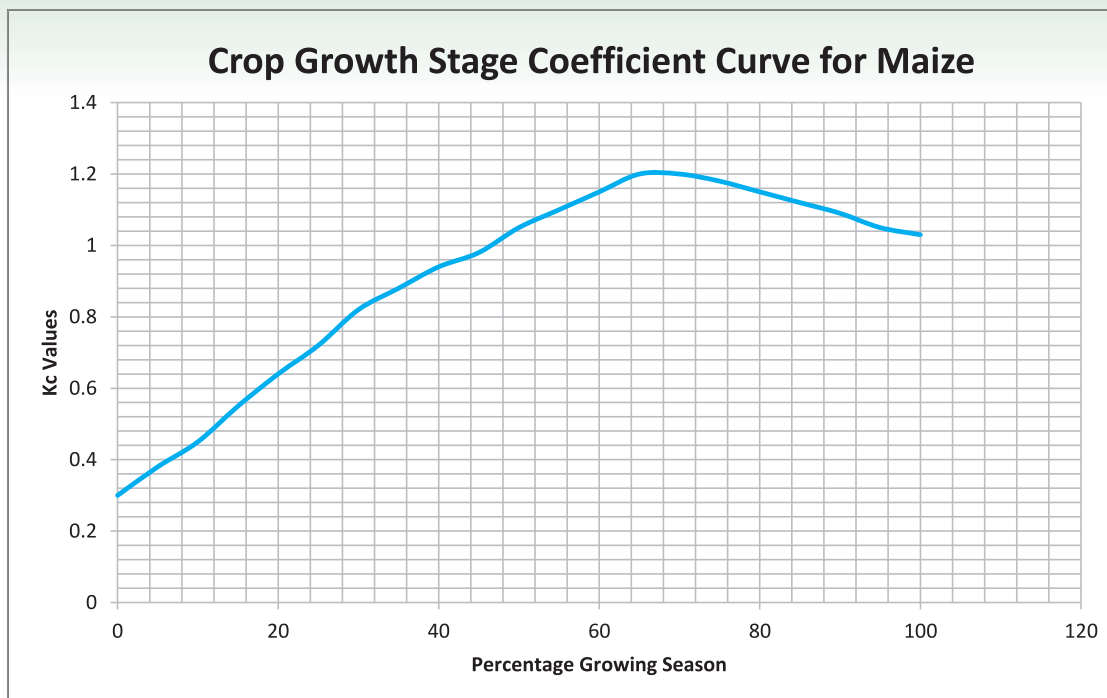


Figure - 4.5 Crop Growth Stage Coefficient (Kc) Curve for Maize

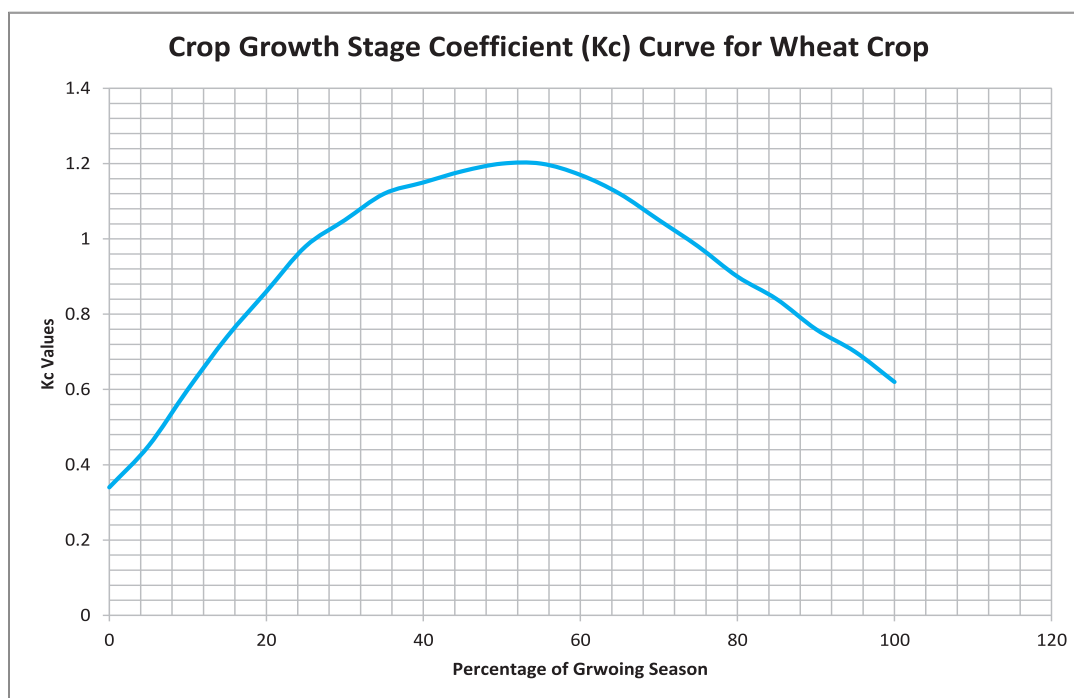


Figure – 4.6 Crop Growth Stage Coefficient (Kc) Curve for Wheat

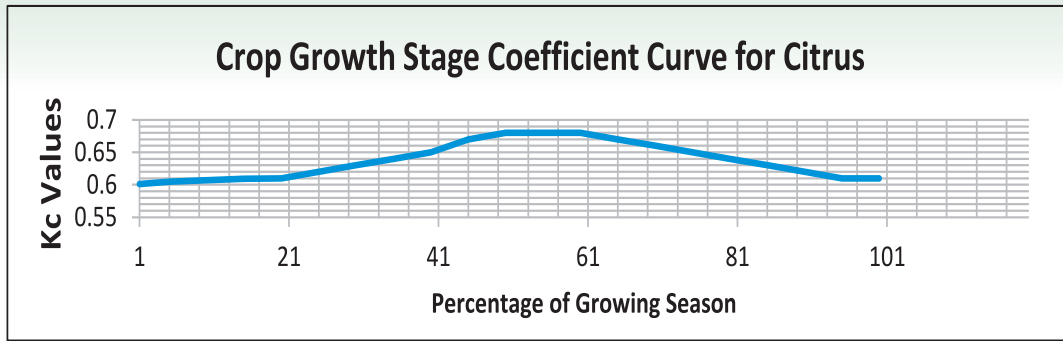


Figure - 4.7 Crop Growth Stage Coefficient (Kc) Curve for Citrus

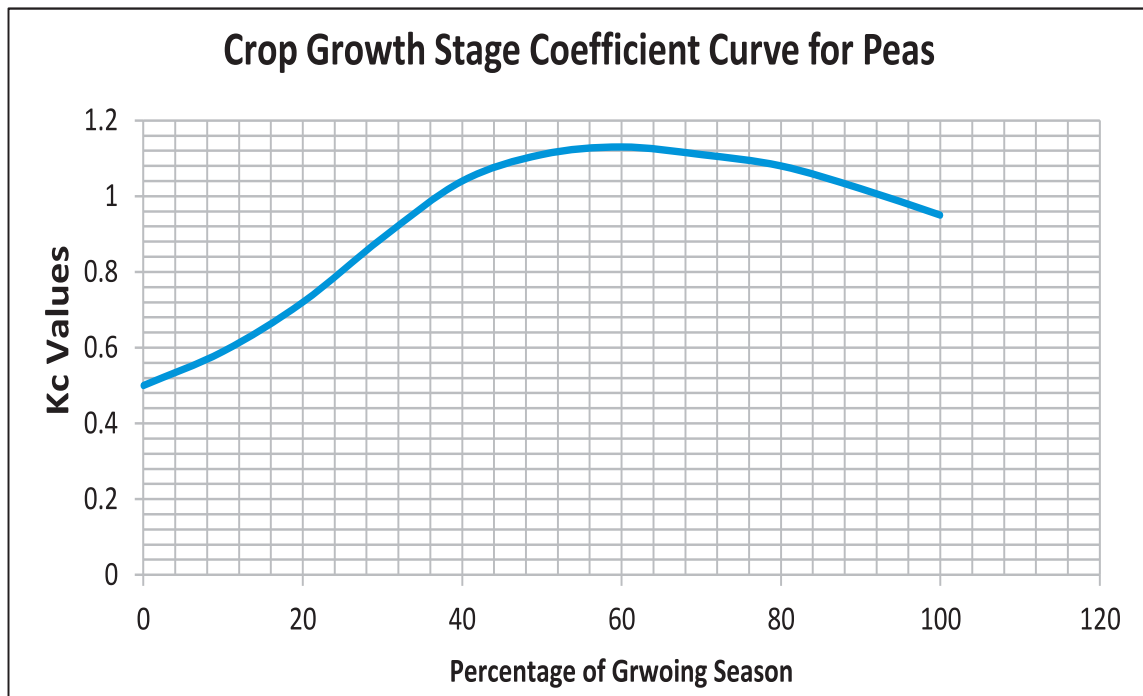


Figure - 4.8 Crop Growth Stage Coefficient (Kc) Curve for Peas

4.3.3. Dual Crop Coefficient Approach ($K_{cb} + K_e$)

In the dual crop coefficient approach, the effects of crop transpiration and soil evaporation are determined separately. Accordingly, this approach is considered more appropriate to be used for systems like **Drip Irrigation**.

Two coefficients are used (i) the basal crop coefficient (K_{cb}) to describe plant transpiration, and (ii) the soil water evaporation coefficient (K_e) to describe evaporation from the soil surface. The concept may be rephrased as:-

$$K_c = K_{cb} + K_e$$

Where

K_{cb} is basal crop coefficient,

K_e is soil moisture evaporation coefficient.

The value of ET_c in this case will be determined as under:

$$ET_c = ET_o (K_{cb} + K_e)$$

4.3.3.1. The basal crop coefficient (K_{cb}).

It is defined as the ratio of ET_c to ET_o when the soil surface layer is dry but the average soil water content of the root zone is sufficient to sustain full plant transpiration at a potential rate (as in drip irrigation). It represents the potential crop factor without soil wetting by irrigation or precipitation. The values of K_{cb} have been presented in FAO Irrigation and Drainage Paper 56. In addition, guidelines have been given to derivate the values of basal crop coefficient through the values developed under single crop coefficient approach already elucidated. The same are reproduced in Table 4.5:

Table 4.5 General Guidelines to Derive K_{cb} Values from K_c Values

Growth Stage	Ground Conditions, Irrigation Practices and Cultural Management	K_{cb}
Initial	Annual Crop with soil surface nearly bare	0.15
	Perennial Crop with soil surface nearly bare	0.15 – 0.20
	Grasses, brush and trees under severe frost conditions	0.30 – 0.40
	Perennial crop with some ground cover Infrequently irrigated plants Frequently irrigated plants	$K_c \text{ ini} - 0.1$ $K_c \text{ ini} - 0.2$
Mid-season	Ground cover more than 80%	$K_c \text{ mid} - 0.05$
	Ground cover less than 80%	$K_c \text{ mid} - 0.10$
Late season	Infrequently irrigated plants	$K_c \text{ end} - 0.05$
	Frequently irrigated plants	$K_c \text{ end} - 0.1$

The values of K_{cb} for important crops are given in Table 4.6 below;

Table 4.6 Values of K_{cb} for Important Crops

Sr. No.	Type of Crop	$K_{cb} \text{ ini}$	$K_{cb} \text{ mid}$	$K_{cb} \text{ end}$
1	Small Vegetables	0.15	0.95	0.85
2	Vegetables - Solanum Family	0.15	1.10	0.70
3	Vegetables – Cucumber Family	0.15	0.95	0.70
4	Roots and Tubers	0.15	1.00	0.85
5	Legumes	0.15	1.10	0.50
6	Fibre Crops	0.15	1.10	0.50
7	Oil Seed Crops	0.15	1.10	0.25
8	Cereals	0.15	1.10	0.25
9	Forages	0.30	1.10	1.05
10	Sugarcane	0.15	1.20	0.70
11	Date Palm	0.80	0.85	0.85
12	Grapes	0.15	0.80	0.40
13	Berries	0.20	1.00	0.40

14	Almond	0.20	0.85	0.60
15	Citrus, no ground cover	0.65	0.65	0.65
16	Citrus with ground cover	0.75	0.75	0.75
17	Olives	0.55	0.65	0.65

4.3.3.2. *The soil evaporation coefficient (K_e)*

It describes the evaporation component from the soil surface. If the soil is wet following rain or irrigation, K_e may be large and its value is taken as 1. The sum of K_{cb} and K_e can, however, never exceed a maximum value, K_{cmax} determined by the soil & atmospheric energy available for evapotranspiration at the soil surface. As the soil surface becomes drier, K_e becomes smaller and falls to zero when no water is left for evaporation.

K_e may be calculated with the help of formula:

$$K_e = K_r (K_{c \max} - K_{cb}) \leq f_{ew} K_{c \max}$$

Where K_e represents soil evaporation coefficient

K_r represents evaporation reduction coefficient

K_{c max} represents maximum value of K_c following rain or irrigation

K_{cb} represents basal crop coefficient and

f_{ew} represents fraction of the upper part of the soil that is wetted as well as exposed from which most of the evaporation takes place.

4.3.3.3. *Evaporation Reduction Coefficient*

In conventional irrigation the canopies of the crops intercept a portion of the radiation falling on the ground where as the remaining radiation energy is directly contributing towards the evaporation process from the soil surface wetted by the surface flooding. In sprinkler irrigation also, the same phenomenon plays the part and thus a considerable weightage goes to the evaporation component in the overall amount of water going to the atmosphere through evapotranspiration. In **drip irrigation**, most of the surrounding soil surface remains dry and thus evaporation component of evapotranspiration is significantly reduced, major share coming from transpiration only. This reduction in evaporation has been designated as “Reduction Coefficient” and is denoted as K_r.

The main reference available with FAO proposes the values of k_r as indicated in Table 4.7.

Table-4.7 Values of k_r as Against Ground Cover Percentage

Ground Cover %age	Value of k_r
10	0.10
20	0.20
30	0.30
40	0.40
50	0.75
60	0.80
70	0.85
80	0.90
90	0.95
100	1.0

As per table given above, it should be noted that if the ground is covered by vegetation up to 100% the value of k_r becomes 1 and thus there will be no reduction in the value of K_c taken under single crop coefficient approach

Explanation about K_{cb} has already been made above.

K_c max gives an upper limit of evaporation and transpiration from any cropped surface after an effective rain or irrigation.

Few is defined as the exposed and wetted soil fraction. In mathematical terms, it may be expressed as:

$$F_{ew} = \min(1-fc, fw)$$

Where 1-fc represents average exposed soil fraction not covered or shaded by vegetation, fw represents average fraction of soil surface wetted by irrigation or precipitation and “min” function demands for selection of the lowest values of “1-fc” and “fw”.

The *estimation of K_e* requires a daily water balance computation of the soil water contents remaining in the upper top soil and it necessitates calculation of the value of each component separately which involves lengthy theoretical explanations and solution of complex formulae. The dual procedure is best for real time irrigation scheduling, for soil water balance computations and for high frequency irrigation systems where effects of day-to-day variations in soil surface wetness and the resulting impacts on daily ET_c are important as in drip irrigation systems, centre pivots and linear move systems.

But this approach requires more numerical and tedious calculations compared to the procedure using values of single time-averaged K_c coefficient. Accordingly, most of the designers have chosen to apply a canopy factor to reduce the E_{tc} values determined through K_c values developed under single crop coefficient approach and bring these at par with the values otherwise determined through dual crop coefficient approach.

4.3.3.4. Dual crop coefficient curve

Because crop canopies are near or at full ground cover during the mid-season stage, soil evaporation beneath the canopy has less effect on crop Evapotranspiration and the value for K_{cb} in the mid-season stage will be nearly the same as K_c . Depending on the ground cover, the basal crop coefficient during the mid-season may be only 0.05-0.10 lower than the K_c value. Depending on the frequency with which the crop is irrigated during the late season stage, K_{cb} will be similar to or less than the K_c value.

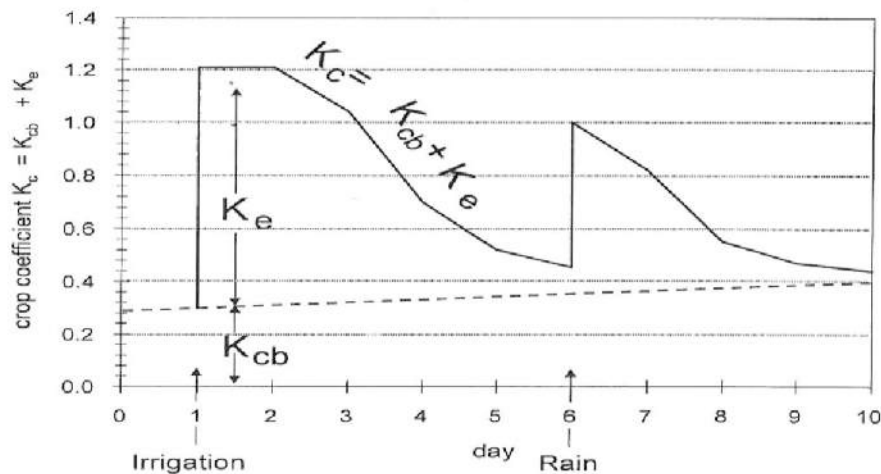


Figure – 4.9 Dual Crop Coefficient Curve

Dual Crop coefficient curve (Fig. 4.9) shows the basal K_{cb} , Soil evaporation K_e and the corresponding single $K_c = K_{cb} + K_e$ curve. It presents typical shapes for the K_{cb} , K_e and single K_c curves. The K_{cb} curve represents the minimum K_c for conditions of adequate soil water and dry soil surface. The K_e represent increased evaporation when precipitation or irrigation has wetted the soil surface and has temporarily increased total E_{To} . These wet soil evaporation decrease as the soil surface layer dries. The wet soil evaporation generally reaches a maximum value of 1.0 - 1.2, depending on the climate, the magnitude of the wetting event and the portion of soil surface wetted.

4.4. ADJUSTING K_c VALUES

The values given in tables 4.1 to 4.4 above correspond to the standard conditions having relative humidity up to 45%, and wind speed of about 2m/S. These values should be adjusted with change in the level/degree of atmospheric parameters.

The k_c values of a crop grown under a particular set of environment change with change in ground cover, crop height and the leaf area on account of growth and development of the crop. It has further been observed that the values of different stages also differ from each other to small extent from one area to the other. The experiments conducted by different researchers reveal that not only the k_c values of the same stage vary from southern regions to the northern regions but the duration of the stages of the same crop may also differ from one region to the other. Hence the values of k_c should be adjusted under environments having extra-ordinary variations.

Out of overall factors, the following have critical impact on the K_c values of crops and thus need to be considered for adjustment as explained below:

4.4.1. Initial Stage

4.4.1.1. *Evaporative Power of the Atmosphere:*

As per FAO Irrigation and Drainage Paper 56, the climate has been classified in the five categories on the basis of humidity as indicated in Table 4.8.

Table 4.8 Classification of Climate on the basis of Humidity

Climate	Relative Humidity (Min)%	Relative Humidity (Mean)%
Arid	20	45
Semi-arid	30	55
Sub-humid	45	70
Humid	70	85
Very humid	80	90

The empirical estimates of monthly wind speeds have been termed as per description given in Table 4.9.

Table 4.9 Categories of Wind Speed

Wind Description	Mean Monthly Wind Speed (at 2m height)
Light Wind	≤1.0 m/s
Light to Moderate Wind	2.0 m/s
Moderate to Strong Wind	4.0 m/s
Strong Wind	≥5.0 m/s

More aridity and high wind speeds will give rise to the K_c values. The same should be adjusted accordingly.

A classic example of the effects of climatic parameters on K_c values have been illustrated in Tables 4.10 referred in FAO ID Paper 56.

Table 4.10 Effect of Climatic Conditions on K_c Values of Middle Stage of Wheat Crop

Humidity Levels	Wind Speeds		
	Light	Moderate	Strong
Arid/Semi-arid	1.17	1.20	1.25
Sub-humid	1.12	1.15	1.20
Humid	1.02	1.05	1.10

4.4.1.2._Time Interval between Wetting Events

In case, frequent wetting events are taking place during a particular period especially through medium and heavy showers, the K_c value should be increased.

4.4.1.3._Magnitude of Wetting

If, after a wetting event, considerable amount of moisture has been absorbed in the top soil, the K_c value should be increased. The criterion to assess the level of wetting event is illustrated in Table 4.11.

Table 4.11 Classification of Rainfall Depths

Type of Rain	Depth of Moisture Absorption in Soil
Very Light (drizzling)	≤3mm
Light (light showers)	5mm

Medium (showers)	$\geq 10\text{mm}$
Heavy (rainstorms)	$\geq 40\text{mm}$

Since different irrigation systems wet different fractions of the soil surface, the values of $K_{c\text{ ini}}$ should be multiplied by the fraction of the surface wetted to adjust for the partial wetting. K_c value will be smaller if the soil surface remains dry for most of the time as in **Drip irrigation**. For this type of irrigation, the fraction of the soil that gets wetted at the top hardly reaches about 0.4.

4.4.2. Mid Stage

At this stage, the effect of climatic variations on the K_c is crop specific and changes with crop height. In general, more arid climates accompanied with greater wind speeds will have higher values of $K_{c\text{-mid}}$ and vice versa. The value of effect of height in the overall calculation for K_c is, however, very small and is easily covered in the formula. The frequency and the magnitude of wetting also do not affect the K_c value at this stage as for the initial because the vegetation fully covers the ground and the effects of surface evaporation on K_c are smaller. However, under frequent irrigations with less than three days interval especially for crops having K_c value less than 1.0, the value can be adjusted to 1.1-1.3.

4.4.3. Late Stage

If the crop is irrigated frequently till it's harvesting resulting in continuous wetting of the top soil, the $K_{c\text{-end}}$ value should be increased. Otherwise, if the crop is allowed to senesce and dries out in the field before the harvest, there is no need of adjusting the given values. More arid climatic conditions with greater wind speeds will, however, tend to make the $K_{c\text{-end}}$ values higher.

FAO I&D Paper 56 has presented three solved examples for cotton crop raised under sprinkler irrigation, furrow irrigation and drip irrigation. The values of k_c calculated through dual crop coefficient approach turned into as follows in Table 4.12.

Table 4.12 Values of K_c of Cotton Crop under Different Methods of Irrigation

Type of Irrigation	Value of K_{cb}	Value of K_e	Value of K_c
Sprinkler Irrigation	0.9	0.40	1.30
Furrow Irrigation	0.9	0.39	1.29
Drip Irrigation	0.9	0.25	1.15

Accordingly, it would be appropriate that the values of K_c to be taken up for calculating CWR under drip irrigation are fine-tuned plausibly.

5. COMPUTATION OF CROP WATER REQUIREMENTS

Once the values of ET_0 pertaining to a particular area for the months corresponding to the crop duration and values of K_c for different stages of the crop are known, it is easy to work out the crop water requirement (CWR) of the crop in that area on daily, weekly, decadal, monthly and seasonal basis. It may be worked out either through *Calculation Sheet* or through computer software developed by FAO named *CROPWAT 8.0*.

5.1. COMPUTATION THROUGH CALCULATION SHEET

In this method basic information is entered in to the columns of an excel sheet and desired columns are developed through multiplications and divisions as reflected in the proposed CWR calculation sheet below.

The CWR calculation sheet is given as Table 5.1. The steps to fill each column are explained after this sheet followed by a solved example referred in Table 5.2.

5.1.1. PROPOSED CROP WATER REQUIREMENT CALCULATION SHEET

The sheet includes columns covering ET_0 value, K_c value and Canopy Factor. The crop water requirement is calculated with the help of given information as per columns indicated in Table 5.1.

Table-5.1. Crop Water Requirement Calculation Sheet

Farmer Name			District		Crop				Area under Crop		
Date of Sowing			Date of Harvest								
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily ET_0	Crop Factor (K_c)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil/Rainfall Contribution	Daily Final CWR (mm)	Weekly/Decadal CWR (mm)
a	b	c	d	e	f	g	h	i	j	k	l
				From ET_0 Table	From CGCC		$h=e*f*g$	$i=h/Eff.$	If effective	$k=i-j$	$L=k*d$

5.1.2. Steps for Calculation of CWR

- i. Refer to Crop Water Requirement Calculation Sheet and enter the months corresponding to the crop growth duration in column (a), decade number (1, 2 or 3) of the month in column (b) & decade number of the crop, based on its total duration, in the column (c) with effect from the date of sowing indicating the number of crop days for the months, decades or weeks of crop duration in column (d).

It should be kept in mind that we are calculating Daily_CWR (crop water requirement) for a particular week or decade because of progressive change in K_c value during every following week or decade. Some professionals take the K_c values on monthly basis and prepare irrigation schedule. It is not incorrect but comparatively less accurate than the schedule prepared on the basis of weekly or ten days' values of K_c . On the other hand, irrigation schedule may be prepared on daily basis also if desired. This schedule will incorporate the changes in K_c values on day to day basis and will rank as the most accurate schedule.

- ii. Refer to Table-3.5 indicating ET_o values for all the months for various districts of Punjab, record corresponding ET_o value of the district against each month, decade or week in column (e).
- iii. Refer to Figures 4.3 – 4.8 reflecting Crop Growth Coefficient Curves or the Tables 4.2 – 4.4. Ascertain the K_c value for each week, decade or month and record it on the crop water calculation sheet against the corresponding week, decade or month in column (f).
- iv. The use of any value of canopy factor is not required under surface irrigation as that approaches 1. Under drip irrigation, this value approaches 1 in case of row crops where soil is wetted on continuous basis. Some experts are of the opinion that even in row crops under drip irrigation the value of canopy factor should be considered as less than one because a part of the soil surface still remains dry. For widely spaced crops and orchards, however, where only a fraction of root zone area is wetted, the value may range from 0.33 to 0.67. Record the values of Canopy Factor for each week, decade or month similar to above in column (g) while calculating the crop water requirement for orchards under drip or where applicable.
- v. Multiply ET_o value of each week, decade or month with the related K_c and canopy values to get the value of Daily Basic CWR for that week, decade or month and enter it in column (h).
- vi. Divide the basic CWR with efficiency factor to determine Daily Gross CWR for that week, decade or month and enter it in column (i).
- vii. Subtract the amount of moisture contributed by soil, rainfall or ground water table reflected in column (j) from the daily gross CWR and this will give us the daily final CWR of that crop. Enter this value in column (k).

- viii. Multiply this daily CWR value with the number of crop days to get the value of CWR of that week/decade/month and make its entry in column (l).
- ix. A total of the values of column (l) indicate the CWR on seasonal basis.

Sample CWR calculation sheet for cotton under Drip Irrigation is given as Table 5.2.

Table 5.2. Calculation of Crop Water Requirement of Cotton under Drip Irrigation

Farmer- Rao Atif				District : Multan		Crop- Cotton			Area		
Sowing Date- 26.4.12				Harvesting Date- 22.10.12							
Month	Decade No. of month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Soil/Rainfall Contribution (mm)	Daily Final CWR (mm)	Decade CWR (mm)
a	b	c	d	e	f	g	h	i	j	k	l
				From Eto Table	From CGCC		$H=E*F*G$	$I=H/.9$	If effective	$K=I-J$	
Apr	1										0.0
	2										0.0
	3	1	5	4.8	0.34	1	1.63	1.81	0.00	1.81	9.1
May	1	2	10	6.1	0.4	1	2.44	2.71	0.00	2.71	27.1
	2	3	10	6.1	0.5	1	3.05	3.39	0.00	3.39	33.9
	3	4	11	6.1	0.62	1	3.78	4.20	0.00	4.20	46.2
Jun	1	5	10	7	0.74	1	5.18	5.76	0.00	5.76	57.6
	2	6	10	7	0.82	1	5.74	6.38	0.00	6.38	63.8
	3	7	10	7	0.92	1	6.44	7.16	0.00	7.16	71.6
Jul	1	8	10	6.1	0.98	1	5.98	6.64	0.00	6.64	66.4
	2	9	10	6.1	1	1	6.10	6.78	0.00	6.78	67.8
	3	10	11	6.1	1	1	6.10	6.78	0.00	6.78	74.6
Aug	1	11	10	5.9	1.1	1	6.49	7.21	0.00	7.21	72.1
	2	12	10	5.9	1.1	1	6.49	7.21	0.00	7.21	72.1
	3	13	11	5.9	1	1	5.90	6.56	0.00	6.56	72.1
Sep	1	14	10	5.1	0.9	1	4.59	5.10	0.00	5.10	51.0
	2	15	10	5.1	0.8	1	4.08	4.53	0.00	4.53	45.3
	3	16	10	5.1	0.7	1	3.57	3.97	0.00	3.97	39.7
Oct	1	17	10	3.4	0.65	1	2.21	2.46	0.00	2.46	24.6
	2	18	10	3.4	0.6	1	2.04	2.27	0.00	2.27	22.7
	3	19	2	3.4	0.5	1	1.70	1.89	0.00	1.89	3.8
									Seasonal Total Requirement		921.3

The table above represents calculation of CWR of closely sown row crops. For orchards being grown under drip irrigation involving adjustment for wetted percentage using canopy factor,

Farmer- Haji Muhammad Zubair				District - Bahawal Nagar			Crop - Citrus		Sowing Date - 10.3.12 Harvesting Date:			
No. of Zones = 4		Size of one zone=1.74 Acre			RR = 5.49 m			PP = 4.27 m				
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Monthly Gross CWR (mm)	Soil/Rainfall Contribution (mm)	Monthly Net CWR (mm)	Daily Net CWR (mm)
a	b	c	d	e	f	g	h	i	j	k	l	m
				From Eto Table	From OGCC or Kc Table		$h=e*f*g$	$I=h/.9$	$J=i*d$	If effective	$l=j-k$	$m=l/d$
Mar	31		21	4.3	0.65	0.33	0.92	1.02	21.52	0.0	21.52	1.02
Apr	30		30	6	0.65	0.34	1.33	1.47	44.20	0.0	44.20	1.47
May	31		31	7.6	0.65	0.35	1.73	1.92	59.55	0.0	59.55	1.92
Jun	30		30	8.3	0.65	0.36	1.94	2.16	64.74	0.0	64.74	2.16
Jul	31		31	6.4	0.65	0.37	1.54	1.71	53.02	0.0	53.02	1.71
Aug	31		31	6.1	0.65	0.38	1.51	1.67	51.90	0.0	51.90	1.67
Sep	30		30	5.5	0.65	0.39	1.39	1.55	46.48	0.0	46.48	1.55
Oct	31		31	4.2	0.65	0.4	1.09	1.21	37.61	0.0	37.61	1.21
Nov	30		30	2.6	0.65	0.41	0.69	0.77	23.10	0.0	23.10	0.77
Dec	31		31	1.8	0.65	0.42	0.49	0.55	16.93	0.0	16.93	0.55
Jan	31		31	1.9	0.65	0.43	0.53	0.59	18.29	0.0	18.29	0.59
Feb	28		28	2.9	0.65	0.44	0.83	0.92	25.80	0.0	25.80	0.92

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

Table 5.3 (c). Calculation of Crop Water Requirement for Citrus Orchard under Drip Irrigation – Second Year

Farmer- Haji Muhammad Zubair				District - Bahawal Nagar			Crop - Citrus		Sowing Date - 10.3.12			
Harvesting Date:		Area under Crop- 6.95 Acres			RR = 5.49 m			PP = 4.27 m				
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Monthly Gross CWR (mm)	Soil/Rainfall Contribution (mm)	Monthly Net CWR (mm)	Daily Net CWR (mm)
a	b	c	d	e	f	g	h	i	j	k	l	m
				From Eto Table	From OGCC or Kc Table		$h=e*f*g$	$I=h/.9$	$J=i*d$	If effective	$l=j-k$	$m=l/d$
Mar	31		31	4.3	0.65	0.45	1.26	1.40	43.32	0.0	43.32	1.40
Apr	30		30	6	0.65	0.46	1.79	1.99	59.80	0.0	59.80	1.99
May	31		31	7.6	0.65	0.47	2.32	2.58	79.97	0.0	79.97	2.58
Jun	30		30	8.3	0.65	0.48	2.59	2.88	86.32	0.0	86.32	2.88
Jul	31		31	6.4	0.65	0.49	2.04	2.26	70.21	0.0	70.21	2.26
Aug	31		31	6.1	0.65	0.5	1.98	2.20	68.29	0.0	68.29	2.20
Sep	30		30	5.5	0.65	0.51	1.82	2.03	60.78	0.0	60.78	2.03
Oct	31		31	4.2	0.65	0.52	1.42	1.58	48.90	0.0	48.90	1.58
Nov	30		30	2.6	0.65	0.53	0.90	1.00	29.86	0.0	29.86	1.00
Dec	31		31	1.8	0.65	0.54	0.63	0.70	21.76	0.0	21.76	0.70
Jan	31		31	1.9	0.65	0.55	0.68	0.75	23.40	0.0	23.40	0.75
Feb	28		28	2.9	0.65	0.56	1.06	1.17	32.84	0.0	32.84	1.17

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

Table 5.3 (d). Calculation of Crop Water Requirement for Citrus Orchard under Drip Irrigation – Third Year

Farmer- Haji Muhammad Zubair			District - Bahawal Nagar			Crop - Citrus			Sowing Date - 1.3.12			
Harvesting Date:			Area under Crop- 6.95 Acres			RR = 5.49 m			PP = 4.27 m			
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Monthly Gross CWR	Soil/Rainfall Contribution (mm)	Monthly Net CWR(mm)	Daily Net CWR (mm)
a	b	c	d	e	f	g	h	i	j	k	l	m
				From Eto Table	From CGCC or Kc Table		$h=e*f*g$	$I=h/.9$	$J=i*d$	If effective	$l=j-k$	$m=l/d$
Mar	31		31	4.3	0.65	0.57	1.59	1.77	54.88	0.0	54.88	1.77
Apr	30		30	6	0.65	0.58	2.26	2.51	75.40	0.0	75.40	2.51
May	31		31	7.6	0.65	0.58	2.87	3.18	98.69	0.0	98.69	3.18
Jun	30		30	8.3	0.65	0.59	3.18	3.54	106.10	0.0	106.10	3.54
Jul	31		31	6.4	0.65	0.59	2.45	2.73	84.54	0.0	84.54	2.73
Aug	31		31	6.1	0.65	0.59	2.34	2.60	80.58	0.0	80.58	2.60
Sep	30		30	5.5	0.65	0.6	2.15	2.38	71.50	0.0	71.50	2.38
Oct	31		31	4.2	0.65	0.6	1.64	1.82	56.42	0.0	56.42	1.82
Nov	30		30	2.6	0.65	0.6	1.01	1.13	33.80	0.0	33.80	1.13
Dec	31		31	1.8	0.65	0.61	0.71	0.79	24.58	0.0	24.58	0.79
Jan	31		31	1.9	0.65	0.61	0.75	0.84	25.95	0.0	25.95	0.84
Feb	28		28	2.9	0.65	0.61	1.15	1.28	35.77	0.0	35.77	1.28

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

Table 5.3 (e). Calculation of Crop Water Requirement for Citrus Orchard under Drip Irrigation – Fourth Year

Farmer- Haji Muhammad Zubair			District - Bahawal Nagar			Crop - Citrus			Sowing Date - 10.3.12			
Harvesting Date:			Area under Crop- 6.95 Acres			RR = 5.49 m			PP = 4.27 m			
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR	Monthly Gross CWR(mm)	Soil/Rainfall Contribution (mm)	Monthly Net CWR(mm)	Daily Net CWR(MM)
a	b	c	d	e	f	g	h	i	j	k	l	m
				From Eto Table	From CGCC		$h=e*f*g$	$i=h/.9$	$j=i*d$	If effective	$l=j-k$	$m=l/d$
Mar	31		31	4.3	0.65	0.62	1.73	1.93	59.69	0.0	59.69	1.93
Apr	30		30	6	0.65	0.62	2.42	2.69	80.60	0.0	80.60	2.69
May	31		31	7.6	0.65	0.62	3.06	3.40	105.50	0.0	105.50	3.40
Jun	30		30	8.3	0.65	0.63	3.40	3.78	113.30	0.0	113.30	3.78
Jul	31		31	6.4	0.65	0.63	2.62	2.91	90.27	0.0	90.27	2.91
Aug	31		31	6.1	0.65	0.64	2.54	2.82	87.41	0.0	87.41	2.82
Sep	30		30	5.5	0.65	0.64	2.29	2.54	76.27	0.0	76.27	2.54
Oct	31		31	4.2	0.65	0.65	1.77	1.97	61.12	0.0	61.12	1.97
Nov	30		30	2.6	0.65	0.65	1.10	1.22	36.62	0.0	36.62	1.22
Dec	31		31	1.8	0.65	0.66	0.77	0.86	26.60	0.0	26.60	0.86
Jan	31		31	1.9	0.65	0.66	0.82	0.91	28.08	0.0	28.08	0.91
Feb	28		28	2.9	0.65	0.66	1.24	1.38	38.71	0.0	38.71	1.38

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

5.2. COMPUTATION OF CROP WATER REQUIREMENTS THROUGH CROPWAT 8.0

5.2.1. Basis of Computation

Various computer programmes have made it possible to analyze real-time weather data collected from the local meteorological weather stations in each zone. Moreover, these models have made it possible not only to simulate the irrigation programmes for rain fed and water deficient areas but have made it easy to even take up the irrigation scheduling component including yield response to water.

CROPWAT 8.0 is one of such programmes. It is an improved version of processing the metrological data to calculate ET_o and crop water requirements. This model is based on water balance calculations where the soil moisture status is determined on daily basis through calculations of periodic evapotranspiration values duly incorporating the incoming amount of irrigation and effective rainfall. The crop water requirements are calculated through processing of the crop data including crop growth stages, K_c factors, root zone depths and allowable soil moisture depletion on decade (10 days) basis. Its table one demands values of the meteorological

parameters comprising minimum & maximum temperatures, humidity percentage, wind velocity, sunshine hours and radiation

intensity as required for Penman – Monteith equation for all the twelve months of the year. These values for each station should be based on at least 10 years and preferably 30 years' average. Moreover, the references for altitude, latitude and longitude also need to be quoted. Based on these values, of CROPWAT 8.0 automatically gives the values of ET_o as mm/day in the last column of this software as given in Fig. 5.1.

Monthly ETo Penman-Monteith - untitled

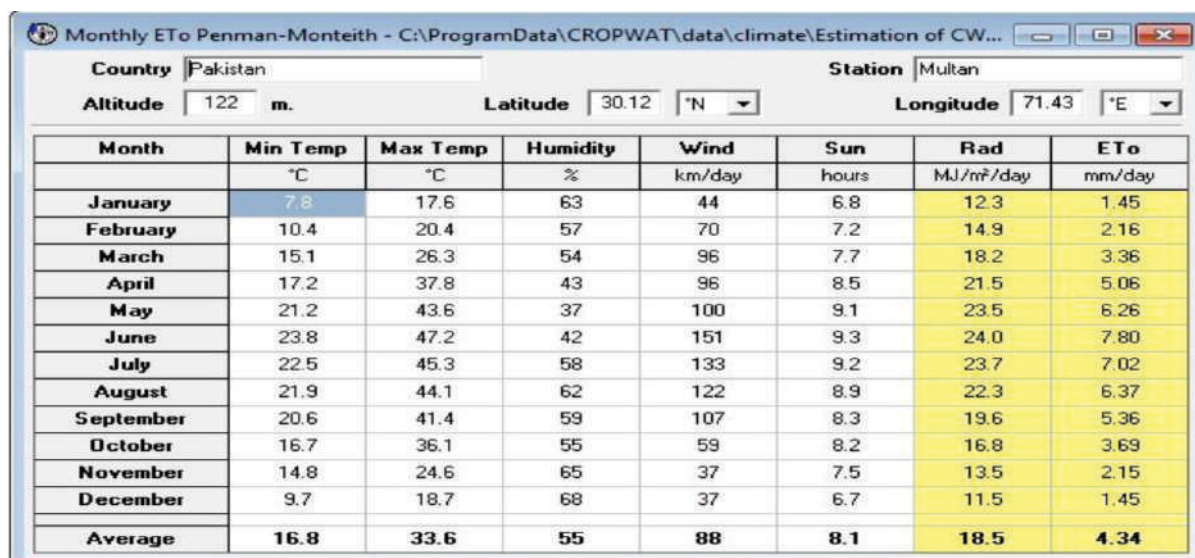
Country Station

Altitude m. Latitude °N Longitude °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January							
February							
March							
April							
May							
June							
July							
August							
September							
October							
November							
December							
Average							

Figure – 5.1. Calculations of the Values of ET_o .

After entry of the values of temperature, humidity, wind velocity and sunshine hours based on climatic data taken from a meteorological station alongwith information about country, station, altitude, latitude and longitude, it automatically develops the values of radiation for each month and then it presents the values of ET_o in the last column. After entry of the requisite values pertaining to Multan District in the foregoing figure, the calculated values are reflected in Fig. 5.2 below:



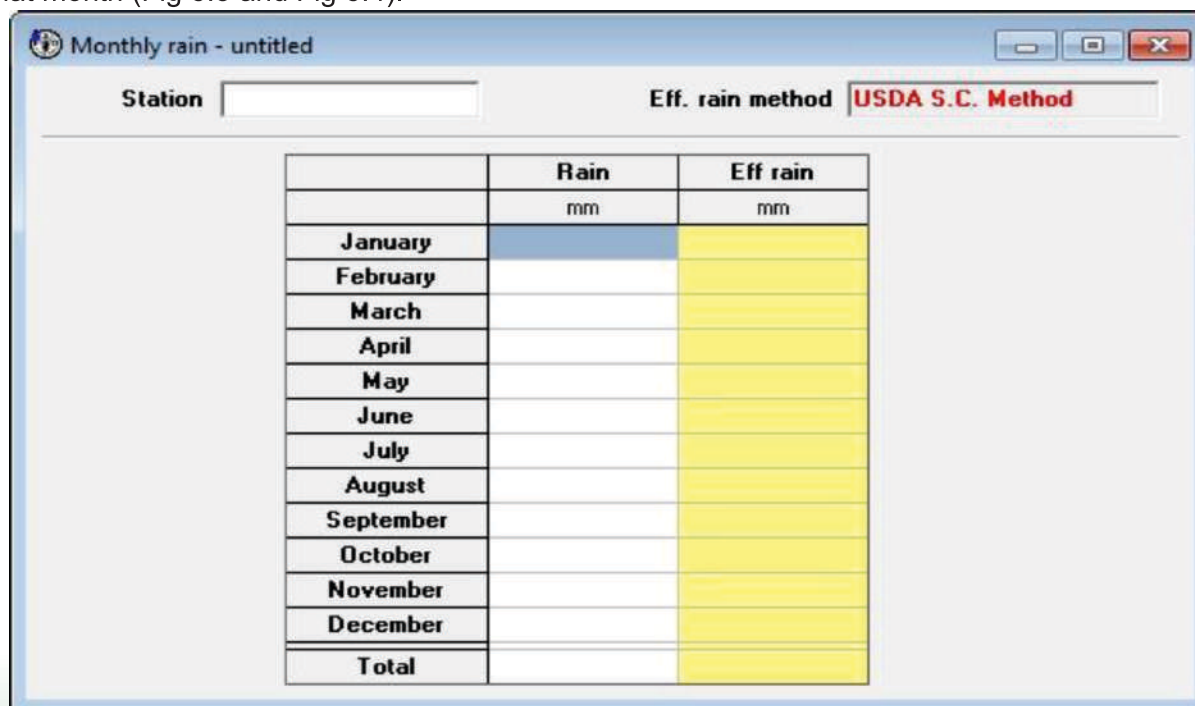
Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\Estimation of CW...

Country: Pakistan Station: Multan
 Altitude: 122 m. Latitude: 30.12 °N Longitude: 71.43 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ET _o mm/day
January	7.8	17.6	63	44	6.8	12.3	1.45
February	10.4	20.4	57	70	7.2	14.9	2.16
March	15.1	26.3	54	96	7.7	18.2	3.36
April	17.2	37.8	43	96	8.5	21.5	5.06
May	21.2	43.6	37	100	9.1	23.5	6.26
June	23.8	47.2	42	151	9.3	24.0	7.80
July	22.5	45.3	58	133	9.2	23.7	7.02
August	21.9	44.1	62	122	8.9	22.3	6.37
September	20.6	41.4	59	107	8.3	19.6	5.36
October	16.7	36.1	55	59	8.2	16.8	3.69
November	14.8	24.6	65	37	7.5	13.5	2.15
December	9.7	18.7	68	37	6.7	11.5	1.45
Average	16.8	33.6	55	88	8.1	18.5	4.34

Figure. 5.2. Calculation of Values of ET_o through CROPWAT 8.0

The next figure of CROPWAT 8.0 converts the rainfall values of an area into effective rainfall for that month (Fig 5.3 and Fig 5.4).



Monthly rain - untitled

Station: Eff. rain method: USDA S.C. Method

	Rain mm	Eff rain mm
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		
Total		

Figure. 5.3 Calculation of effective Rainfall

Monthly rain - C:\ProgramData\CROPWAT\data\rain\Rainfall Table - Mumtaz.CRM

Station: Eff. rain method: **USDA S.C. Method**

	Rain	Eff rain
	mm	mm
January	0.0	0.0
February	0.0	0.0
March	0.0	0.0
April	0.0	0.0
May	0.0	0.0
June	13.0	12.7
July	16.0	15.6
August	22.0	21.2
September	0.0	0.0
October	0.0	0.0
November	0.0	0.0
December	0.0	0.0
Total	51.0	49.5

Figure. 5.4 Calculation of Effective Rainfall through CROPWAT 8.0

Figure 5.5 demands crop data including crop's name, its planting date, duration of each growth stage, rooting depth, critical depletion level, crop height and yield response factor. It processes this data and systematically develops the values of Kc factor on decadal basis for respective stages of growth. The values developed this way are reflected in the Fig. 5.5 & Fig 5.6.

Dry crop - untitled

Crop Name: Planting date: Harvest:

	initial	development	mid-season	late season	total
Kc Values					
Stage (days)					
Rooting depth (m)					
Critical depletion (fraction)					
Yield response f.					
Crop height (m)			(optional)		

Figure. 5.5 Calculation of Crop Factors

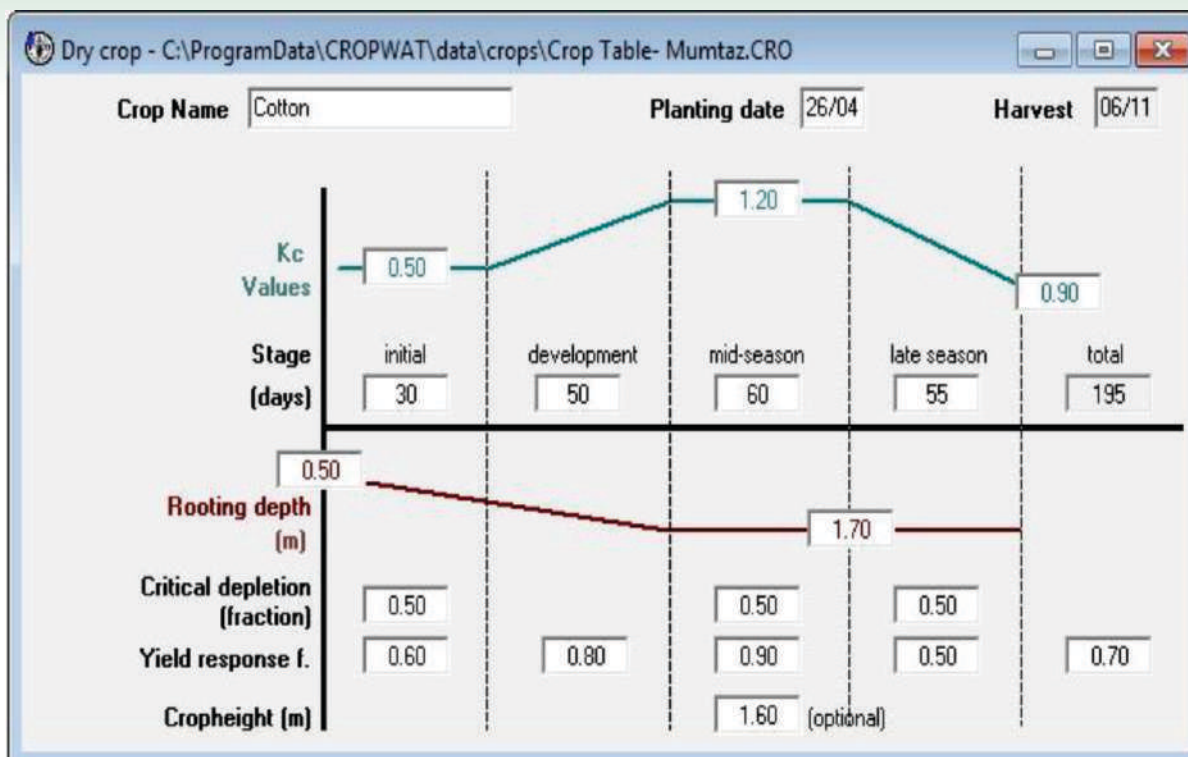


Figure. 5.6 Calculation of Crop Factors through CROPWAT 8.0

Next figure of the CROPWAT 8.0 automatically works out the crop water requirement on the basis of information developed through above mentioned software as reflected in Fig 5.7 and Fig 5.8.

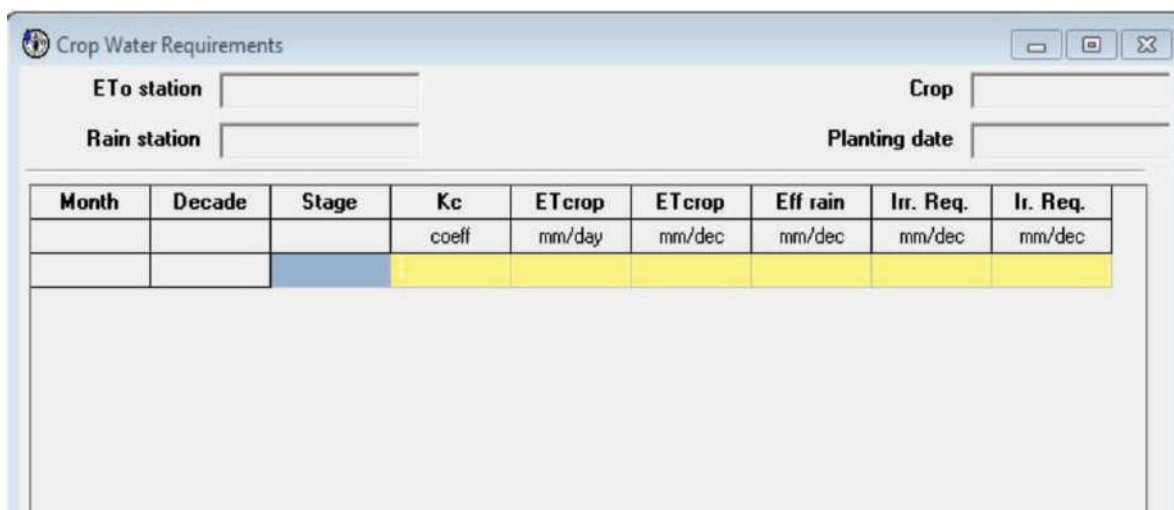


Fig. 5.7 Calculation of Crop Water Requirement

The same Figure with processed data is given below:

Crop Water Requirements

ET_o station: Multan Crop: Cotton

Rain station: Multan Planting date: 26/04

Month	Decade	Stage	K _c	ET _c	ET _c	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Apr	3	Init	0.50	2.73	13.7	0.0	13.7
May	1	Init	0.50	2.93	29.3	0.0	29.3
May	2	Init	0.50	3.13	31.3	0.0	31.3
May	3	Deve	0.53	3.58	39.3	0.1	39.2
Jun	1	Deve	0.67	5.01	50.1	3.1	46.9
Jun	2	Deve	0.82	6.60	66.0	4.7	61.3
Jun	3	Deve	0.96	7.45	74.5	4.9	69.6
Jul	1	Deve	1.11	8.08	80.8	4.8	76.0
Jul	2	Mid	1.23	8.61	86.1	5.1	81.0
Jul	3	Mid	1.23	8.40	92.4	5.8	86.6
Aug	1	Mid	1.23	8.13	81.3	7.3	74.0
Aug	2	Mid	1.23	7.86	78.6	8.3	70.2
Aug	3	Mid	1.23	7.44	81.9	5.6	76.3
Sep	1	Mid	1.23	7.03	70.3	0.1	70.2
Sep	2	Late	1.21	6.50	65.0	0.0	65.0
Sep	3	Late	1.15	5.53	55.3	0.0	55.3
Oct	1	Late	1.09	4.63	46.3	0.0	46.3
Oct	2	Late	1.03	3.80	38.0	0.0	38.0
Oct	3	Late	0.97	3.07	33.7	0.0	33.7
Nov	1	Late	0.91	2.43	14.6	0.0	14.6
					1128.2	49.7	1078.5

Figure. 5.8 Calculation of Crop Water Requirement through CROPWAT 8.0

It may be noted in Fig. 5.8 that values of K_c have been systematically transformed on decadal basis. It is also possible to draw a crop growth coefficient curve with the help of these figures for the crop under consideration. Accordingly, it shows that if the values of $K_{c\text{ ini}}$, $K_{c\text{ mid}}$ and $K_{c\text{ end}}$ of any crop are fed in this program, it automatically transforms these values on decadal basis and one can draw the crop growth coefficient curve for that crop if desired.

5.2.2. Processing of Data for Determination of ET_o, K_c and Crop Water Requirement through CROPWAT 8.0

The data from three meteorological stations has been processed through CROPWAT 8.0 and the Values of ET_o and crop water requirements of various crops grown in the adjoining areas of those stations have been calculated. The data of all three stations given in the report has been generated by FAO Software CROPWAT 8.0. Meteorological Station – Multan

5.2.3. Meteorological Station - Multan

The climatic data of meteorological station, Multan has been obtained and the same has been processed to calculate ET_o values of the district as given in table 5.4. The maximum evapotranspiration of the area is during the month of June i.e. 7.03 mm/day and minimum is

during the months of December and January i.e. 1.41 mm/day. The crops that may be brought under sprinkler or drip irrigation are Cotton, Wheat, Sugarcane, Maize and Mango. Accordingly, Crop Water Requirements (CWR) of these crops have been presented in Tables 5.5 to 5.9 respectively. These values may be used for planning, designing, and irrigation scheduling of HEIS in Multan area.

Table-5.4. Values of ET_o based on Data of Meteorological Station, Multan

Altitude:	122	Longitude:	71.43 0E	Latitude	30.12 0N	ET _o
Month	Avg. Temp	Humidity	Wind	Sun	Radiation	
	°C	%	km/day	hours	MJ/m ² /day	mm/day
January	12.7	63	44	6.8	12.3	1.41
February	15.4	57	70	7.2	14.9	2.09
March	20.7	54	96	7.7	18.2	3.24
April	27.5	43	96	8.9	22	4.77
May	32.4	37	100	9.6	24.2	5.95
June	35.5	42	151	8.8	23.3	7.03
July	33.9	58	133	8.1	22	6.1
August	33	62	122	9.2	22.8	5.87
September	31	59	107	9	20.6	5.07
October	26.4	55	59	8.2	16.8	3.45
November	19.7	65	37	8	14	2.14
December	14.2	68	37	6.7	11.5	1.41
Average	25.2	55	88	8.2	18.5	4.04

Table-5.5 Crop Water Requirement of Cotton for Multan Areas

Month	Decade	Stage	Kc	ET _c	ET _c	Eff rain	Irr. Req.
			Coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	Init	0.35	2.08	12.5	1.8	11
May	3	Init	0.35	2.21	24.3	3.4	20.9
Jun	1	Init	0.35	2.38	23.8	2.5	21.3
Jun	2	Dev	0.39	2.8	28	2.1	25.9
Jun	3	Dev	0.51	3.52	35.2	7.6	27.7
Jul	1	Dev	0.65	4.14	41.4	15.8	25.6
Jul	2	Dev	0.78	4.74	47.4	21.6	25.8
Jul	3	Dev	0.92	5.51	60.6	17.9	42.8
Aug	1	Mid	1.01	5.98	59.8	12.9	46.9
Aug	2	Mid	1.01	5.91	59.1	10.1	49
Aug	3	Mid	1.01	5.64	62.1	7.9	54.1
Sep	1	Mid	1.01	5.37	53.7	5.5	48.3
Sep	2	Mid	1.01	5.1	51	3	48
Sep	3	Mid	1.01	4.56	45.6	2.2	43.4

Oct	1	Late	0.96	3.82	38.2	1.3	36.9
Oct	2	Late	0.84	2.91	29.1	0.2	28.9
Oct	3	Late	0.72	2.18	24	0.4	23.6
Nov	1	Late	0.61	1.56	15.6	0.6	15
Nov	2	Late	0.49	1.05	10.5	0.6	9.9
Nov	3	Late	0.41	0.77	3.9	0.6	3.3
					725.8	117.9	608.2

Table-5.6. Crop Water Requirement of Wheat in Multan Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.3	0.64	3.9	0.4	3.5
Nov	3	Init	0.3	0.57	5.7	1.2	4.5
Dec	1	Init	0.3	0.5	5	1.9	3.1
Dec	2	Deve	0.35	0.49	4.9	2.4	2.5
Dec	3	Deve	0.56	0.79	8.7	2.4	6.3
Jan	1	Deve	0.79	1.11	11.1	2.3	8.8
Jan	2	Mid	0.95	1.33	13.3	2.3	11
Jan	3	Mid	0.95	1.56	17.1	2.6	14.5
Feb	1	Mid	0.95	1.77	17.7	2.7	15.1
Feb	2	Mid	0.95	1.99	19.9	2.8	17.1
Feb	3	Late	0.9	2.22	17.7	4	13.7
Mar	1	Late	0.7	2.01	20.1	5.7	14.4
Mar	2	Late	0.49	1.57	15.7	7	8.7
Mar	3	Late	0.33	1.25	5	2.2	2
					165.8	39.8	125.2

Table-5.7. Crop Water Requirement of Sugarcane in Multan Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	2	Init	0.52	2.62	15.7	1.8	13.9
Sep	3	Init	0.4	1.81	18.1	2.2	15.9
Oct	1	Init	0.4	1.6	16	1.3	14.7
Oct	2	Dev	0.42	1.45	14.5	0.2	14.3
Oct	3	Dev	0.52	1.56	17.2	0.4	16.8
Nov	1	Dev	0.62	1.6	16	0.6	15.4
Nov	2	Dev	0.72	1.54	15.4	0.6	14.8
Nov	3	Dev	0.82	1.55	15.5	1.2	14.3
Dec	1	Dev	0.91	1.51	15.1	1.9	13.2
Dec	2	Mid	0.98	1.39	13.9	2.4	11.5
Dec	3	Mid	0.99	1.39	15.3	2.4	12.9
Jan	1	Mid	0.99	1.39	13.9	2.3	11.6
Jan	2	Mid	0.99	1.39	13.9	2.3	11.6
Jan	3	Mid	0.99	1.61	17.7	2.6	15.1
Feb	1	Mid	0.99	1.84	18.4	2.7	15.7
Feb	2	Mid	0.99	2.06	20.6	2.8	17.8
Feb	3	Mid	0.99	2.44	19.5	4	15.6
Mar	1	Mid	0.99	2.82	28.2	5.7	22.5
Mar	2	Mid	0.99	3.2	32	7	25
Mar	3	Mid	0.99	3.71	40.8	6.1	34.7
Apr	1	Mid	0.99	4.21	42.1	4.8	37.2
Apr	2	Mid	0.99	4.71	47.1	4.1	43
Apr	3	Mid	0.99	5.1	51	3.8	47.2
May	1	Mid	0.99	5.48	54.8	3.4	51.4
May	2	Mid	0.99	5.87	58.7	3	55.7
May	3	Mid	0.99	6.23	68.5	3.4	65.2
Jun	1	Mid	0.99	6.72	67.2	2.5	64.7
Jun	2	Late	0.96	6.97	69.7	2.1	67.6

Jun	3	Late	0.91	6.27	62.7	7.6	55.1
Jul	1	Late	0.86	5.54	55.4	15.8	39.6
Jul	2	Late	0.81	4.97	49.7	21.6	28
Jul	3	Late	0.76	4.58	50.4	17.9	32.6
Aug	1	Late	0.71	4.21	42.1	12.9	29.2
Aug	2	Late	0.66	3.86	38.6	10.1	28.5
Aug	3	Late	0.61	3.39	37.3	7.9	29.3
Sep	1	Late	0.55	2.95	29.5	5.5	24
Sep	2	Late	0.52	2.62	10.5	1.2	9
					1212.9	178	1029.6

Table-5.8. Crop Water Requirement of Maize in Multan Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Aug	2	Init	0.3	1.76	17.6	6.1	11.5
Aug	3	Init	0.3	1.68	16.8	7.9	8.9
Sep	1	Deve	0.35	1.88	18.8	5.5	13.3
Sep	2	Deve	0.53	2.7	27	3	24
Sep	3	Deve	0.72	3.26	32.6	2.2	30.4
Oct	1	Mid	0.9	3.6	36	1.3	34.7
Oct	2	Mid	0.95	3.29	32.9	0.2	32.7
Oct	3	Mid	0.95	2.88	31.7	0.4	31.3
Nov	1	Mid	0.95	2.46	24.6	0.6	24.0
Nov	2	Late	0.94	2.02	20.2	0.6	19.6
Nov	3	Late	0.78	1.49	14.9	1.2	13.7
Dec	1	Late	0.58	0.96	9.6	1.9	7.7
Dec	2	Late	0.41	0.58	5.8	1.7	4.1
					281.5	32.5	249.2

Table-5.9 Crop Water Requirement of Mango in Multan Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	2	Init	0.61	3.08	18.5	1.8	10.8
Sep	3	Init	0.9	4.07	40.7	2.2	38.5
Oct	1	Init	0.9	3.59	35.9	1.3	34.6
Oct	2	Init	0.9	3.1	31	0.2	30.9
Oct	3	Init	0.9	2.71	29.8	0.4	29.5
Nov	1	Init	0.9	2.32	23.2	0.6	22.6
Nov	2	Init	0.9	1.93	19.3	0.6	18.7
Nov	3	Init	0.9	1.71	17.1	1.2	15.9
Dec	1	Init	0.9	1.49	14.9	1.9	13
Dec	2	Dev	0.9	1.26	12.6	2.4	10.2
Dec	3	Dev	0.88	1.25	13.7	2.4	11.3
Jan	1	Dev	0.87	1.23	12.3	2.3	10
Jan	2	Dev	0.86	1.21	12.1	2.3	9.8
Jan	3	Dev	0.85	1.38	15.2	2.6	12.6
Feb	1	Dev	0.83	1.55	15.5	2.7	12.8
Feb	2	Dev	0.82	1.71	17.1	2.8	14.3
Feb	3	Dev	0.81	2	16	4	12
Mar	1	Dev	0.8	2.28	22.8	5.7	17.1
Mar	2	Mid	0.79	2.56	25.6	7	18.6
Mar	3	Mid	0.79	2.96	32.6	6.1	26.5
Apr	1	Mid	0.79	3.37	33.7	4.8	28.8
Apr	2	Mid	0.79	3.77	37.7	4.1	33.6
Apr	3	Mid	0.79	4.08	40.8	3.8	37
May	1	Mid	0.79	4.39	43.9	3.4	40.5
May	2	Mid	0.79	4.7	47	3	44
May	3	Mid	0.79	4.98	54.8	3.4	51.4
Jun	1	Mid	0.79	5.37	53.7	2.5	51.2
Jun	2	Late	0.78	5.65	56.5	2.1	54.3
Jun	3	Late	0.76	5.22	52.2	7.6	44.6
Jul	1	Late	0.74	4.76	47.6	15.8	31.8
Jul	2	Late	0.72	4.41	44.1	21.6	22.4
Jul	3	Late	0.7	4.23	46.5	17.9	28.7
Aug	1	Late	0.68	4.05	40.5	12.9	27.6
Aug	2	Late	0.66	3.88	38.8	10.1	28.7
Aug	3	Late	0.64	3.59	39.5	7.9	31.6

Sep	1	Late	0.62	3.31	33.1	5.5	27.7
Sep	2	Late	0.61	3.08	12.3	1.2	10.8
					1148.6	178	964.4

5.2.4. Meteorological Station - Lahore

The climatic data obtained from the **Lahore** metrological station (Table-5.10) is used to calculate ETo of the districts falling in this area. The maximum evapotranspiration of the area is during the month of May i.e. **6.21** mm/day and minimum is during the month of February i.e. **2.32** mm/day. The crops that could be grown using sprinkler or drip irrigation are wheat, Potato, and Maize. Accordingly, Crop Water Requirement (CWR) of these crops has been given in the following Tables. Table 5.11 represents Maize, Table 5.12 represents Wheat and table 5.13 represents Potato. In addition to Maize, wheat and potato Lahore District and adjoining areas grow crops such as sugarcane and vegetables of all types. Orchards of citrus and guava are also grown extensively in this part of the mixed crops zone. The CWR of these crops has also been calculated as reflected in tables 5.14 to 5.16. These values of CWR may be used for planning, designing, and irrigation scheduling of HEIS in Lahore district and adjoining areas.

Table-5.10. E₀ Based On Data of Lahore Meteorological Station

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m2/day	Mm/day
January	7.9	18.1	71	44	5.5	10.6	1.3
February	11.4	22.5	60	88	7.6	15	2.32
March	16.4	27.6	54	106	8	18.2	3.56
April	21.9	34.9	40	113	9.2	22.3	5.31
May	26	38.9	37	100	9.8	24.4	6.21
June	27.5	38.3	49	100	9.2	23.8	6.19
July	27.4	38.4	70	91	7.5	21.1	5.42
August	27.3	34.9	72	62	7.9	20.7	4.85
September	25.5	34.4	66	66	8.1	19.1	4.37
October	20.6	31.8	62	37	8.6	16.9	3.25
November	14.4	27.3	63	29	7.9	13.4	2.09
December	9.4	21.3	69	27	6.8	11.2	1.4
Average	19.6	30.7	59	72	8	18.1	3.86

Table-5.11. Crop Water Requirement of Maize in Lahore Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	3	Init	0.3	1.57	3.1	8.6	3.1
Aug	1	Init	0.3	1.51	15.1	40.1	0
Aug	2	Deve	0.31	1.49	14.9	36.4	0
Aug	3	Deve	0.49	2.28	25.1	29.7	0
Sep	1	Deve	0.73	3.32	33.2	21.8	11.3
Sep	2	Deve	0.97	4.22	42.2	15.1	27.1
Sep	3	Mid	1.12	4.45	44.5	12.1	32.4
Oct	1	Mid	1.12	4.05	40.5	9	31.5
Oct	2	Mid	1.12	3.63	36.3	5.3	31
Oct	3	Mid	1.12	3.2	35.2	4.8	30.4
Nov	1	Late	1	2.49	24.9	4.5	20.4
Nov	2	Late	0.75	1.56	15.6	3.6	12.1
Nov	3	Late	0.49	0.91	9.1	3.1	6.1
Dec	1	Late	0.35	0.57	0.6	0.2	0.6
					340.3	194.3	205.9

Table-5.12. Crop Water Requirement of wheat in Lahore Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.3	0.63	3.8	2.1	2
Nov	3	Init	0.3	0.56	5.6	3.1	2.5
Dec	1	Init	0.3	0.49	4.9	2	2.9
Dec	2	Deve	0.36	0.5	5	1.2	3.8
Dec	3	Deve	0.62	0.85	9.3	3.1	6.2
Jan	1	Deve	0.9	1.14	11.4	5.8	5.6
Jan	2	Mid	1.09	1.31	13.1	7.6	5.5
Jan	3	Mid	1.1	1.73	19	7.5	11.5
Feb	1	Mid	1.1	2.18	21.8	7.1	14.6

Feb	2	Mid	1.1	2.55	25.5	7.2	18.3
Feb	3	Late	1.03	2.81	22.5	7.8	14.7
Mar	1	Late	0.79	2.5	25	9.1	15.9
Mar	2	Late	0.53	1.87	18.7	9.9	8.8
Mar	3	Late	0.34	1.41	5.6	2.9	1.6
					191.2	76.5	113.9

Table-5.13. Crop Water Requirement of Potato in Lahore Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	2	Init	0.5	1.78	10.7	6	5.7
Mar	3	Init	0.5	2.07	22.8	8.1	14.7
Apr	1	Deve	0.51	2.39	23.9	5.4	18.6
Apr	2	Deve	0.65	3.47	34.7	3.5	31.2
Apr	3	Deve	0.86	4.81	48.1	4.6	43.6
May	1	Mid	1.06	6.31	63.1	5.1	58
May	2	Mid	1.11	7.02	70.2	5.4	64.9
May	3	Mid	1.11	6.98	76.8	9.7	67.1
Jun	1	Mid	1.11	6.9	69	12.7	56.3
Jun	2	Mid	1.11	6.9	69	15.8	53.2
Jun	3	Late	1.06	6.32	63.2	26.4	36.8
Jul	1	Late	0.93	5.27	52.7	41.7	11
Jul	2	Late	0.79	4.3	43	53.5	0
Jul	3	Late	0.71	3.72	7.4	8.6	7.4
					654.7	206.3	468.5

Table-5.14. Crop Water Requirement of Vegetables in Lahore Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	2	Init	0.7	2.49	15	6	10
Mar	3	Init	0.7	2.9	31.9	8.1	23.8

Apr	1	Deve	0.73	3.45	34.5	5.4	29.2
Apr	2	Deve	0.84	4.44	44.4	3.5	40.9
Apr	3	Deve	0.94	5.3	53	4.6	48.4
May	1	Mid	1.02	6.11	61.1	5.1	56
May	2	Mid	1.03	6.47	64.7	5.4	59.3
May	3	Mid	1.03	6.43	70.7	9.7	61
Jun	1	Late	1	6.19	61.9	12.7	49.2
Jun	2	Late	0.94	5.8	40.6	11	24.8
					477.8	71.4	402.6

Table-5.15. Crop Water Requirement of Sugarcane in Lahore Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	2	Init	0.66	2.89	17.3	9	4
Sep	3	Init	0.4	1.6	16	12.1	3.8
Oct	1	Init	0.4	1.45	14.5	9	5.5
Oct	2	Deve	0.43	1.39	13.9	5.3	8.6
Oct	3	Deve	0.56	1.6	17.6	4.8	12.8
Nov	1	Deve	0.7	1.73	17.3	4.5	12.8
Nov	2	Deve	0.83	1.74	17.4	3.6	13.8
Nov	3	Deve	0.96	1.79	17.9	3.1	14.8
Dec	1	Deve	1.09	1.78	17.8	2	15.8
Dec	2	Mid	1.19	1.66	16.6	1.2	15.4
Dec	3	Mid	1.19	1.63	17.9	3.1	14.8
Jan	1	Mid	1.19	1.51	15.1	5.8	9.3
Jan	2	Mid	1.19	1.43	14.3	7.6	6.7
Jan	3	Mid	1.19	1.87	20.6	7.5	13.1
Feb	1	Mid	1.19	2.36	23.6	7.1	16.4

Feb	2	Mid	1.19	2.76	27.6	7.2	20.4
Feb	3	Mid	1.19	3.26	26.1	7.8	18.2
Mar	1	Mid	1.19	3.75	37.5	9.1	28.4
Mar	2	Mid	1.19	4.24	42.4	9.9	32.5
Mar	3	Mid	1.19	4.94	54.3	8.1	46.2
Apr	1	Mid	1.19	5.64	56.4	5.4	51
Apr	2	Mid	1.19	6.33	63.3	3.5	59.8
Apr	3	Mid	1.19	6.69	66.9	4.6	62.3
May	1	Mid	1.19	7.12	71.2	5.1	66.1
May	2	Mid	1.19	7.51	75.1	5.4	69.8
May	3	Mid	1.19	7.47	82.2	9.7	72.5
Jun	1	Mid	1.19	7.38	73.8	12.7	61.1
Jun	2	Late	1.17	7.22	72.2	15.8	56.4
Jun	3	Late	1.11	6.58	65.8	26.4	39.5
Jul	1	Late	1.05	5.97	59.7	41.7	18
Jul	2	Late	1	5.39	53.9	53.5	0.5
Jul	3	Late	0.94	4.89	53.8	47.5	6.4
Aug	1	Late	0.88	4.42	44.2	40.1	4.1
Aug	2	Late	0.82	3.98	39.8	36.4	3.4
Aug	3	Late	0.76	3.57	39.2	29.7	9.5
Sep	1	Late	0.7	3.17	31.7	21.8	9.9
Sep	2	Late	0.66	2.89	11.5	6	4
					1406.5	493	907.7

Table-5.16. Crop Water Requirement of Citrus in Lahore Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	2	Init	0.5	2.22	13.3	6	3.9
Mar	3	Init	0.5	2.9	31.9	8.1	23.8
Apr	1	Init	0.5	3.31	33.1	5.4	27.7
Apr	2	Init	0.5	3.72	37.2	3.5	33.7
Apr	3	Init	0.5	3.93	39.3	4.6	34.7
May	1	Init	0.5	4.18	41.8	5.1	36.8
May	2	Deve	0.68	4.38	43.8	5.4	38.5
May	3	Deve	0.68	4.25	46.7	9.7	37.1
Jun	1	Deve	0.66	4.09	40.9	12.7	28.2
Jun	2	Deve	0.64	3.98	39.8	15.8	24
Jun	3	Deve	0.63	3.71	37.1	26.4	10.8
Jul	1	Deve	0.61	3.46	34.6	41.7	0
Jul	2	Deve	0.59	3.21	32.1	53.5	0
Jul	3	Deve	0.57	3	33	47.5	0
Aug	1	Deve	0.56	2.8	28	40.1	0
Aug	2	Mid	0.55	2.65	26.5	36.4	0
Aug	3	Mid	0.55	2.56	28.2	29.7	0
Sep	1	Mid	0.55	2.48	24.8	21.8	2.9
Sep	2	Mid	0.55	2.39	23.9	15.1	8.8
Sep	3	Mid	0.55	2.18	21.8	12.1	9.7
Oct	1	Mid	0.55	1.98	19.8	9	10.8
Oct	2	Mid	0.55	1.77	17.7	5.3	12.4
Oct	3	Mid	0.55	1.57	17.2	4.8	12.4
Nov	1	Mid	0.55	1.36	13.6	4.5	9.1
Nov	2	Mid	0.55	1.15	11.5	3.6	7.9

Nov	3	Mid	0.55	1.02	10.2	3.1	7.1
Dec	1	Late	0.55	0.9	9	2	7
Dec	2	Late	0.62	0.87	8.7	1.2	7.5
Dec	3	Late	0.62	0.85	9.4	3.1	6.2
Jan	1	Late	0.62	0.79	7.9	5.8	2.1
Jan	2	Late	0.62	0.75	7.5	7.6	0
Jan	3	Late	0.62	0.98	10.8	7.5	3.3
Feb	1	Late	0.62	1.24	12.4	7.1	5.2
Feb	2	Late	0.62	1.45	14.5	7.2	7.3
Feb	3	Late	0.62	1.71	13.7	7.8	5.8
Mar	1	Late	0.62	1.96	19.6	9.1	10.6
Mar	2	Late	0.62	2.22	8.9	4	3.9
					870.3	493	439.4

5.2.5. Meteorological Station - Mianwali

The climatic data obtained from Mianwali is used to work out ETo (Table 5.17) of this district. The maximum evapotranspiration of the area is during the month of June i.e. 6.18 mm/day and minimum is during the month of January i.e. 1.41 mm/day. The crops that could be grown using sprinkler irrigation are wheat and pulses whereas those which may be brought under drip irrigation systems are cotton and citrus. Accordingly, Crop Water Requirements (CWR) of these crops has been given in the Table 5.18 for wheat, Table 5.19 for cotton, Table 5.20 for citrus and Table 5.21 for pulses. These CWR may be used for planning, designing, and irrigation scheduling of HEIS in Mianwali district and adjoining areas.

Table-5.17. ETo Based on Data of Mianwali Meteorological Station

Altitude:	360	Longitude:	71.58 0E	Latitude	34.10 0N	
Month	Avg Temp	Humidity	Wind	Sun	Rad	ETo
	°C	%	km/day	hours	MJ/m2/day	mm/day
January	11.6	67	55	7.1	12.6	1.41
February	14.1	64	63	7.5	15.2	1.94

March	19.2	63	74	7.8	18.3	2.91
April	25.4	55	81	9.1	22.3	4.34
May	30.8	43	92	10.1	24.9	5.71
June	34.5	44	92	9.3	24	6.18
July	33.5	60	96	8.3	22.3	5.75
August	32.3	66	41	8.7	22	5.05
September	30.4	61	59	9.6	21.4	4.74
October	25	58	44	9.4	18.2	3.37
November	18.8	64	37	8.6	14.6	2.12
December	13.3	68	44	7.5	12.3	1.44
Average	24.1	59	65	8.6	19	3.75

Table-5.18. Crop Water Requirement of Wheat in Mianwali Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.3	0.64	3.8	0.4	3.5
Nov	3	Init	0.3	0.57	5.7	1.9	3.7
Dec	1	Init	0.3	0.5	5	3.7	1.3
Dec	2	Deve	0.35	0.5	5	4.8	0.2
Dec	3	Deve	0.56	0.8	8.8	4.9	3.9
Jan	1	Deve	0.79	1.12	11.2	4.9	6.4
Jan	2	Mid	0.95	1.34	13.4	5	8.3
Jan	3	Mid	0.95	1.51	16.7	5.9	10.7
Feb	1	Mid	0.95	1.68	16.8	6.2	10.7
Feb	2	Mid	0.95	1.85	18.5	6.7	11.9
Feb	3	Late	0.9	2.03	16.2	10.2	6
Mar	1	Late	0.7	1.82	18.2	15.7	2.5
Mar	2	Late	0.49	1.41	14.1	19.7	0
Mar	3	Late	0.33	1.13	4.5	5.9	0
					157.9	96	69.1

Table-5.19. Crop Water Requirement of Cotton in Mianwali and Adjoining Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	Init	0.35	2	12	4	8.7
May	3	Init	0.35	2.05	22.6	7.2	15.4
Jun	1	Init	0.35	2.13	21.3	6.1	15.2
Jun	2	Deve	0.39	2.42	24.2	5.6	18.7
Jun	3	Deve	0.51	3.1	31	12.9	18.1
Jul	1	Deve	0.64	3.75	37.5	22.8	14.7
Jul	2	Deve	0.76	4.38	43.8	30.1	13.7
Jul	3	Deve	0.9	4.94	54.4	29.7	24.6
Aug	1	Mid	0.98	5.2	52	30	22

Aug	2	Mid	0.98	4.97	49.7	31.2	18.5
Aug	3	Mid	0.98	4.87	53.6	25.8	27.8
Sep	1	Mid	0.98	4.84	48.4	19.4	29
Sep	2	Mid	0.98	4.77	47.7	14.5	33.1
Sep	3	Mid	0.98	4.28	42.8	10.8	32
Oct	1	Late	0.94	3.58	35.8	6.3	29.4
Oct	2	Late	0.83	2.78	27.8	2.1	25.7
Oct	3	Late	0.71	2.1	23.1	1.8	21.2
Nov	1	Late	0.6	1.51	15.1	1.6	13.5
Nov	2	Late	0.49	1.03	10.3	0.7	9.6
Nov	3	Late	0.4	0.76	3.8	1	2.8
					656.7	263.5	394

Table-5.20 Crop Water Requirement of Citrus in Mianwali Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Mar	2	Init	0.4	1.17	7	11.8	0
Mar	3	Init	0.7	2.37	26	16.4	9.7
Apr	1	Init	0.7	2.7	27	11.7	15.3
Apr	2	Init	0.7	3.04	30.4	8.9	21.5
Apr	3	Init	0.7	3.36	33.6	8.3	25.3
May	1	Init	0.7	3.68	36.8	7.6	29.1
May	2	Deve	0.69	3.93	39.3	6.7	32.7
May	3	Deve	0.65	3.8	41.9	7.2	34.7
Jun	1	Deve	0.61	3.7	37	6.1	30.9
Jun	2	Deve	0.57	3.57	35.7	5.6	30.1
Jun	3	Deve	0.53	3.23	32.3	12.9	19.4
Jul	1	Deve	0.49	2.88	28.8	22.8	6
Jul	2	Deve	0.45	2.59	25.9	30.1	0
Jul	3	Deve	0.41	2.26	24.8	29.7	0
Aug	1	Deve	0.37	1.94	19.4	30	0
Aug	2	Mid	0.35	1.75	17.5	31.2	0
Aug	3	Mid	0.35	1.71	18.8	25.8	0
Sep	1	Mid	0.35	1.7	17	19.4	0
Sep	2	Mid	0.35	1.67	16.7	14.5	2.2
Sep	3	Mid	0.35	1.5	15	10.8	4.2
Oct	1	Mid	0.35	1.32	13.2	6.3	6.9
Oct	2	Mid	0.35	1.17	11.7	2.1	9.6
Oct	3	Mid	0.35	1.02	11.2	1.8	9.4
Nov	1	Mid	0.35	0.88	8.8	1.6	7.2
Nov	2	Mid	0.35	0.73	7.3	0.7	6.7
Nov	3	Mid	0.35	0.65	6.5	1.9	4.6
Dec	1	Late	0.35	0.59	5.9	3.7	2.2
Dec	2	Late	0.4	0.58	5.8	4.8	1

Dec	3	Late	0.4	0.57	6.3	4.9	1.4
Jan	1	Late	0.4	0.57	5.7	4.9	0.8
Jan	2	Late	0.4	0.57	5.7	5	0.6
Jan	3	Late	0.4	0.64	7	5.9	1.1
Feb	1	Late	0.4	0.71	7.1	6.2	0.9
Feb	2	Late	0.4	0.78	7.8	6.7	1.2
Feb	3	Late	0.4	0.91	7.3	10.2	0
Mar	1	Late	0.4	1.04	10.4	15.7	0
Mar	2	Late	0.4	1.17	4.7	7.9	0
					663.3	407.6	314.7

Table-5.21. Crop Water Requirement of Pulses in Mianwali Areas

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	2	Init	0.4	1.94	11.6	8.7	4.3
Sep	3	Init	0.4	1.74	17.4	10.8	6.6
Oct	1	Deve	0.44	1.69	16.9	6.3	10.6
Oct	2	Deve	0.63	2.12	21.2	2.1	19.1
Oct	3	Deve	0.84	2.47	27.2	1.8	25.3
Nov	1	Mid	0.99	2.51	25.1	1.6	23.5
Nov	2	Mid	1	2.11	21.1	0.7	20.5
Nov	3	Mid	1	1.88	18.8	1.9	16.9
Dec	1	Mid	1	1.66	16.6	3.7	12.9
Dec	2	Late	0.91	1.3	13	4.8	8.2
Dec	3	Late	0.58	0.82	9	4.9	4.1
Jan	1	Late	0.37	0.52	1	1	1
					199	48.3	153.1

6. IRRIGATION SCHEDULING

Sweet water resources are proving limited day by day world over whereas their demand is increasing exponentially because of ever-rising population. Moreover, the cost of irrigation has increased to a level that the farmer's resultant income is diminished to critical extent. This necessitates the development of methods/techniques that help in production of crops with minimum use of water thereby maximizing the water productivity. Certainly, the focus needs to be made on efficient management of irrigation water realising more crop per drop of water.

Efficient irrigation management stipulates that the farm manager be familiar with the concepts encompassing “when to irrigate his crop” and “how much water to apply” to save the crop both from stress as well as over irrigation. Stress of water hampers a number of physiological functions depending upon water especially the synthesis of carbohydrates, absorption of nutrients and transpiration whereas over irrigation results in deficiency of air in the root zone and thus impedes a number of biological activities depending upon oxygen. Both of these shortfalls lead to reduction in the potential yield of the crop. Then providing water to the crop at a volume more than the required as per water holding capacity of the soil in the root zone is not only the loss of water and energy consumed in its conveyance/pumping but it leads to leaching of precious nutrients down from the root zone thereby depriving the crop of proper growth and development. The goal of irrigation scheduling, therefore, is to supply water to crop sufficient to let it perform all of its physiological functions without any decline in their rate on one hand while minimising the loss of water through its provision in quantity/volume not higher than the absorption capacity of the root zone.

Proper irrigation scheduling requires competent and professional decision making process. No doubt, the advent of precision irrigation methods such as high efficiency irrigation systems have brought a revolutionary saving in the use of irrigation water compared to the conventional irrigation methods yet there exists a dire need for introducing new methods of accurate irrigation scheduling to curtail upon the sumptuous use of water being applied to raise the agronomic and horticultural crops.

Precise irrigation scheduling has also been supported by the recent research findings that maintenance of slight deficit in terms of irrigation paves way for switching of plant physiological orders from vegetative to reproductive phase through improving the partitioning of carbohydrates to flowers and fruit s development in the plants. This observation has given rise to the new horizons in the field of irrigation such as “Regulated Deficit Irrigation (RDI)” and “Partial Root-zone Drying (PRD)” where irrigation is provided to different parts of the root system on alternate basis. It has been, however, established that effective irrigation scheduling helps in not only achieving judicious use of irrigation water but also in improving the growth and development of crops.

7. ETHODS OF IRRIGATION SCHEDULING

Several methods have been devised by the irrigation experts to determine proper time of applying irrigation to a crop and estimating the volume of water to be applied during the irrigation. All of these can be categorized in three broad groups.

7.1. SOIL - RELATED METHODS

This group includes approaches through which the soil contents are estimated in terms of percentage of water or in terms of tension for moisture that is existing in the soil compared to the level of moisture at its field capacity and the irrigations are scheduled on the bases of this percentage or tension. Methods such as Feel and Appearance, Gravimetric measurement, Use of Gypsum Blocks, Use of Tensiometers, Gamma Rays attenuation, Time Doman Reflectometry and Use of Neutron Probe have been referred very often.

Depending upon “Soil Moisture Percentage” or “Soil Moisture Deficit”, a method termed as Check Book Method has been introduced by the irrigation experts for scheduling irrigations. Regular record of moisture status is maintained from the beginning of the crop and irrigation is applied when the moisture reaches a particular level of percentage or deficit.

Tensiometers and gypsum blocks are now available having provisions of digital readouts. Moreover, the possibility of their attachment with “Data Loggers” has improved their utility to a considerable level. The units often used for expressing the level of tension are bars or atmospheres.

All of these methods need establishment of a correlation with respect to plant water use for scheduling irrigations and all have certain merits and demerits concerning particularly the accuracy of results, difficulty in use and cost effectiveness.

A general assumption or principle is kept in view while scheduling irrigations through soil related methods. It has been realized on the basis of research observations that plants can easily absorb water from soil so far it is above 50% of the moisture held between wilting point and the field capacity referred as “Available Water Holding Capacity”. In clayey soils, this limit is considered better if fixed as 60% as these soils hold the moisture more tightly compared to other soils, for loamy soils, this should be 50% and in case of sands, one can go even up to 40% although the water holding capacity of sandy soils is the least i.e. almost 1/3 of the capacity of clays. The frequency of irrigations, however, will be higher in case of sandy soils.

7.2. PLANTS - RELATED METHODS

The criterion used in this category of methods is the same as above i.e. moisture contents of the plant parts or in case of deficiency the moisture stress in the plant parts. The symptoms reflected

by the plants or direct measurements of the moisture contents are made as base for deciding the time to irrigate. As per opinion of the most of the professionals, plants related methods may be considered as most dependable as the same reflect an integration of all the factors contributing/leading towards making an appropriate decision for scheduling of irrigations. Irrigation scheduling through Plant Appearance (Wilting and/or Curling of leaves), Measurement of transpiration through Stem Flow, sap flow, and stomatal conductance, Measurement of water tension through Pressure Chamber, Measurement of Trunk Diameter Fluctuations, Measurement of Leaf Transpiration through Porometer, Measurement of Canopy Temperature through Infrared Thermometry and Thermography are the methods falling under this category. In addition, use of dendrometry, fruit gauges, and other tissue water content sensors and measurements of growth have also been taken up. It is, however, realised that plant related methods lack the ability to provide dependable means of assessing the volume of water required for irrigation.

7.3. WEATHER - RELATED METHODS

The amount of water used by the plant for its growth and development normally referred as consumptive use or evapotranspiration has been observed to be a function of weather parameters including radiation, temperature, humidity and wind velocity. The value of crop evapotranspiration is denoted by ET_c and is determined with the help of reference evapotranspiration (ET_o) and the ratio of evapotranspiration of any crop at a particular stage of growth to that of reference crop referred as crop coefficient (K_c). This approach has become highly popular because of its accuracy and practicability. The values of ET_o for various locations have been determined by the experts through direct, indirect and empirical methods. Recently, a panel of experts of FAO has recommended Penman Monteith equation as a method to determine ET_o values which is now being used world over. Similarly, the values of K_c have also been determined by the respective experts for wide spread locations. The use of evaporation pans has been considered an easy way of determining consumptive use of crops by many researchers but the approach of determining ET_c through multiplication of ET_o with K_c has proven its worth being the most accurate and has, therefore, achieved a universal acceptance.

The method/approach mentioned the last has been adopted for preparation of irrigation schedules for crops being grown through HEISs under PIPIP and is discussed hereunder with respect to its application in the field.

The relative suitability of different approaches for specific crop and climatic situations needs to be assessed with the aim of indicating the strengths and weaknesses of different approaches in the light of their suitability over different spatial and temporal scales. The soil- and plant-based methods also possess definite potential for automated irrigation control using various scheduling techniques.

8. PREPARATION OF AN IRRIGATION SCHEDULE

Primarily, preparation of an irrigation schedule depends upon the criterion one opts out of the three key bases i.e. whether it should be plant based or soil based or weather based. An Irrigation Schedule may be prepared depending upon any of the three bases. It is, however, important that estimation of the volume of water to be applied may be made along with the proper time of application of water. Accordingly, some of experts have proposed a combination of techniques based on above mentioned criteria to develop an effective irrigation schedule.

Plant based methods are good indicators of proper time for application of water but these do not help in determining the volume of water required to compensate for the loss of water evapotranspired through the plant. The determination of volume of water can fairly be made either through soil based assessments or weather based measurements. For practical purposes, therefore, soil based or weather based methods or some combinations of the same appear to be more appropriate.

Two methods are presented for adoption in the field by the project staff as well as literate farmers.

8.1. IRRIGATION SCHEDULING BASED ON SOIL MOISTURE PERCENTAGE

In this method, soil is first tested for its textural class and available water holding capacity. It is then brought to its field capacity level through the soaking (*rauni*) irrigation as per requisite volume of water and this point is supposed as 100 % moisture level of the soil. MAD (Management Allowed Deficit) value is also fixed at this stage i.e. at what percentage of soil moisture the crop will be irrigated again. MAD value may range from 50% to 90% of the available soil moisture. As the moisture is depleted from the root zone on account of consumptive use by the crop / evaporative demand of the atmosphere and its level reaches the MAD value, irrigation is applied as per volume of water depleted from the soil. The depletion level of moisture may be checked on daily basis either through some soil moisture measurement gadget or recorded on the basis of crop evapotranspiration (ET_c) as already explained. This method is referred as “Check Book Method” and is normally based on soil moisture “deficit” rather than soil moisture “percentage”. It is applicable in either way and is fairly dependable for practical purpose in the field. The pre-requisite data required for this method is given in Table 8.1, a sample prerequisite data in Table 8.1 (a) and sample irrigation schedule based on soil moisture percentage for potato crop for MAD level fixed at 85% is given in Table 8.2.

Table 8.1 Pre-requisite Data for Preparation of Irrigation Schedule on basis of Soil Moisture Percentage

Farmer's Name	District:	Crop: Potato	Area under Crop: Acres	Date of Sowing:	Date of Harvest:	
Effective Rooting Depth of Crop: cm	Discharge:		Application Rate: mm/hr		No. of Zones:	Size of one Zone: M2
Soil Texture:	Moisture % at Field Capacity:	Moisture % at Wilting Point:	Moisture Contents at Field Capacity: cm/m	Moisture Contents at Wilting Point: cm/m	Available Water Holding Capacity of Soil: cm/m or cm/cm or mm/cm	

Table 8.1 (a).Sample Pre-requisite Data for Preparation of Irrigation Schedule on basis of Soil Moisture Percentage

Farmer's Name: MMA	District: Okara	Crop: Potato	Area under Crop: 0.31 Acres	Date of Sowing: 27.10.17	Date of Harvest: 2.3.18	
Effective Rooting Depth of Crop: 60 cm	Discharge: 7 M3 per hour		Application Rate: 22.3 mm/hr		No. of Zones: 4	Size of one Zone: 314 M2
Soil Texture: Loam	Moisture % at Field Capacity: 34%	Moisture % at Wilting Point: 12%	Moisture Contents at Field Capacity: 34 cm/m	Moisture Contents at Wilting Point: 12 cm/m	Available Water Holding Capacity of Soil: 22 cm/m or 0.22cm/cm or 2.2mm/cm	

Table 8.2. Irrigation Schedule of Potato on the Basis of Soil Moisture Percentage (approx. 85%)

Month	Days involved	Initial Moisture Contents upto 60 cm depth (mm)	ET ₀ Value of the day (mm)	Kc Value Applicable	Daily Depletion/ CWR (mm)	Four Days Depletion (mm)	Addition by Rainfall (mm)	Net Four Days Depletion	Balance Moisture Contents (mm)	Resultant %age of Field Capacity	Time to Irrigate	Net CWR (mm)	Application Rate	Irrigation Time per Zone per Day (hr)	Irrigation Time/ Zone /Day (min)	Volume of Water to be Applied (m3)
Nov 6-9	4	132.0	1.9	0.3	0.57	2.28	0	2.28	130	98.3						-
Nov 10-13	4	129.7	1.9	0.4	0.76	3.04	0	3.04	129	97.7						-
Nov 14-17	4	129.0	1.9	0.5	0.95	3.8	0	3.8	126	95.4						
Nov 18-21	4	125.9	1.9	0.6	1.14	4.56	0	4.56	121	91.9						
Nov 22-24	4	121.4	1.9	0.7	1.33	5.32	0	5.32	116	87.9						
Nov 25-28	4	116.0	1.9	0.8	1.52	6.08	0	6.08	110	83.3	Irrigate	22	22.3	0.99	59	6.93
Nov 29-30	2	132.0	1.9	0.8	1.52	3.04	0	3.04	129	97.7						
Dec 1-4	4	129.0	1.4	0.8	1.12	4.48	0	4.48	125	94.3						
Dec 5-8	4	124.5	1.4	0.9	1.26	5.04	0	5.04	119	90.5						
Dec 9-12	4	119.5	1.4	0.9	1.26	5.04	0	5.04	114	86.7	Irrigate	18	22.3	0.81	47	5.67
Dec 13-16	4	132.0	1.4	0.9	1.26	5.04	0	5.04	127	96.2						
Dec 17-20	4	127.0	1.4	1	1.4	5.6	0	5.6	121	92.0						
Dec 21-24	4	121.4	1.4	1	1.4	5.6	0	5.6	116	87.7						
Dec 25-28	4	117.4	1.4	1.1	1.54	6.16	0	6.16	111	84.3	Irrigate	21	22.3	0.94	56	6.58
Dec 29-31	3	132	1.4	1.1	1.54	4.62	0	4.62	127	96.5						
Jan 1-4	4	127.38	1.5	1.1	1.65	6.6	0	6.6	121	91.5						
Jan 5-8	4	122.78	1.5	1.15	1.73	6.9	0	6.9	116	87.8						
Jan 9-12	4	115.88	1.5	1.15	1.73	6.9	0	6.9	109	82.6	Irrigate	23	22.3	1.03	62	7.21
Jan 13-16	4	132	1.5	1.15	1.73	6.9	0	6.9	125	94.8						
Jan 17-20	4	125.1	1.5	1.15	1.73	6.9	0	6.9	118	89.5						

Month	Days involved	Initial Moisture Contents upto 60 cm depth (mm)	ET ₀ Value of the day (mm)	Kc Value Applicable	Daily Depletion/ CWR (mm)	Four Days Depletion (mm)	Addition by Rainfall (mm)	Net Four Days Depletion	Balance Moisture Contents (mm)	Resultant %age of Field Capacity	Time to Irrigate	Net CWR (mm)	Application Rate	Irrigation Time per Zone per Day (hr)	Irrigation Time/ Zone /Day (min)	Volume of Water to be Applied (m ³)
Jan 21-24	4	118.2	1.5	1.15	1.73	6.9	0	6.9	111	84.3	Irrigate	21	22.3	0.94	56	6.58
Jan 25-28	4	132	1.5	1.15	1.73	6.9	0	6.9	125	94.8						
Jan 29-31	3	125.1	1.5	1.15	1.73	5.18	0	5.175	120	90.9						
Feb 1-4	4	119.9	2.4	1.15	2.76	11	0	11.04	109	82.5	Irrigate	23	22.3	1.03	62	7.21
Feb 5-8	4	132	2.4	1.1	2.64	10.6	0	10.56	121	92.0						
Feb 9-12	4	121.44	2.4	1	2.4	9.6	0	9.6	112	84.7	Irrigate	20	22.3	0.89	53	6.23
Feb 13-16	4	Stop irrigation														

8.2. IRRIGATION SCHEDULING BASED ON EVAPOTRANSPIRATION MEASUREMENTS

The irrigation schedule of a crop on the basis of evapotranspiration requires four documents:

One - Basic Data Sheet to record all particulars pertaining to the Farm, Crop and the system (Table 8.3),

Two - the Table reflecting values of reference evapotranspiration (ET_o) for all the districts of Punjab (Table 3.5),

Three - the values of crop growth coefficient to be taken from either the Table 4.1 (Miscellaneous Crops), Table 4.2 (Agronomic Crops), Table 4.3 (Vegetable Crops) and Table 4.4 (Orchards) or the curve regarding the particular crop ascertaining the weekly, decadal or monthly changes due to growth (Figures 4.3 to 4.8) and

Four - the Irrigation Schedule Calculation Sheet (Table 8.4) along with the formulae to process and develop required information necessary to reach the objective.

Afterwards, an Irrigation schedule on the basis of crop evapotranspiration may be completed through following three steps:

1. Calculation of Crop Water Requirement (CWR)
2. Calculation of Application Rate and
3. Calculation of Application Time.

The same are discussed in detail below:

8.2.1. Calculation of Crop Water Requirement (CWR)

This is the basic step for preparation of an irrigation schedule. The same has already been covered in detail under chapter 5.

8.2.2. Calculation of Daily Application Rate

The time in which a specific crop water requirement can be fulfilled depends on two factors:

- a. The amount of water being diverted or applied to a field per unit time also termed as “Flow Rate”. Higher is the amount of flow, lesser will be the time required to fill the root zone.
- b. The size of the field or zone being irrigated i.e. bigger is the field, longer will be the time required to complete the irrigation.

Both of these factors have been put together in the term “Application Rate” which may be defined as the amount of water being applied to a unit piece of land in a unit time. The units for flow rate used commonly are “Liters per second (lps), Liters per hour (lph) and Cubic meters per hour (m^3/h) whereas the units for area used commonly are “Square meters (m^2) and Hectares (Ha)”. If

the flow rate is in liters per hour (usual discharge/flow rate of emitters) and the area is in m^2 , the unit for Application Rate is “mm/hour”. Its simple mathematical relationship is given as under:

$$\text{Application Rate (mm/hr)} = \text{Flow Rate in Liters per Hour} / \text{Area in } m^2$$

If the system flow rate is taken in cubic meters (m^3) per hour and the area is taken in hectares, then:

$$\text{Application Rate (mm/hr)} = \text{System Flow Rate (} m^3/\text{hr)} * 0.1 / \text{Area (Ha)}$$

Calculate application rate separately and enter it in appropriate cell of the Irrigation Schedule (IS) Preparation Sheet as well as in column I.

8.2.3. Calculation of Application Time

It is the time required to complete the CWR of a field or zone. The application rate has already been calculated. Application Time can be calculated by dividing the CWR of a day by the application rate. The formula is:

$$\text{Application Time (hours)} = \text{CWR (mm/day)} / \text{Application Rate (mm/hr)}$$

In this way, one can calculate the time of application for all the weeks or decades or even months as per assessment period of daily CWR.

With the help of formula given above, determine the values of application time in hours and enter it in column (m) of the calculation sheet given at table 5.2 reproduced below with certain additions as table 8.3. Multiply these values with the number of minutes in an hour to get the values of application time per zone in minutes and enter the same in column (n). To calculate the time required to irrigate all the zones, multiply the time value for one zone with the number of zones.

The Irrigation Schedule for orchards is normally prepared on monthly basis instead of weekly or decadal (ten days) basis. In addition, the amount of water to be applied is calculated on per plant basis. For that, divide the values of last column reflecting “Volume of water required” by the number of days of the month to calculate the volume on per day basis, then divide by the number of zones to calculate the volume on per zone basis then multiply with 1000 to convert the value in litres/day/zone. Divide this value with the number of plants in the zone to get the volume of water on per plant basis. It is, however, to be kept in view that the number of emitters must be increased every year as per increase in volume of water per plant up to fourth year.

The sample Irrigation Schedules (Year 1-4) for citrus orchard on the basis of evapotranspiration have been given in Tables 8.5 – 8.8.

Table. 8.3 Basic Data Sheet for Preparation of Irrigation Schedule

Sr. No.	Particulars	Detail
A	Farm Specifics	
1	Name of Farmer	
2	Educational Level	
3	Village	
4	Tehsil	
5	District	
B	Crop Data	
1	Name of Crop	
2	Crop Growth Duration	
3	Total Area of The Crop	
4	Date of Sowing	
5	Expected Date of Harvesting	
6	R-R Distance	
7	P-P Distance	
8	ET _o Values for the Period of Crop Duration	
9	Crop Growth Coefficient Curve	
10	Tentative Values of Canopy Factor	
C	System Particulars	
1	Type of System (Drip or Sprinkler)	
2	System Flow Rate/Discharge	
3	System Efficiency	
4	Moisture Status of the Root Zone Before Sowing	
5	Depth of Ground Water Table	
6	Value of Effective Rainfall on its Occurrence	
7	Number of Zones	
8	Area of Each Zone	
9	L-L Distance	
10	E-E Distance	
11	Discharge/Flow Rate of Each Emitter	
12	Number of Emitters in one Zone	
13	Value of Daily CWR	
14	Irrigation Cycle	
15	Storage Tank Capacity	

Table 8.4: Calculation Sheet for Irrigation Schedule

[illegible]

Table 8.5 Irrigation Schedule of Citrus- Haji Muhammad Zubair (1st Year)

Farmer- Haji Muhammad Zubair			District - Bahawal Nagar		Crop - Citrus		Sowing Date -10.3.12		Harvesting Date:		Area under Crop- 6.95 Acres		No. of Plants per Zone =300						
No. of Zones = 4		Size of one zone=1.74 Acre					RR = 5.49 m					PP = 4.27 m		System Flow Rate = 14418 LPH		App. Rate (mm/H) = 2.05			
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR(mm)	Monthly Gross CWR(mm)	Soil/Rainfall Contribution (mm)	Monthly Net CWR(mm)	Daily Net CWR(mm)	Application Rate (mm/H)	Irrigation Time/zone/Day (hours)	Time/zone/Day (minutes)	Irrigation Time for all zones(Hrs)	Volume of water Required per Month (m3)	Volume of Water /Zone per Day (Liters)	Volume of Water per Plant per Day (Liters)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
				From Eto Table	From CGCC or Kc Table		$h=e*f*g$	$i=h/.9$	$J=i*d$	If effective	$l=j-k$	$m=l/d$	From Design Data	$o=m/n$	$p=o*60$	$q=o*No. ofZones$	$r=d*SRR*q$	$s=r/d/No. ofZones*1000$	$t=s/No. ofPlants/Zone$
Mar	31		21	4.3	0.65	0.33	0.92	1.02	21.52	0.0	21.52	0.69	2.05	0.34	20	1.35	410	4883	16
Apr	30		30	6	0.65	0.34	1.33	1.47	44.20	0.0	44.20	1.47	2.05	0.72	43	2.87	1243	10362	35
May	31		31	7.6	0.65	0.35	1.73	1.92	59.55	0.0	59.55	1.92	2.05	0.94	56	3.75	1675	13512	45
Jun	30		30	8.3	0.65	0.36	1.94	2.16	64.74	0.0	64.74	2.16	2.05	1.05	63	4.21	1821	15178	51
Jul	31		31	6.4	0.65	0.37	1.54	1.71	53.02	0.0	53.02	1.71	2.05	0.83	50	3.34	1492	12028	40
Aug	31		31	6.1	0.65	0.38	1.51	1.67	51.90	0.0	51.90	1.67	2.05	0.82	49	3.27	1460	11774	39
Sep	30		30	5.5	0.65	0.39	1.39	1.55	46.48	0.0	46.48	1.55	2.05	0.76	45	3.02	1307	10896	36
Oct	31		31	4.2	0.65	0.4	1.09	1.21	37.61	0.0	37.61	1.21	2.05	0.59	36	2.37	1058	8534	28
Nov	30		30	2.6	0.65	0.41	0.69	0.77	23.10	0.0	23.10	0.77	2.05	0.38	23	1.50	650	5415	18
Dec	31		31	1.8	0.65	0.42	0.49	0.55	16.93	0.0	16.93	0.55	2.05	0.27	16	1.07	476	3840	13
Jan	31		31	1.9	0.65	0.43	0.53	0.59	18.29	0.0	18.29	0.59	2.05	0.29	17	1.15	515	4150	14
Feb	28		28	2.9	0.65	0.44	0.83	0.92	25.80	0.0	25.80	0.92	2.05	0.45	27	1.80	726	6481	22

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

Table 8.6 Irrigation Schedule of Citrus- Haji Muhammad Zubair (2nd Year)

Farmer- Haji Muhammad Zubair			District - Bahawal Nagar			Crop - Citrus		Sowing Date - 3.12		Harvesting Date:		Area under Crop- 6.95 Acres		No. of Plants per Zone =300					
No. of Zones = 4		Size of one zone=1.74 Acre		RR = 5.49 m		PP = 4.27 m		System Flow Rate = 14418 LPH		App. Rate (mm/H) = 2.05									
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency & Gross CWR	Monthly Gross CWR	Soil/Rainfall Contribution (mm)	Monthly Net CWR(mm)	Daily Net CWR(mm)	Application Rate (mm/H)	Irrigation Time/zone/Day (hours)	Irrigation Time for all zones(Hrs)	Volume of water Required per Month (m3)	Volume of Water /Zone per Day (Liters)	s=r/d/No. of Zones *1000	t=s/No. of Plants per Zone
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
				From Eto Table	From CGOC or Kc Table		$h=e*f*g$	$l=h/.9$	$J=j*d$	If effective	$l=j-k$	$m=l/d$	From Design Data	$o=m/n$	$p=o*60$	$q=o*No. of Zones$	$r=d*SFR*q$		
Mar	31		31	4.3	0.65	0.45	1.26	1.40	43.32	0.0	43.32	1.40	2.05	0.68	41	2.73	1219	9829	33
Apr	30		30	6	0.65	0.46	1.79	1.99	59.80	0.0	59.80	1.99	2.05	0.97	58	3.89	1682	14019	47
May	31		31	7.6	0.65	0.47	2.32	2.58	79.97	0.0	79.97	2.58	2.05	1.26	76	5.03	2250	18144	60
Jun	30		30	8.3	0.65	0.48	2.59	2.88	86.32	0.0	86.32	2.88	2.05	1.40	84	5.61	2428	20237	67
Jul	31		31	6.4	0.65	0.49	2.04	2.26	70.21	0.0	70.21	2.26	2.05	1.10	66	4.42	1975	15929	53
Aug	31		31	6.1	0.65	0.5	1.98	2.20	68.29	0.0	68.29	2.20	2.05	1.07	64	4.30	1921	15493	52
Sep	30		30	5.5	0.65	0.51	1.82	2.03	60.78	0.0	60.78	2.03	2.05	0.99	59	3.95	1710	14248	47
Oct	31		31	4.2	0.65	0.52	1.42	1.58	48.90	0.0	48.90	1.58	2.05	0.77	46	3.08	1376	11094	37
Nov	30		30	2.6	0.65	0.53	0.90	1.00	29.86	0.0	29.86	1.00	2.05	0.49	29	1.94	840	7000	23
Dec	31		31	1.8	0.65	0.54	0.63	0.70	21.76	0.0	21.76	0.70	2.05	0.34	21	1.37	612	4937	16
Jan	31		31	1.9	0.65	0.55	0.68	0.75	23.40	0.0	23.40	0.75	2.05	0.37	22	1.47	658	5308	18
Feb	28		28	2.9	0.65	0.56	1.06	1.17	32.84	0.0	32.84	1.17	2.05	0.57	34	2.29	924	8249	27

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

Table 8.7 Irrigation Schedule of Citrus- Haji Muhammad Zubair (3rd Year)

Farmer- Haji Muhammad Zubair		District - Bahawal Nagar		Crop - Citrus		Sowing Date - 3.12		Harvesting Date:		Area under Crop- 6.95 Acres		No. of Plants per Zone =300								
No. of Zones = 4		Size of one zone=1.74 Acre		RR = 5.49 m		PP = 4.27 m		System Flow Rate = 14418 LPH		App. Rate (mm/H) = 2.05										
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR(mm)	Monthly Gross CWR(mm)	Soil/Rainfall Contribution (mm)	Monthly Net CWR(mm)	Daily Net CWR(mm)	Application Rate (mm/H)	Irrigation Time/zone/Day (hours)	Irrigation Time/zone/Day (minutes)	Irrigation Time for all zones(Hrs)	Volume of water Required per Month (m3)	Volume of Water /Zone per Day (Liters)	s=r/d/N	t=s/No. of Plants /Zone
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	
				From Eto Table	From OGCC or Kc Table		$h=e*f*g$	$l=h/9$	$J=i*d$	If effective	$l=j-k$	$m=l/d$	From Design Data	$o=m/n$	$p=o*60$	$q=o*No. of Zones$	$r=d*SFR_q$	$s=r/d/N$	$t=s/No. of Plants /Zone$	
Mar	31		31	4.3	0.65	0.57	1.59	1.77	54.88	0.0	54.88	1.77	2.05	0.86	52	3.45	1544	12450	41	
Apr	30		30	6	0.65	0.58	2.26	2.51	75.40	0.0	75.40	2.51	2.05	1.23	74	4.90	2121	17677	59	
May	31		31	7.6	0.65	0.58	2.87	3.18	98.69	0.0	98.69	3.18	2.05	1.55	93	6.21	2776	22390	75	
Jun	30		30	8.3	0.65	0.59	3.18	3.54	106.10	0.0	106.10	3.54	2.05	1.73	104	6.90	2985	24874	83	
Jul	31		31	6.4	0.65	0.59	2.45	2.73	84.54	0.0	84.54	2.73	2.05	1.33	80	5.32	2378	19180	64	
Aug	31		31	6.1	0.65	0.59	2.34	2.60	80.58	0.0	80.58	2.60	2.05	1.27	76	5.07	2267	18281	61	
Sep	30		30	5.5	0.65	0.6	2.15	2.38	71.50	0.0	71.50	2.38	2.05	1.16	70	4.65	2011	16762	56	
Oct	31		31	4.2	0.65	0.6	1.64	1.82	56.42	0.0	56.42	1.82	2.05	0.89	53	3.55	1587	12800	43	
Nov	30		30	2.6	0.65	0.6	1.01	1.13	33.80	0.0	33.80	1.13	2.05	0.55	33	2.20	951	7924	26	
Dec	31		31	1.8	0.65	0.61	0.71	0.79	24.58	0.0	24.58	0.79	2.05	0.39	23	1.55	692	5577	19	
Jan	31		31	1.9	0.65	0.61	0.75	0.84	25.95	0.0	25.95	0.84	2.05	0.41	24	1.63	730	5887	20	
Feb	28		28	2.9	0.65	0.61	1.15	1.28	35.77	0.0	35.77	1.28	2.05	0.62	37	2.49	1006	8986	30	

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

Table 8.8 Irrigation Schedule of Citrus- Haji Muhammad Zubair (4th Year)

Farmer- Haji Muhammad Zubair			District - Bahawal Nagar			Crop - Citrus		Sowing Date - 3.12		Harvesting Date:		Area under Crop- 6.95 Acres		No. of Plants per Zone =300					
No. of Zones = 4			Size of one zone=1.74 Acre			RR = 5.49 m		PP = 4.27 m		System Flow Rate = 14418 LPH		App. Rate (mm/H) = 2.05							
Month	Days of the month	Decade No. of crop	No. of Crop Days	Corresponding Daily Eto (mm)	Crop Factor (Kc)	Canopy Factor	Daily Basic CWR (mm)	Efficiency Adjustment & Gross CWR(mm)	Monthly Gross CWR(mm)	Soil/Rainfall Contribution (mm)	Monthly Net CWR(mm)	Daily Net CWR(mm)	Application Rate (mm/H)	Irrigation Time/zone/Day (hours)	Irrigation Time/zone/Day (minutes)	Irrigation Time for all zones(Hrs)	Volume of water Required per Month (m3)	Volume of Water /Zone per Day (Liters)	Volume of Water per Plant per Day (Liters)
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
				From Eto Table	From CGOC or Kc Table		$h=e^{**}g$	$l=h/.9$	$J=i^{**}d$	If effective	$l=j-k$	$m=l/d$	From Design Data or Cell R3	$o=n/h$	$p=o^{*}60$	$q=o^{*}No. of Zones$	$r=d^{*}SR^{*}q$	$s=r/d/N$	$t=s/No. of Plants /Zone$
Mar	31		31	4.3	0.65	0.62	1.73	1.93	59.69	0.0	59.69	1.93	2.05	0.94	56	3.76	1679	13542	45
Apr	30		30	6	0.65	0.62	2.42	2.69	80.60	0.0	80.60	2.69	2.05	1.31	79	5.24	2267	18896	63
May	31		31	7.6	0.65	0.62	3.06	3.40	105.50	0.0	105.50	3.40	2.05	1.66	100	6.64	2968	23935	80
Jun	30		30	8.3	0.65	0.63	3.40	3.78	113.30	0.0	113.30	3.78	2.05	1.84	111	7.37	3187	26561	89
Jul	31		31	6.4	0.65	0.63	2.62	2.91	90.27	0.0	90.27	2.91	2.05	1.42	85	5.68	2540	20481	68
Aug	31		31	6.1	0.65	0.64	2.54	2.82	87.41	0.0	87.41	2.82	2.05	1.38	83	5.50	2459	19830	66
Sep	30		30	5.5	0.65	0.64	2.29	2.54	76.27	0.0	76.27	2.54	2.05	1.24	74	4.96	2146	17880	60
Oct	31		31	4.2	0.65	0.65	1.77	1.97	61.12	0.0	61.12	1.97	2.05	0.96	58	3.85	1720	13867	46
Nov	30		30	2.6	0.65	0.65	1.10	1.22	36.62	0.0	36.62	1.22	2.05	0.60	36	2.38	1030	8584	29
Dec	31		31	1.8	0.65	0.66	0.77	0.86	26.60	0.0	26.60	0.86	2.05	0.42	25	1.67	748	6034	20
Jan	31		31	1.9	0.65	0.66	0.82	0.91	28.08	0.0	28.08	0.91	2.05	0.44	27	1.77	790	6370	21
Feb	28		28	2.9	0.65	0.66	1.24	1.38	38.71	0.0	38.71	1.38	2.05	0.67	40	2.70	1089	9722	32

Note: (i) In case of rainfall, the schedule may be adjusted accordingly.

(ii) The schedule in view is for young plants and is a guideline only.

(iii) Withholding irrigation before flowering is helpful in induction of more flowers.

9. DAILY AND SEASONAL VOLUME OF WATER

For additional facilitation of the professionals, a column titled “Volume of Water Required” has been added at the end of the Irrigation Schedule Calculation Sheet. Though it does not have direct relationship with irrigation scheduling, an estimate of the amount of water required for a particular day may help the farmer in timely planning and ensuring the availability of requisite amount of water in the storage tank in case it is short. The amount of water required may be calculated as under:

$$\text{Volume of Water/Day (m}^3\text{)} = \text{System Flow Rate (m}^3\text{)} * \text{Irrigation Time/Day (hr)}$$

For seasonal estimate of the volume of water required by the crop, the daily values of volume will be multiplied with the requisite number of crop days to obtain the volume required in a week or decade and this value should be entered in column (p). A total of these decadal values will give us the seasonal water requirement/volume for that crop.

In addition, this value helps in comparing the volume of water applied under drip irrigation with the volume of water needed under surface irrigation. Certainly, a considerable volume of water applied under surface irrigation goes waste because of its absorption in areas out of the root zone and its evaporation up in the atmosphere without any use to the crop. The devastation of energy is another overwhelming loss. These losses contribute in lowering the efficiency of the surface irrigation system sometimes down to 50%. This comparison may help the farmers in extra planning in relation to their irrigation system and thus saving not only the precious water resource but also the valuable energy from wastage.

The volume water consumed in surface irrigation of a crop can be calculated as under;

The example is taken of the citrus orchard with its irrigation schedule given in table 10. The area of the orchard is 15 acres, discharge at the farm is 1.5 cusecs, time required for irrigation of one acre is 2 hours and the number of irrigations in one year is 20.

$$\text{Discharge in surface irrigation} = 1.5 \text{ cusecs} = 42 \text{ lps} = 151.2 \text{ m}^3/\text{hr}$$

$$\text{Time for one irrigation} = 2 \text{ hr}$$

$$\text{Volume for one irrigation} = 151.2 * 2 \text{ (hours)} = 302.4 \text{ m}^3 \text{ per acre}$$

$$\text{Volume for 15 acres irrigation} = 302.4 * 15 = 4536 \text{ m}^3$$

$$\text{Volume for 20 irrigations} = 4536 * 20 = 90720 \text{ m}^3$$

This volume can now be compared with that required under drip system.

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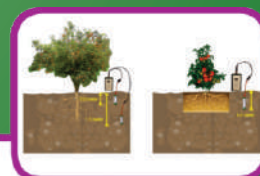
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Directorate General Agriculture (Water Management)
Punjab, Lahore

Agriculture House, 1st Floor, 21-Davis Road, Lahore

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E-mail: pipipwm@gmail.com, Website: www.ofwm.agripunjab.gov.pk