Micro Irrigation Engineering
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Lecture - 07
Determination of Evapotranspiration

Hello everybody, welcome to lecture 7. In lecture 6 we discussed about evapotranspiration various terminologies dealing with evapotranspiration. We also discussed a direct measurement of evapotranspiration by using Lysimeter. There are several methods, and some of them I am going to discuss in this lecture 7.

So, here we will be discussing methods, which are based on water balance, methods which are using climatological data where principle up energy balance is dealt.

So, in previous lecture 6, we discussed about different methods in which we were talking about the measurement of evapotranspiration by using Lysimeter, by taking observations, by conducting experiments, or by collecting data of soil moisture depletion and water balance. So, we will discuss some of these methods which can be used for measurement, and then there is an indirect way of estimating evapotranspiration by using climatological data, which are using the weather parameters such as temperature or using radiation or combining several weather-based data.

It can be temperature, it can be radiation, it can be relative humidity or various other parameters such as vapor pressure, relative humidity, taking the observations taking this your wind velocity or using pan evaporimeter. So, let us try to go into detail about these methods. Of course, direct measurement methods are time-consuming and the installation of several gadgets is relatively expensive.

However, they give a closer estimate or precise estimate of evapotranspiration. Whereas, in indirect methods here one or more metrological data are used, and then there are empirical equations that have been established for a specific location and they are being used widely by several researchers.

Now, when we come to the field experimental based method, in this particular method water is applied to the field and it is measured and then the changes in the soil moisture content in the field plots are measured by installing several soil moisture measurement gadgets. The amount of water which is supplied is measured by using a water meter. So, a seasonal amount of irrigation water is estimated.

$WR=IR+ ER (M_s – M_e)$

When we are using irrigation water (IR) how much amount of irrigation is being given, what is the effective rainfall (ER) which is occurring, when we are multiplying with the change in the soil moisture content means initial soil moisture content (M_s) as well as in the final soil moisture content at the end of the season (M_e). So, the seasonal water requirement for the whole crop season is estimated when we have the data measured the amount of water that has been applied for irrigation.

And then your effective rainfall which is occurring during the season. Effective rainfall means rainfall that is stored in the crop root zone depth and that is used by the plant for meeting the evapotranspiration requirement. So, this amount is used for calculating the water requirement. Then this amount is utilized to determine the seasonal water requirement.

Of course, here this method requires precision in the measurement of irrigation water. And of course, the information means of the soil moisture condition for the short term water use, how much amount of water which is stored in the soil profile, how much amount of water it has gone as deep percolation loss, all these are utilized in this information but that is not providing the full complete detail about how much amount of water it is used for using the peak moisture use rate of the crop.

Soil moisture depletion as its name gives, this method is used to determine the conjunctive use of field crop grown on fairly uniform soil and when the depth to groundwater much water is such that it does not influence the soil moisture fluctuation. This means a contribution of groundwater by capillary action in the root zone depth does not influence. It is one of the important considerations, one should use when someone wants to use the soil moisture depletion method for estimating the evapotranspiration requirement.

So, this particular method involves soil moisture measurement and the soil profile at various depths and during the entire crop season period, such data are taken. These data are utilized to estimate consumptive use. The seasonal consumptive use means we are summing the consumptive use on the monthly basis or daily basis and then total seasonal consumptive use is estimated by using the equation.

$$u = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} \times A_i \times D_i$$

Here it is given that u is the total sum of the moisture depletion in layer 1, moisture depletion in layer 2, so the total number of soil layers. Suppose, we have a 60 centimeter of the soil profile in which we are dividing it into four soil layers, 15 centimeters, 15 centimeters these four layers and then data are considered from each layer upon layer up to 60 centimeter root zone depth. Then this moisture content at the first time means at the initial stage.

And at the second after irrigation when you have given weight is given. So, at the second sampling, this difference is utilized to find out what soil moisture depletion it has taken place. Then multiplying the apparent specific gravity at a particular layer say the first layer is 15 centimeters as I told that that value will be used multiplying the depth top layer that will be 15 centimeters at layer 1.

So, that will be the amount of water it has been used for meeting the consumptive use of the crop. Like this you know for the entire whole crop season such data are utilized and then the total consumptive use for the crops region is estimated.

The water balanced method here as you can see on the right side of the diagram. So, precipitation or irrigation can be the input and then the water which is in the study area whatever it is falling. So, this water if it becomes more than the infiltration capacity of the soil. Then what happened this water appears as surface runoff and then the part of the water which infiltrates below the soil surface and then this water is causing the increase in the soil moisture content.

So, increase in the soil moisture content which is known as the soil water, and if it becomes more than the water holding capacity of the soil this water goes as deep percolation that causes the rise of the water table. So, there will be input components from the groundwater that will be the capillary water, some water it will go as percolation, some water it will use for the evaporation, water which is used by the crop for transpiration. So, the combined term is used to find out the evapotranspiration requirements.

So, precipitation and irrigation are balance with the evapotranspiration plus surface runoff and sub-surface drainage that is a deep percolation which I am telling here, and then the change in soil moisture content. So, if all the parameters which are influencing this water balance are measured except the evapotranspiration. So, that evapotranspiration value is estimated by balancing all the terms.

Now, indirect way of estimating evapotranspiration. When only temperature data are available it is Thornthwaite, he established the evapotranspiration by using the temperature data. Then Soil Conservation Service Blaney-Criddle method or Hargreaves method are solely based on the temperature data. Radiation-based data, these are Turc, Priestley Taylor, Jensen-Haise, FAO 24 radiation method using the radiation-based method and combining the energy balance means that is your radiation and temperature.

So, Penman, Penman-Monteith, and FAO 56 penmen Monteith, these methods are utilizing the temperature as well as the radiation, relative humidity as well as wind speed these data have been utilized to compute evapotranspiration. Pan Evaporimeter, is a simple method this has also been utilized to determine the evapotranspiration of the crop.

Now, let us discuss in detail about the indirect way of estimating the evapotranspiration, where temperature alone is used. So, the Blaney-Criddle method is one of the methods established as early as 1950. And this method requires temperature as well as daylight hours, how many hours of sunshine hours are available in a particular month. This daylight hour is a factor which is purely depending on the latitude of a particular place.

So, the Blaney-Criddle approach estimates the potential evapotranspiration by using the equation here it is given by

$$\mathrm{PET} = 0.46\mathrm{p}(\mathrm{T} + 17.8)$$

Now, PET is the potential evapotranspiration in millimeters per day. Which is a mean value over the month and p is here is written here it should be small p so, that is a monthly percentage of the total daytime hours of the year in a particular month. Capital T refers to mean monthly temperature in degrees Celsius, which is the average of daily maximum and a minimum temperature value.

$$\mathrm{U} = \mathrm{KF} = \sum \mathrm{kf} = \sum \mathrm{u}$$

Where,

U = seasonal consumptive use of water by the crop for a given period (mm)

u = monthly consumptive use (mm)

K = empirical seasonal consumptive use consumptive us for the growing season

F = sum of the monthly consumptive use factors (f) for the growing season

k = empirical consumptive use crop coefficient for the month (u/f)

f = value of monthly PET (mm)

So, having got this value for each month (f) so we will sum all the monthly data for the entire crop season. If the crop says it is of 120 days duration so, for each month, month 1 that is 30 days plus 30 days plus 30 days like 120 days data of these u value that is your potential evapotranspiration values are summed and then these values are obtained to get the total seasonal consumptive use (U) of the values.

Then Thornthwaite method, of course, this method considered as one of the pioneering person who brought the concept of potential evapotranspiration. And he established this method purely by taking the mean monthly temperature as early as 1948. And he established that potential evapotranspiration is exponentially related to mean monthly temperature. And the established relationship that

$$e = 1.6(10t/I)^a$$

Where,

e = unadjusted PET (cm per month)

t = mean air temperature (°C)

I = annual or seasonal heat index, the summation of 12 values of monthly heat indices (i) when,

$i = (t/5)^{1.514}$

Now, 'a' is the exponent which is given by

$$a = 0.0000006751(I^3) - 0.000071(I^2) + 0.01792(I) + 0.49239$$

Now, I is the annual heat index and this is computed by taking the temperature data, what is this temperature data? It is a mean monthly air temperature. So, for each individual these I have to be estimated that it is small i that is for each month and this will be summed up for all total months and this e is the unadjusted potential evapotranspiration.

Unadjusted means, here we are considering per month. So, a month is taken as 30 days. Suppose a particular month is 31 days, then whatever value we have estimated will be multiplied by 31 by 30. So, we will get a factor that will be multiplied by the estimated value. So, we here, in this particular method we are using mean air temperature as t, and then we are computing from this mean air temperature is small i.

And this temperature is for say we have got 12-month data. So, it is per day say January 1. So, the mean monthly temperature of January 1 will be used divided by 5 to the power 1.514 that will be the small i for January month. Then similarly for February month like this, you know up to December all 12 months i's will be calculated. These 'i' will sum up, all these small i will give capital I and that will be utilized to find out the unadjusted and then this will be adjusted and corrected value of the potential evapotranspiration will be determined.

Hargreaves method is another method. He establish the potential evapotranspiration based on the data collected from the Lysimeter which had green grass covering the entire Lysimeter. So, he proposed an equation which is given as

$$PET = 0.0135(t + 17.78)R_s$$

Now, t is the mean monthly temperature in degrees Celsius, R_S is the incident solar radiation in Langleys per day.

Now, Langley to convert in millimeters per day means these incident radiations in mm per day one has to multiply with 10 divided by the latent heat of the water. This will give the value in millimeters per day and then temperature data. We have to use it in the mean daily temperature like this one has to obtain the potential evapotranspiration.

Another method is the FAO Penman-Monteith equation. There are a large number of methods. Now I am coming to the most precise method which has been advocated by several agencies and FAO 56 method has been proposed as an accurate value that gives an estimate of reference evapotranspiration, ET_0 if you remember we discussed in previous class about ET_0. So, ET_0 is known as a reference crop evapotranspiration.

So, reference crop evapotranspiration ET_0 is given by

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where ET_0 is the reference evapotranspiration which is expressed in mm per day. R_n refers to net radiation at crop surface, which is given by MJ/ m^2/ day, and T is the mean daily air temperature at 2-meter height. This is taken as a reference height. So, the temperature measured at any other height has to be converted to a 2-meter height. Simply wind speed is also collected at any other height that has to be converted for the region in FAO 56. This conversion factor is available. e_s is the saturation vapor pressure. So, this is from the evaporating body when the ideal condition is maintained at saturation vapor pressure is measured. Then actual vapor pressure means at a given air temperature what is the actual vapor pressure that exists at any height that has to be used in this equation. And then the difference in or deficit in the saturation paper pressure that is causing the evapotranspiration is the difference in e_s minus e_a. Delta refers to the slope of the vapor pressure curve. So, this slope is plotted between e_s minus e_a with the temperature. So, this slope is practically it is given by kilo Pascal per degree Celsius and gamma is the psychometric constant. So, this is also obtained by using a psychometric chart.

So, reference evapotranspiration the ET_0 provides a standard to which evapotranspiration at different periods of the year or in other regions can be compared. Evapotranspiration of several crops can be related to ET_0. Now, this particular method can be applied in a wide variety of conditions, it can be applied in an arid region, it can be applied in the semi-arid region, it can be applied in the humid and Sub-humid region. This is the advantage compared to other methods.

Of course, there is a limitation it involves several weather parameters like you know the minimum temperature, maximum temperature, minimum relative humidity, maximum relative humidity, wind speed at 2-meter height solar radiation sunshine hour. So, several parameters are required which is one of the major limitations when someone wants to use the FAO 56 Penman-Monteith equation.

But, it gives the precise estimate of ET_0 and it can provide the basis for developing consistent crop coefficient value and that I am going to discuss in the coming lectures. So, crop coefficient also one can be used after getting the value of ET_0, and ET_c if someone has got from the experiments, then K_c can be established.

Pan evaporation method or Pan Evaporimeter, is a simple method and this is available in the majority of the agro meteorological observatory and here the pan data can be used to find out the different evapotranspiration. So, a pan is made up of stainless steel cylinder, the diameter of the pan is 120.7 cm inner diameter of the cylinder and the depth of this pan is 25 centimeters.

Then, the water level in the Pan is maintained about 20 centimeters and at one end of this particular pan, there is a stilling basin. So, whatever water is available in the pan in the stilling basin same level of water is used. So, when we are taking an observation, it does not get disturb the water level in the pan. So, the amount of water depleted due to evaporation is measured in the stilling basin by using a hook gauge.

So, the amount of water evaporating from the pan is determined by measuring the change in the water level in the stilling basin provided in the pan and correcting whatever precipitation or rainfall had occurred. So, rainfall data is measured by using the rain gauge and that data is subtracted from whatever rain had occurred during the irrigation, during the measurement period in one day, normally observation is collected once in 24 hours.

There are several Pans available. In India, we have the Indian Metrological Department (IMD) they have also established the standard size of the pan which is similar to the same dimension as per the US Weather Bureau Reclamation. A Pan Evaporimeter is most commonly used for estimating the pan evaporation. And, it is a relatively simple device inexpensive device and to determine the evaporative capability of the atmosphere.

So, the atmosphere provides energy to withdraw water in the form of water vapor from the surface. So, reference crop evapotranspiration which we call ET_0 is related to the evaporation taking place from a pan.

$ET_o = E_p \times k_p$

Now, we can say the actual value of the pan value which we are using, we are required to multiply it with the pan coefficient. So, we will discuss the pan coefficient (K_p).

So, a reference crop evapotranspiration is expressed in millimeters per day and the amount of evaporation that is taking place from a pan is given by E p and then K p is the pan coefficient.

Now, pan coefficient values one has to multiply depending on the condition in which a pan is kept. So, this particular table explains the pan coefficient for a different pan sitting and environmental as well as a different level of relative humidity, wind speed. So, FAO irrigation underneath paper 24 provides this table and this is a standard table that is followed in all the conditions.

So, class A pan was placed in a short green grass-covered area. If there is in the adjoining area, green grass and the relative humidity conditions are say if it is low humidity, if it is a medium humidity, if it is high humidity and then what are the wind speed prevailing in that particular region when the data are being collected. So, wind speed if it is light means when it is less than 2 meters per second when it is a moderate 2 to 5 if it is strong if it is very strong.

So, far relative humidity condition and then what is facing the particularly green grass it exists at this site at the particular site of the class A pan. If it is 1 meter if it is 10 meters if it is 100 meters. So, the green grass stands opposite to the side of the adjoining your pan. So, accordingly, the crop coefficient value lets say that if the relative humidity is less than 40% and the wind speed is light.

So, and then it is a short green grass it is available at 10 meters at the adjoining of the pan. The value of pan coefficient ID is 0.65. If it is 100 meters at 0.7, if it is you know 1000 meters means it is one kilometer then 0.75. If it is you know relative humidity is 40 to 70% the value if say it is

1 kilometer away then it is your 0.85 then greater than 70% for the same in all wind conditions at 0.85.

Now, if the pan is kept in a dry place fallow land the values of the value of pan coefficient will differ. So, depending on the site at which pan evaporation is kept one has to use the appropriate value of pan coefficient to obtain the value of the correct value of the pan evaporation, reference evapotranspiration. Now, this particular value of ET_0 is to be multiplied with the crop coefficient, so, as to get the evapotranspiration requirement of a particular crop.

So, let us summarize this lecture we have discussed about different methods of determining evapotranspiration and that is your direct method which is field-based, experiment-based, soil moisture depletion based, or field water balance by method. Another one we discussed about using the indirect way that it is by using the weather parameters by Blaney-Criddle, Hargreaves, Thornthwaite, FAO Penman-Monteith equation, and Pan Evaporation.

So, and then the fourth coming lecture we will discuss about the crop coefficient and how to determine the water requirement of the crop.

And you may refer to this literature in detail to get more information if you want to learn. So, these books as well as the FAO 56 which can be used as the main reference paper which is a base for many of these books, they are quoting this reference so FAO 56, FAO 24 are the two main manuals. These two manuals are the base for establishing the Lysimetric base experiment conducting or by using the different other metrological data observations. So, thank you very much and good day.