Micro Irrigation Engineering
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Lecture - 41
Sprinkler Irrigation System Design

Hello participants. Now I will discuss on lecture 41. This lecture 41 is on sprinkler irrigation system design. In the previous lecture, we discussed on the importance of sprinkler irrigation system. We discussed about different types of sprinkler irrigation system and then what are the different parameters which are considered in the sprinkler irrigation system.

When we want to install a sprinkler irrigation system, we need to have full knowledge about the area and the resources which are available there, so that the system is designed and installed in the field and we can get the best performance out of this. So this lecture 41, is on sprinkler irrigation system design.

We will be talking about sprinkler system hydraulics. We will discuss about what are the different parameters which are required for the design of a sprinkler irrigation system.

The basic aim of the design of the sprinkler irrigation system is to apply a uniform depth of water to the whole field. In the surface irrigation method even if we are trying our best, but when water flows over the land surface, the water which is at the upstream end of the field receives water for a longer period. So it gets more time for infiltration by the time waterfront it advances to the downstream end.

So we talk of the uniform depth of irrigation water to apply in surface irrigation system it is just impossible. Here in the case of sprinkler irrigation system, it is possible to apply the uniform depth of water all throughout the field. This is the main aim. We wish to apply the desired rate of application of water. Means precipitation intensity should be as per the desired application rate.

Means it should not be more than the infiltration capacity of the soil. It should be exactly matching with the infiltration rate of the soil. The second part, the breakup of the sprinkler jet, which converts to the droplet size. That causes the deterioration of soil structure and that seals the surface. So sealing of the surface is not desired. It makes compactness, it does not require.

So it is possible to bring down the water droplets in the desired size if we choose adequate pressure if we choose the appropriate size of the sprinkler nozzle. The efficiency desired to reduce energy requirements in the operating system and to maximize the area of coverage.

This is another point. If the system is designed properly, we have to choose or we will get horsepower of the pump which will require lesser energy, lesser power requirement, and lesser fuel consumption. So this way the energy requirement is reduced and also we will achieve higher system efficiency.

Now the different steps involved in the design of sprinkler system. So the number one is stated here an inventory of resources. Now inventory of resources means, how much is the land where we need to give irrigation. How much is water available. So whether it is of adequate quantity. What is the source of water? Is it groundwater, is it surface water, it is pond water, it is a flowing river, stream water, and then the type of power source available.

Whether we are using electrical energy, whether we are using the diesel operated pump, or we are using alternative sources of energy. Maybe it is solar panel, solar system we are using or we are using the wind energy. So this is falling very much under the inventory of resources. The land which we want to cultivate and bring under irrigation then how is the topography of that land.

So the area is to be surveyed. The topography elevation in the field at all the points where the irrigation is to be given we need to supply water whether it is at the highest point and that particular point is to be considered while we are designing the system. So that the water it reaches at the highest point and this point when we are considering that elevation will be considered while we are laying the lateral system. So this will help in the designing of the system. So topography map of the area is one of the important components.

Soil. The soil here what type of soil it is? Is it a fine-textured soil means clayey soil, more of the clay content? Is it coarse-textured soil like sandy soil? So infiltration rate of these soils are considered while we are allowing the water to fall over the ground surface.

So soil texture, soil structure, and then the nutrient aspect of the soil is also equally important. Whether we need to apply some certain chemicals along with the irrigation water, so this part also we need to consider. Then source of water as I told you that what is the source, surface water, and groundwater. Quantity, whether the how much amount of water it is available.

Accordingly, we will plan to apply for irrigation purpose. And then the quality of water. Quality is equally important, whether it needs treatment before it is brought for irrigation. So quality or it is sediment-laden water. So before it is introduced to the sprinkler irrigation system we need to apply a gravity system or we need to apply an adequate filtration system before it is brought for irrigation.

So there are different ways to analyze the water quality which already I have discussed in the water quality part. So we will discuss about this part. Then the quantity of water to be applied. What is the quantity of water available in the first point I discussed. Second point, how much is the demand. So demand will be worked out after knowing the evapotranspiration requirement of the crop.

Now, the ET of the crop will depend upon which season the crop is being grown. Is it a summer month, is it winter month, and is it the rainy season. So this is going to affect the evapotranspiration requirement of the crop and also depending on the type of soil and then the sensitivity of the crop, the irrigation schedule will be prepared.

Now water which is coming out of the sprinkler nozzle. Since it is a rotating sprinkler nozzle, it is forming a circle. So the maximum coverage is attained when the jet coming out of the sprinkler nozzle is at an angle between 30 and 32 degree above the horizontal. And normally 30 degree is used for rotating at a sprinkler system.

The empirical relationship to obtain the radius of the wetted area can be estimated by using the expression

$R = 1.35\sqrt{dh}$

Where,

R = radius of the wetted area covered by sprinkler (m)

d = diameter of nozzle (mm)

h = pressure head at nozzle (m)

So this can be obtained empirically. While we will conduct an experiment on the performance evolution part you will also find out what is the radius of coverage.

A typical sprinkler system when it is sprinklers are laid are connected with the lateral. So you can see here this is one lateral. Now, this lateral is connected to this part let us see. In here water is taken from some source with the help of a pump. And it is supplied by using a mainline and on this mainline, the laterals are attached. One lateral is here, another lateral is here and then laterals are moved forward.

So when a sprinkler is operating it performs a certain percentage of overlap. So this is the typical water distribution pattern from a single sprinkler. Now the other sprinkler which is kept at a certain spacing let us say it is at 50% of the diameter of coverage, the other sprinkler is kept. So the wetting is formed by the secondary sprinkler. So this is the common area.

The water which will be received at this part of the circle, it will be the water which is distributed by this sprinkler and also water distributed by the second sprinkler. And this part what you are seeing there will be meant here again what we are seeing here at this particular place the water is being received by three sprinklers. Such type of overlap will occur. So a single sprinkler when the water is being distributed you see how the wetting means soil moisture movement from a single sprinkler it will look like. So more water is available beneath the sprinkler head.

A discharge of the sprinkler nozzle is estimated by

$Q = CA\sqrt{2gh}$

Q = nozzle discharge (m^3 s^{-1})

A = cross-sectional area of nozzle, (m^2)

g = acceleration due to gravity (m s^{-2})

h = pressure head at nozzle (m)

C = coefficient of discharge which is of function of friction and contraction losses (= 0.8 to 0.98)

So this way we will calculate, one can get how much is the discharge from a single nozzle. Now the discharge from the single nozzle means it will depend upon how much is the diameter of coverage. The selection of sprinkler will depend on what is diameter of coverage, what is the pressure available means nozzle pressure because this is your h, it is given and then how much is the discharge coming out of the sprinkler, which is a function of h and of course wind condition. This is also that whether wind in that particular place it is a calm wind place or it is in the coastal zone where the wind is a major problem. So one has to use these units to get the discharge from this and the selection is made by considering these points.

Now when we come to the design of laterals, lateral receives water from the main pipeline and also from the sub-main pipeline. And then on the lateral risers and above the riser sprinkler heads are mounted. So means sprinkler lateral is connected to the main or if it is a very large area there can be a manifold and then on the lateral risers, a riser is a smaller pipeline over which the sprinkler is placed and then on the riser pipeline, a sprinkler nozzle is mounted.

Now design capacity of the sprinkler on a lateral is based on the average operating pressure. This is where we are taking care that what is the operating pressure which is available on the sprinkler. So if we want to find out first of all we will find out what is the average operating pressure in the sprinkler system.

So here the lateral means we need to take care the frictional loss in the lateral pipeline is 20% of the average operating pressure. So average operating pressure you can see here, it can be estimated by the pressure at the farthest sprinkler. Now, let us see this is the case. There is a main pipeline which is perpendicular to the board, you can see here and on this main pipeline, the main pipeline is receiving water from the pump. And then on the main pipeline, the lateral has been attached. In this particular figure what we are seeing that the lateral is kept at a certain elevation. Means it is going up the hill. The pressure profile it is lateral is laid up the hill means it is on the elevated land. And on this lateral sprinklers are mounted.

So sprinkler this is one sprinkler and means this is one riser pipeline and on this riser pipeline, the sprinkler nozzles are mounted. Now you see this is the last sprinkler. And at this last sprinkler, the pressure available is H naught. This is the H naught pressure. And somewhere the average pressure means we are measuring it somewhere at this point that means not exactly at the end of the pipeline, but we are considering somewhere at the 25% of the distance from the extreme end. And this average pressure is measured. So this is given by Ha. That is the average pressure.

$$H_a = H_o + \frac{1}{4} H_f$$

So H naught equal to 25% of the head loss due to friction.

Now if we are considering suppose this lateral we are, it is placed here on the elevation but if it is this particular lateral is on the level land. So what will happen? The pressure available, the pressure available in the main pipeline means what will be the pressure available in the main pipeline, it will be the pressure required at the last sprinkler plus head loss due to friction. This means the Ha means your average pressure at the end, which will be given by

$H_n = H_o + H_f$

Now design of the lateral, what we are doing here, we are substituting, let me just tell you that we are substituting, we can write here

$$H_n = H_a + \frac{3}{4}H_f \pm \frac{3}{4}H_e + H_r$$

Where,

H_a = Average head at the sprinkler lateral (m)

H_0 = pressure at the sprinkler at the sprinkler on the farthest end (m)

H_n = Head at the main (m)

H_f = Friction loss at the sprinkler lateral (m)

H_e = Maximum difference in elevation between first and last sprinkler on the lateral (m)

H_r = Riser height (m)

So this particular expression, it is taking care of the average pressure. It is taking care of the head loss due to friction and then plus-minus 3 by 4 He this is here it is a He that is the elevation. So elevation is the head at the elevation it is you can see here the maximum difference in the elevation between the first and the last sprinkler. Let me just show you the diagram. Here this is the first sprinkler on this one. So what is the elevation? Means suppose sprinkler is somewhere here and this last sprinkler.

So this is the elevation difference that is He. Now 3 by 4 He because we are taking at this particular place. So we are putting it 3 by 4 plus minus 3 by 4 He because at this point we are considering. So we have taken here 0.3 this is plus-minus 3 by 4 e. Now, plus means there is what happened when the sprinkler lateral is running uphill. So this we will consider. So here the Ha means this is your the value that is average head at the sprinkler, H naught is the pressure at the farthest end of the sprinkler and Hn is the head at the main. This is your Hn. Hf is the head loss due to friction in the lateral. He, as I told you this is the elevation difference, and Hr is the height of the riser pipeline.

Means this pipeline. If we are here it is given Hr that is the height of the riser. This is the riser pipeline. So this has been added. Now if suppose the riser if suppose we are not putting riser. In the lateral itself these sprinkler nozzles are attached. Then Hr will be equal to zero.

So by solving the equation means we are putting it H naught has been this H naught is written in terms of Ha and then Ha can be written like this. 3 by 4 He is positive when the lateral is running up the hill and it is negative when it is down the slope. So this would be 3 by 4 He. Now the size of the main pipeline the size of the main pipeline is a function of the rate of flow and frictional losses.

The diameter of the main pipeline is selected such that the normal means water application cost is low. This means the size of the main pipeline is what happened because the main is supplying water to the laterals. So depending on the number of laterals, it is receiving water from the lateral. So one lateral so multiplied by the number of lateral.

So that will be the discharge from a single lateral that will be considered and discharged from the multiple laterals. So this particular lateral should take the total flow. So here it is another part that is one has to optimize that how many number of laterals that can be operated. If we take all laterals to operate at simultaneously then the size of the pipeline will be large, size of the pipeline will be large.

And then the head loss due to friction will be computed in the same manner as we are calculating in the case of lateral. So here we will be taking the same case. Now, normally head loss in the main is taken as a 3 m. Means head loss to friction is taken as a 3 m for a smaller system, particularly for Indian landholding. So 3 m is considered as a head loss through friction but one has to calculate. And then 12 m is the means the head loss due to friction. It is considered for a very large farm where the large area it is being used for cultivation of the crop.

The next party height of sprinkler riser pipeline. When we are considering the height of the sprinkler riser pipes, sprinklers are located just above the crop to be irrigated. Therefore, the height of the riser will depend on the height of the crop. This means the water which is emerging out of the sprinkler nozzle should not be interfered by the crop.

So the height of riser pipes should be above the crop and then particularly some crops some plantation it interferes, then we need to raise the height of the riser pipe, such riser pipes should be provided with a tripod so that it remains stable, it does not fall when water is being supplied by the riser pipe to the sprinkler nozzle because it is vibrating.

So it should be properly erected by putting the tripod. To avoid excessive turbulence in the riser pipe minimum length is normally 30 cm or even 1 m that is one means of 25 mm diameter that is used. So 30 cm for the smaller crop. But for the crops like sugarcane, it would be large. But normally the pipelines, riser pipeline, and sprinkler is of 1 m in size.

Sprinkler spacing, the sprinkler's distribution uniformity depends on the operating pressure, wind velocity, rotation of sprinkler, and spacing between the sprinklers and laterals. So spacing is another part that has to be taken that is how much is the pressure and then what is the wind speed. And then the spacing between the sprinklers on the lateral means the spacing of the sprinklers along the lateral that is also taken care. Adjustment of the sprinkler and spacing should be made or there should be provision so as to achieve maximum uniformity. In general, the depth of water near the sprinkler is more and gradually it decreases when the sprinkler jet goes out of the circle, which means outer circle.

So while we decide the sprinkler spacing, one important point is wind speed. It affects the water distribution pattern. So overlapping is provided in order to get better uniformity. So overlapping of the spray pattern of the individual sprinkler is required to get the uniform depth of water coverage. So here you can see when there is no wind so the spacing is of 65% of the water spread area is given. When the wind speed is 0 to 6 km per hour, 60% of water spreads. 6.5 to 13, 50% and then greater than 13 km this is 30% of the water spread. This means as the wind speed increases the spacing between the sprinklers decreases. So there is more closure. So the arrangement of the sprinkler is done so as to increase the water spread area overlap. But if there is a wind of considerable speed the spacing between sprinklers gets reduced.

Now sprinkler discharge considering the area of coverage. So selection depends on the wetted diameter of the nozzle, due to the nozzle at a given operating pressure nozzle and then the combination of sprinkler spacing lateral moves and application rate, suiting to the soil and wind condition. The required discharge of an individual sprinkler is a function of the water application rate and two-way spacing of the sprinkler.

Two-way here spacing of sprinkler along with the lateral, spacing of the sprinkler along the main. So discharge from an individual sprinkler is given by

$$q = \frac{S_l \times S_m \times I}{3600}$$

Where,

q = required discharge of individual sprinkler ($L\ s^{-1}$)

S_l = spacing of sprinklers along the laterals (m)

S_m = spacing of laterals along the main (m)

I = optimum application rate ($mm\ h^{-1}$)

So depending on the type of unit which we are using if it is in means, I application rate is millimeter per hour and Sl is the spacing of sprinklers along the lateral is Sl and Sm is the mean spacing of the lateral, spacing of laterals along the main or spacing of the sprinklers along the main. That way also it can be told.

The same thing which I told here is that the application rate it is to be given in such a way that it does not form runoff. And application rate will depend upon the particular type of soil texture and the depth of soil. It will also depend upon this land slope, prevailing land slope.

So the soil texture is coarse, means if it is let us say coarse sandy soil and then application rate it is given 5.1 mm per hour and we keep on reducing the size means your texture means the soil particle it is reducing. This means when coming to the very fine texture soil the application rate it is decreasing. So this is the purpose. It is explained here that when we are selecting a particular type of application rate, we need to see that what the application rate is.

Here is another table it has been provided. The slope is one part and also the type of soil and then the above land surface. Means values based on the infiltration capacity of the soil, based on that it has been decided. So if you can see here the units are in inch per hour. This unit is an inch per hour. And these are the prevailing land slope.

So if it is a say soil surface is not protected means bare land. We can say bare land, but if it is light sandy soil for bare land, the application rate is 0.5 to 0.75% for the land slope in the range of 0 to 5%. For the same soil, you can see when there is a residue or heavy grass cover the application rate can be increased for the given same slope. And then for the same slope when you see with the different soil texture without means so it is medium textures soil with sandy loam, fine sandy loam, and silt loam, this is the range. And then for a heavy texture that is the clayey type of soil that is 0.1 to 0.25. So this way one has to decide the value.

So the equation which I was telling you Q is equal to Sm into Sl multiplied by I divided by 3600. So these values have to be chosen. And this is since it is in inches per hour. So this will be multiplied and brought in the terms of a millimeter per hour that value can be used. The capacity of the sprinkler system means one has to decide what should be the discharge capacity of the pump. So this discharge capacity of the pump will depend upon how much area to be irrigated and what should be the depth of irrigation and then the number of operating hours.

$$Q = 2780\frac{A\times d}{F\times H\times E}$$

So the area in hectare means when we are expressing Q in liter per second. So crop area in a hectare, depth of water application in centimeter and then what is the irrigation interval. This means how many days one irrigation cycle will be completed. And number of hours the system is operating and then water application efficiency. So having got this value, one can find out the system capacity. Now, this system capacity can be matched with the total discharge a mainline has to handle.

Now I have given you in the previous in this particular slide, where I talked about the head loss due to friction. If you see this particular slide, where head loss due to friction has come. Now this head loss due to friction can be estimated just I estimated by any one of those three equations. And which has been explained in the design of the drip irrigation system. So this is a generalized equation where head loss due to friction can be computed by using this equation

$$H_f = \frac{K\times c\times L\times Q^m}{D^{2m+n}}\times F$$

Where, K is a unit constant, c is another constant that is to be used for a particular equation. L is the length of the lateral or pipeline you can say and Q is the discharge to be handled by the pipeline. It could be a lateral pipeline. It can be the main pipeline. It can be sub-main pipeline and D is the diameter of the pipeline. And this capital F is the reduction factor. This capital F is the reduction factor.

So reduction factor already we have discussed and depending on the type of the unit which we are putting it, one can use a particular value of the reduction factor. So one can use the particular value of constant. So let us say that is small c which is there for the Darcy-Weisbach equation so 277778. Then L is the length of the pipeline and M will be in the case of the Darcy-Weisbach equation if I am using the metric means SI unit then this is m equal to 2. And n if I am taking the Darcy-Weisbach equation this is 1. And the D is the diameter in millimeter. Accordingly, the value and K is the particular unit constant.

So that K will of course has to be obtained by using appropriate expression say in the case of Darcy-Weisbach equation we will be using this equation. And f is to be obtained from the Moody diagram. And this is for the Hazen-Williams equation. This is for the Scobey formula. So accordingly the value of the K will be obtained.

Now to find out what will be the head which will be required for the pump to operate? So this total head against which the pump will operate will be the head required that is

$H_t = H_n + H_{ft} + H_j + H_s$

Where,

H_t = Total design head against which the pump operates (m)

H_n = Maximum head required at the main to operate sprinkler on lateral at the require average pressure, including riser height (m)

H_j = Elevation difference between the pump and the junction of the lateral and the main (m)

H_s = Suction head (elevation difference between the pump and source of water) (m)

Now having got the value of the total head requirement, this can be expressed the power requirement in kilowatt can be expressed by 9.8 into the discharge that is Q which we require to operate the main pipeline. So this is the total discharge in meter cube per second. And this Ht just now which I told that is the total head requirement. And Ep is the pump efficiency.

So this is the pump power. Now, this pump power can be expressed in the terms of horsepower that is

$$kW = \frac{9.8 \times Q \times H_t}{E_p}$$

Where,

kW = input power delivered to pump (kW)

Q = discharge rate (m^3s^{-1})

H_t = total head (m)

E_p = pump efficiency (decimal fraction, 0.6 to 0.7)

Then horsepower of the pump can be given by this your kW by 0.746 multiplied by the drive efficiency.

So you may refer to these reference materials for this particular topic. And then let us try to summarize the whole lecture. We discussed about different design parameters. We discussed about the hydraulics flow through the lateral pipeline, hydraulics flow through the main pipeline, and then total the how the water is the water horsepower, pump horsepower can be estimated. Now in the forthcoming lecture, we will discuss about evaluation of a sprinkler irrigation system. Thank you very much.