Micro Irrigation Engineering
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Lecture - 08
Crop Coefficient and Crop Water Requirement

Hello, dear participants of this course, I welcome you to lecture 8. In this lecture, we will discuss about crop coefficient and crop water required. In the previous lecture, lectures 6, 7 we discussed about evapotranspiration and we estimated evapotranspiration by using reference crop evapotranspiration and crop coefficient. We were estimating reference evapotranspiration and multiplying with the crop coefficient to determine actual crop evapotranspiration.

But sometimes when we are using Lysimeter or we are using FAO 56 method and in Lysimeter if we have grown a reference crop where we are maintaining ideal condition means there is no deficiency in soil moisture content when it is covering the entire ground and it is grown with grass. So, whatever amount of water is evapotranspired by the grass or reference crop is ET_0.

And actual evapotranspiration of the crop in another Lysimeter in the adjacent condition is maintained. So, one can get the crop coefficient value by using the actual evapotranspiration of the given crop divided by the reference evapotranspiration, reference crop evapotranspiration, or potential evapotranspiration. So, one can get crop coefficient value. Now, we will discuss in detail in this lecture 8 about crop coefficient.

Now, in this particular lecture, we will discuss about single crop coefficient which is a very which has been in majority of the literature, it is being used single crop coefficient. Dual crop coefficient very limited work or information is available. But particularly for micro-irrigation, this is very relevant. So, let us try to know what did you do well with crop coefficient and how it can be utilized, and how it can be determined. Water requirement of a crop, different crops, is another important thing for irrigation planning.

So, we will be discussing about water requirement of different crops. So, let us know what is the crop coefficient? So, crop coefficient is when we are calculating ET_c that is crop evapotranspiration, we are multiplying reference crop evapotranspiration with K_c, it gives the value of actual crop evapotranspiration. Now, ET_o of grass means the reference crop means it is the crop which is used as the reference crop which is usually you know ideal crop where ideal situations.

$$ET_c = ET_o \times K_c$$

Like well water condition etc. is maintained when this particular crop water is you know from the atmosphere the demand of the atmosphere, the energy provided by the atmosphere it is used. It is providing the energy for evapotranspiration. So, the amount of water evapotranspired by the reference crop is ET_0. And this ET_0 when we multiplied with the K_c factor our crop coefficient, it gives the actual evapotranspiration of the crop. So, K_c is one need to determine what is the K_c value?

Now, why crop coefficient approach is important? ET_0 represents an index of climatic demand means reference evapotranspiration, basically, it is influenced by the atmospheric parameters. K_c varies predominantly with the crop characteristics. So, ET_0 climatic demand and then the crop characteristics at the K_c, it is influenced by the crop characteristics. It is only limited to a certain extent, it is only limited with the climate.

It means very limited means not much influence of the climate at there, but mainly it is the crop characteristics. And this enables the transfer of standard values of the crop coefficient between location and climate. So, means a particular place where the crop is being grown and then what is the climatic situation it exists this makes the change in the value of the crop coefficient. And this is the primary reason for the global acceptance and usefulness of the crop coefficient approach has been you know considered to determine the actual crop evapotranspiration.

The crop coefficient is the ratio of actual crop evapotranspiration which we call ET_c to the reference evapotranspiration. It is the ratio of ET_c to the ET_0 and it represents the integration of four primary characteristics. What are those four primary characteristics? One is crop height and the other one is Albedo and crop canopy resistance and soil evaporation. So, that distinguishes the typical field crop from a reference crop.

So, means crop characteristics are incorporated in the determination of K_c or it is incorporated in these four parameters. So, different crops have different K_c values, and changing the characteristics of the crop over the growing season also affects the K_c value. And evaporation is integrated part of your evapotranspiration, conditions affecting soil operation means condition here that whether what is the moisture content of the soil. Whether it is ploughed soil, whether it is the old soil, whether it is already leveled. So, this influences the K_c value.

Now, the factors which influence the crop coefficient, here we can see K_c at the mid-season stage and the crop you can see here some crops like pineapple, peaches, cotton. And some grass reference, mean this is your reference crop as your grass. So, crops that are falling mean you can see pineapple, peaches, cherry, apple here crop coefficient at the mid-season stage is less than the grass reference crop.

And crops which are you know greater than one means K_c value at the mid-season stage is greater than one it is cotton, some of the vegetable crops and then large vegetable crops and sugarcane. So, crop type influences the crop coefficient value. Why it is so? Due to differences in the albedo means reflectance characteristics of the crop. It influences the crop coefficient value, crop height, aerodynamic property means the leaf.

And then the canopy structure, the shape of the leaf. These also influence the value of the crop coefficient. Stomata property, the evapotranspiration from fully grown area well-watered crop differs from ET_0. So, the crop type is one part then spacing between the plants. How close they

are? How spaced they are? And then the taller canopy height and roughness of many fully grown agriculture crops, this crops to have K_c factor larger than one. This is what we see in these crops which have got more K_C value, greater than 1.

Climate does influence so, it is the wind so, aerodynamic property between the grass reference surface and agriculture crop is not only crop-specific, but this also affects. It also varies with the climatic condition and crop height because aerodynamic properties are greater for many agricultural crops compared to grass reference. As we are giving here ET_c means K_c is you know the ratio of ET_c to ET_0.

So, for many crops, the value of K_c is increasing as the wind speed increases and decreases with relative humidity. So, the K_c value means for more arid regions and conditions having greater wind speed have got higher K_c value. More humid climates and conditions of lower wind speed have got a lower K_c value.

So, this influence, now we can see from this particular figure. In this figure, we can see here the K_c values are ranged from point A to here, it is given range is given point A to 1.5. So, for short crops, if we see short crops like cabbage, onion the K_c value range is when the case for very humid conditions when we are putting the K_c value is less than 1.1. In some cases, you know it goes up to maximum means less than 1.2 rather we can say.

And when we go for the crops which are the character comes in the taller crop range say cotton, maize or sugar cane. And particularly for extremely arid and wind conditions. Then what we find is the K_c value goes high. So, in the statement which I gave for a low wind speed and a very humid condition, the value of K_c is lower as compared to the taller crops and arid and windy conditions.

That is what one can see from this particular graph. So, the means K_c is influenced by climate and weather conditions and also the type of crop characteristic short crop or large crop.

Soil evaporation. Now, this also influences the crop coefficient value. So, the difference in soil evaporation and crop transpiration between field crops and reference surfaces are integrated within the crop coefficient. Let us see here it is plotted you know K_c values on the ordinate and then plant you know the plant growth characteristic it is plotted on the x-axis. Now, what do we see here? This is in the early stage means it is in the seedling stage and as the plant grows.

So, means initially what we see there are two leaves and four leaves and then as the plant grows, means it starts covering the ground cover. It means canopy growth development is causing the covering of the ground. So, at the initial stage, let us say this soil is in a typical dry soil characteristic it is shown here. So, soil evaporation is dominant in the initial growth stage of the crop or seedling stage.

And when it goes toward the growth of the crop it starts covering the ground cover. So, what we see, transpiration of the crop is more you know dominant. Which we call a basal crop coefficient where transpiration is dominant. So, the value of the soil evaporation coefficient at the beginning stage is more. Now, this is one case when dry soil exists that means a dry conditional soil surface exists and this is the wet surface when we are given enough moisture is being maintained our irrigation is being given.

So, a horizontal line here represents the K_c value when the soil surface is kept continuously wet or irrigation is being maintained all throughout. A curved dotted line which we see. So, the curved line corresponds to the K_c when the surface is kept dry, but the crop received sufficient water to sustain transpiration means that much amount of moisture is maintained where the crop can be able to maintain the transpiration but the value of crop coefficient we can see here.

It is closer to 2.1 and when it is in wet condition when we are maintaining this then the crop coefficient value is more than one. So, here for wet soil conditions, the K_c value may exceed one

and for dry soil conditions, K_c is small as low as 0.1. So, the soil surface, what is the condition of the moisture content in the soil? This also causes the Kc, influence on the K_c value.

Now, let us see another aspect of the crop coefficient. So, let us see this part. Just now, I told you that when the crop is let us say the crop has at the initial stage. Few weeks say when the crop just has emerged, leaves have emerged. So, this week, this stage is called an initial stage. Now the crop starts producing leaves and it goes to the development stage. So, for few weeks let us say that it is in the crop development stage means the ground is started covering with the plant.

So, as the number of leaves, it increases say vegetable crop or any other crop, it is not covering the ground. So, what we are seeing for few days? It is covering 25% of the ground and 40% of the ground cover and then 60%. So, it goes to a particular it has reached to a stage when the development it has taken place fully. And then it comes to the mid-season stage, we call it a maturity stage, crop it has got full maturity stage that is a mid-season stage.

And then it comes to the end-stage. So, total crop growth stages can be divided into four stages. The initial stage, crop development stage, mid-season stage, and late-season stage. Now when the crop head covered the fully ground and then it is in the full, you know fully grown plant and it is starts emerging flowers and then it is started giving fruits. Now here is another part it is being shown the same crop when we are giving or maintaining some certain irrigation interval.

So, if you are giving a very short interval of frequent irrigation, this is your wet condition being maintained and this is slightly you know the dry condition means partial moisture conditions or we can see soil moisture deficient is being maintained. So, it influenced the crop coefficient value. So, this crop when we see this is the nature of the graph when we are maintaining certain the soil moisture deficiency.

And whereas, here what we see when we are giving frequent irrigation. So, particularly we can say in the case of micro irrigation system, we are not maintaining deficit condition. We are

exactly maintaining an ideal condition where the crop does not have to go for any moisture stress. So, this is more relevant for micro-irrigation conditions. Now, the K_c value when the deficit is being maintained at initially state we find that it is more or less you know it is maintaining little slightly more than 0.2.

And when for the same initial stage we are getting almost equal to 1 or more than 1 in the initial means in the initial stage soil evaporation component is predominant. And when it comes to the crop development stage the nature of the graph you can see here, there is a considerable change in the value for crop type, humidity, or when this is being maintained.

There are a variety of crops which are being shown. So, lower the value of K_c value for short height crops say cabbage, onion, or apples as compared to the sugarcane, cotton, or maize crop. Now for the crop, in the harvesting stage or it is in a drying stage, the K_c value is reduced drastically. So, these four stages, crop growth stages are influencing the K_c value and this K_c value is influenced by the soil moisture condition and then the type of crop.

So, as it is explained here as the crop develops ground cover, crop height, and leaf area changes means leaf area index changes. Due to differences in evapotranspiration during various growth stages, K_c for a given crop will vary over the growing period. And at the mid-season stage that is the stage, K_c reaches the maximum value. So, maximum value when there is you know infrequent irrigation is being given when frequent irrigation is being given that value is there but it reaches a peak value of the K_c.

And Kc value at the end is the late-season stage that reflects the crop and water management practices. How the water management? How the irrigation is being given? Whether irrigation is being given by micro-irrigation, it is being given by surface irrigation or it is given by sprinkler irrigation.

Now, here we will be discussing about single crop coefficient approach where only K_c value is used whether K_c is combined. So, let us know that what single crop coefficient? It means and that is in the majority of literature, you may find that the single crop coefficient approach has been used. Now, in the single crop coefficient approach the effect of crop transpiration and soil evaporation, these two components are combined means it involves the K_e and the crop transpiration that is K_{cb}.

So, both are equally combined in a single crop coefficient. The coefficient integrates the difference in soil evaporation and crop transpiration rate between crop and grass reference surfaces. So, as the single crop coefficient average in soil evaporation and transpiration. The approach is used to compute ET_c, it is for a weekly or longer period. Although calculation may proceed on the daily time step.

So, here we are computing the evapotranspiration or by taking the number of days. So, particularly for surface irrigation system or to a certain extent on weekly basis for sprinkler irrigation system, a single crop coefficient approach is been used.

In the dual crop coefficient approach effects of the crop transpiration, soil evaporation is determined separately. Two coefficients are used, one is the basal crop coefficient that is K_{cb} to describe plant transpiration and the soil water evaporation coefficient which we call K_e. So, here these two components are considered and these two components are important. We have seen that at initially Stage K_e predominant at the growing stage as well as the late-season stage or mid-season stage, K_{cb} is you know predominant.

So, the basal crop coefficient is defined at the ET_c to $ET_{0,}$ where the soil surface layer is dry but where the average soil water content of the root zone is adequate to sustain full-plant transpiration. The soil evaporation coefficient K_e describes the evaporation component from the soil surface.

Now, it is the left side diagram when we see this is the generalized crop coefficient. So, the left side diagram is for a single crop coefficient means K_c initial, this is a typical graph generalized by you know crop coefficient graph which we are seeing here. So, K_c initial then K_c development, K_c mid-season, and then K_c late season means all four stages look like this.

Whereas, in a dual crop coefficient K_e and K_{cb} these two components are shown. So, K_e is predominant means the evaporation component is predominant at the initial growth stage. And then it is started you know the evaporation is started slowly reducing as the crop development takes place. It narrows down to a minimum value that is the K_e component becomes the lesser as compared to the K_{cb} and then K_e means.

So, in the mid-season and late-season stage K_e is the lesser as compared to the initial season, the initial crop growth stage. So, this is important when the crop is in the different growth stages and one needs to calculate while using.

So, general selection criteria for the crop coefficient approach it is used when we are taking a single crop coefficient. It is used for irrigation planning and design, it is used for irrigation management, it is used for you know non-frequent water applications by giving irrigation through surface irrigation means border irrigation, furrow irrigation or sprinkler irrigation where 10 day or monthly data and daily data are summed and then one can irrigation is being given.

Whereas dual crop coefficient uses the real-time irrigation scheduling data, it is used for frequent application of water like micro-irrigation, automated sprinkler irrigation system, and detailed soil and hydrologic water balance. If someone wants to use the data, in your daily water balance. So, the dual crop coefficient is more relevant for daily calculation.

Now, let us come to crop water requirements. Crop water requirement, it is the total quantity of water required by a crop irrespective of its source in a given time for its full normal growth, development under field condition at a given place. So, it includes the amount of water to mature

an adequately irrigated crop to meet the losses due to evapotranspiration plus losses during application of irrigation water means, if it is surface irrigation, there will be losses that is the if it is border irrigation, if it is a check basin irrigation there will be unavoidable losses.

An additional quantity of water is required for special operations such as land preparation, transplanting purposes if the soil has salt so we need to apply water for the leaching of salts. So, below the crop root zone, there could be some situation where of the frost control so, this is especially.

So, total water required that is aided to get the irrigation water requirement. And now, typical water requirement values for the variety of crops though it is given 1200 millimeter for rice. But it is used more than 1800 in some cases, but it depends on in which season the rice is being grown. So, the value of crop water requirement from rice to you know your field crops, field cereal crops, vegetable crops, horticultural crops as well as vegetable crops.

So, fruit crops vegetable crop all these crops which are available and these values can be used as your reference value of course. These values will vary depending on this soil, depending on the particular variety of the crop, depending on the climatic condition, where it is being grown but this can be used as a reference value or design of irrigation system.

Net irrigation requirement as the name say that it is the total amount of water required to bring the soil moisture content in the root zone depth to field capacity. So, determining the moisture content, the difference at the field capacity, and moisture content before irrigation. This difference at the different layers when we multiply with the bulk density of soil, multiplying with the depth of root zone then one can get what is the net irrigation requirement.

$$NIR = \sum_{i=1}^{n} \frac{M_{fc\,i} - M_{b\,i}}{100} \cdot \rho_{b\,i} \cdot D_i$$

Where,

NIR = net amount of water to be applied during irrigation, cm

M_{fci} = gravimetric moisture content at field capacity in the i^{th} layer of the soil, (%)

M_{bi} = gravimetric moisture content before irrigation in the i^{th} layer of the soil, (%)

$\rho_{b\,i}$ = bulk density of the soil in the i^{th} layer, g/cm^3

Di = depth of the i^{th} soil layer, cm, within the root zone, cm

n = number of soil layers in the root zone D

Now, the total soil profile, soil layer it can be given made several you know sampling it can be made. So, 4 layers, 3 layers, 5 layers that depends so i refers to the number of soil layers, and then these values can be used to find out the net irrigation requirement.

And then to get the Gross irrigation requirement. So, net irrigation requirement after we have completed, we need to divide this value with the overall irrigation efficiency. This will give the gross irrigation requirement. Now, with reference to surface irrigation as well as when we want to supply water in the command area by using the canal irrigation water, there are some certain terminologies which are used which are important from an irrigation point of view.

So, duty is one of the term which is commonly used and duty is defined as what is the amount of means the rate of flow per unit area. It can be given so, the area that can be irrigated by the continuous supply of irrigation water. So, a rate of 1 cubic meter per second of water throughout the base period this value is used and it is expressed in a hectare per cubic meter per second.

The base period is another term that is used. This is the period over which irrigation water is to be supplied for the production of any crop. Normally, this is equal to the period between the first and last irrigation applied to a crop. Delta is another term. This defines the depth of the water during crop season to be given to meet the crop water requirement and this does not have any relevance to the area of the crop field.

It is expressed in millimeters or centimeters. There is a relationship between duty, delta, and base period. So, delta means your depth of water can be related as equal to 864 multiplied by B by D. So, delta when we express in a centimeter base period when we express in days and D when we express in a hectare per cubic meter, then this is given by delta equal to 864 into B by D.

So, now in this particular lecture, we have let us summarize this particular we have covered the concept of single and dual crop coefficient. We have discussed about crop water requirement and irrigation requirement terminologies and we will be discussing about the different types of Agro-Metrological instruments used to determine evapotranspiration. So, we will demonstrate some of those equipment in the coming class.

And so, that you can have the full knowledge of how this equipment can be used for estimating the evapotranspiration as well as the other field water balanced wet measurement. It is done for determining the measurement of evapotranspiration.

So, these are the references which you can refer to your study. So, thank you very much and good day.