Micro Irrigation Engineering

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Lecture – 42
Performance Evaluation of Sprinkler Irrigation System

Hello, participants. I invite you to Lecture 42 of the Micro Irrigation Engineering course. Lecture 42 is on the performance evaluation of a sprinkler irrigation system component. System component here, one of the components which I am considering is the sprinkler head. Any system or particularly with respect to the sprinkler irrigation system, we are interested to evaluate its performance. So, that system can be installed and it can work as per the desired capacity.

So, this particular component whether it is working satisfactorily and this is one aspect to evaluate satisfactory working of sprinkler component. Another one is to design the system as it is behaving, as it is performing in the field. Accordingly, operating pressures, the spacing between the sprinklers, and the application rate of the sprinkler nozzle can be decided and it can be operated.

So, mainly in this particular topic, we are going to cover the evaluation of sprinkler parameters. And we will work out the data collected from the field. How the various evaluation parameter, performance parameters it can be estimated?

When we talk of the performance of a sprinkler nozzle, so, sprinkler nozzle when we say nozzle is evaluated for its application rate and its suitability with respect to the infiltration capacity of the soil. So, primary factors are important parameters we can say which influence its operation. One is operating pressure and another one is nozzle geometry. These 2 are the important factors that affect the water application rate.

When we say, how much is the discharge which is coming out of the sprinkler that will depend upon the operating pressure. Nozzle geometry, I mean to say what is the diameter of the nozzle opening? What is the shape? Whether it is a circular shape? Whether it is a rectangular shape nozzle? Or, it is a square shape nozzle. So, water emerging out of the sprinkler nozzle is going to be influenced by the shape of the nozzle opening.

And then angle, at what angle of throw, the jet which is emerging out of the sprinkler nozzle at what angle it is emerging. So, how the particular nozzle angle is fixed at the time of manufacturing? Now, the parameters which are evaluated for any sprinkler irrigation system, it is evaluated based on the, what is the discharge from a sprinkler? How much distance it is throwing?

How the sprinkler nozzle it is distributing the jet when it is getting broken? And then how its movement takes place. How the distribution takes place? What is the size of the droplet? How much is the application rate for a given pressure? And then, we want to evaluate, how uniform water it has been sprinkling or distributing out of the sprinkler nozzle. So, how it is uniformly distributing the water droplets which are falling? So, there is one specific index which has been prepared that is uniformity coefficient.

Discharge from a sprinkler is a function of the diameter of the nozzle and operating pressure. These 2 are the important thing and C is the coefficient of a discharge. The discharge from a sprinkler nozzle, normally the sprinkler nozzle geometry is circular in shape and looks like an orifice and therefore it is orifice flow. So, the value of x is approximately equal to 0.5, i, which here it is given that is the number of sprinkler nozzles or sprinkler head that i varies from 1 to n.

So, total discharge from a system is estimated by using this expression

$$Q = \sum_{i=1}^{n} K \, . \, C_i \, . A_i \, . P_i^{xi}$$

Where K is the constant that depends on how many number of sprinklers it has been used. And of course, they, another one is that what is the unit which we are giving? Say we are putting it in centimeter or millimeter or we are putting here it is also in kilopascal. So, according to the unit, the value of K will change. And also the discharge can be expressed in meter cube per second, liter per second. Normally, these 2 units we are using.

This is one particular company's pressure discharge relationship. So, when we are giving pressure from a sprinkler nozzle, which is expressed in pound per square inch. And these are the 2 diameters. One diameter is for the range nozzle. The diameter of the range nozzle is 3 by 32 inch. And 6 by 64, 6 by 64 is for the spreader nozzle. So, particularly this nozzle, there are I mean there are twin nozzle system and this twin nozzle when suppose it is operating at 25 psi. That is 25 pounds per square inch. It will deliver a 1.2 gallon per minute discharge. So, like this for different pressure the discharge table, it is supplied by the manufacturer. It is available. Or else, one can calculate the value of the discharge.

Now, the distance of throw, this is one parameter which I told the distance of throw it governs the spacing between the adjacent sprinkler means a distance of throw will depend upon the pressure. More the pressure more will be the distance of throw. So, we want to have better or uniform coverage of this sprinkler jet that is coming out of this.

So, we will decide what should be the spacing between the sprinkler nozzles along the main as well as along the lateral. So, that way it is decided. Normally, this distance of the throw is published by the manufacturer. And manufacturer gives the leaflet where operating pressure, what is the diameter of the nozzle for a given diameter, how much is the distance of throw for different operating pressures and nozzle sizes, so, that information is available.

Distribution pattern, how the water is being distributed. So, the distribution pattern will depend upon the operating pressure, nozzle geometry, wind speed, etcetera. There are several things that are influencing the distribution pattern. A wide range of droplets caused by the higher operating pressure results in a triangular shape distribution pattern in which the depth of application increases linearly from the outer edge of the pattern towards the sprinkler. Varying nozzle means nozzle angle affects the pattern that is a wetted area and then means the pattern shape.

Now, here what we are seeing is the distribution pattern. I was telling you that when there are different operating pressures and when the pressure applied is low, you see here that the sprinkler is at this particular point and then water is distributed. So, in some places, it is more, larger depth and then immediately adjacent to the sprinkler, 0 refers to the sprinkler head is at this place. And then, either side of the sprinkler means it is on either side what you find that the water is being distributed by the sprinkler head which is located here. And in this side as well as this side you find symmetry. So, water distribution here the depth of water is more. It is low. So, this is why it is so because of the low pressure. When optimum pressure is given or ideal pressure is maintained, you will find this is a typical water distribution pattern from a sprinkler.

So, more is the depth of water at the center or where the sprinkler nozzle is available because the spreader nozzle is distributing more amount of water nearer to the sprinkler. And as we go further from the sprinkler on either side. So, we find that this depth of water is less. It is reducing. But this is ideal and we are required to give appropriate overlap so that the uniform depth of water can be maintained. Here, in this case, when the pressure is very high you find that this type of shape it maintains. So, the distribution of water, ideal distribution of water is this one when the optimum pressure is maintained.

Droplet size is also influenced by the operating pressure. And it affects when the droplet size is large, what happens, it causes the impact on the ground surface means water droplets that resemble like rainfall. When the droplet size is more, what will happen, it will restrict or will make the formation of the seal. So, it will have a sealing effect. And that will cause higher runoff, as well as, soil erosion will take place. So, nozzle opening shape and operating pressure is going to affect the droplet size as compared to the nozzle angle.

Application rate from a sprinkler nozzle, it should be such that, it does not form runoff. It should be less than the infiltration capacity of the soil. The average application rate of an individual sprinkler is given by

$$I = \frac{360 \times Q}{A}$$

Where,

I = rate of water application (cm h^{-1})

Q = sprinkler discharge (L s^{-1})

A = wetted area of sprinkler (m^2)

If we are expressing Q in liter per second and area wetted by any sprinkler it is in a square meter, then we need to multiply with 360 to take care of the unit constant. When there are several identical sprinklers, they are placed in a field, and then the sprinklers could be a square pattern. It could be a rectangular pattern. That L suppose is larger than the S then it is going to be the rectangular pattern. If L is equal to S then it becomes a square pattern.

Now, application rate when there are several identical sprinklers are in operation then one can find out, what is the application rate? So,

$$I = \frac{360 \times Q}{L \times S}$$

What is L? L is the distance between the sprinklers along the lateral. S is the distance between the sprinklers along the main. So, the application rate is estimated like this. The higher the application rate, the more will be the runoff. Poor water distribution and loss of water are going to take place.

The other important parameter of evaluation is the uniformity coefficient. It is an index to measure the uniform depth of water application. And it is affected by what is the pressure, what is the size of the nozzle, and what is the spacing between the sprinkler it has been kept? And, whether there is an ideal wind condition calm wind condition exist? Or, if there is more wind speed. So, it may cause the drift. Wind may cause the drift in the water distribution pattern. So, we need to take care while we are deciding the spacing between the sprinklers depending upon the application rate, depending on the operating pressure. So, that is going to make the difference in the value of the uniformity coefficient.

Now, in order to estimate the uniformity coefficient, it is the Christiansen in 1942, gave this expression and this expression is still valid. So, this is an important parameter to evaluate the sprinkler uniformity coefficient. What is the sprinkler uniformity coefficient? It is given by

$$C_u = 100\left(1.0 - \frac{\sum X}{mn}\right)$$

Where,

m= average value of all observations

n=total number of observation points

X= numerical deviation of individual observations from the average application rate

So, we will say suppose we have got 15 number of sprinkler depth observations. So, what we will find out from the 15 depths of sprinkler observation that has been collected, we will first find out the numerical average, the arithmetic average of these values. So, 15 values, the sum of the depth divided by the number of observations will give you the average value of all the observations.

Now, from there, actually whatever average we have got, so individual values, so, xi that is x1 minus m will be the one value that is one deviation. Then another deviation will be xi. That is x2 minus m, x3 minus 1, like this you know x15 minus m. And then we will take the difference values. Sum of deviations of that value. And then that is taken as an absolute value. So, those sums are will be used to find out the numerical deviation. And that is divided by m into n. If we find from the observation it is equal to 85% or more than 85%, it is considered satisfactory. And if it is more than 90%, then it comes under very good performance.

Now, the various parameters which are used to evaluate sprinkler system that for a given operating pressure, what is the discharge coming out of the sprinkler? So, this is given by

$$Q = C.\ a.\sqrt{2gh}$$

What is C? C is the coefficient of discharge which is a function of friction as well as contraction losses. Small a is the area of cross-section of the sprinkler nozzle. If it is circular then we can simply write pi d square by 4; h is the operating pressure. If you are expressing everything in meter means a, you are expressing in square meter and then if you are putting h in meter then the corresponding discharge will be in meter cube per second.

Now, the water spread area of the sprinkler. So, when a sprinkler is being operated. So, once it is operated it gets this stable value. One needs to find out, what is the radius of coverage?

So, this radius of coverage, this particular radius of coverage is wetted area. This is R. That is given by capital R. And so, the water spread area of the sprinkler is given by

$A = \pi R^2$

Now, this R is nothing but the radius of the wetted area that has been given by Cavazza and Pillsbury 1986. They have got an empirical relationship and that empirical relationship has been used.

$R = 1.35\sqrt{dh}$

Where d is the diameter of the sprinkler nozzle.

Now, another parameter one can evaluate is the break-up jet index. Break-up jet index, basically it is giving that at a given operating pressure when the sprinkler nozzle, the particular jet it appears, so it hits on the arm, and that hitting on the swing arm which deflects. So, it guides the water to flow through that is smooth. But it hits and that starts the break-up jet droplets. So, those droplets, break-up jet is evaluated by this expression.

$P_d = h / (10q)^{0.4}$

Where h is the operating pressure, q is the discharge in liter per second. So, this Q is a capital Q which is expressed in cubic meter per second. Here, this q is also in the discharge form. And then it is given by liter per second.

Now, the values of Pd because h if you know and q you know, then you can find out, what is the Pd? Now, if Pd that is a break up by jet index is given by Pd if it is greater than 2 that condition of the drop size is good means it is acceptable. It is good. If it is a Pd equal to 4, the condition of the droplet size is best. And then if the Pd is greater than 4, then pressure is being wasted. Means electricity or any energy which we are using for operating the sprinkler, we are wasting the energy because the operating pressure it is at the higher side. The other part of the evaluation is the uniformity of application.

$$C_u = 100\{1.0 - \frac{\Sigma X}{m \times n}\}$$

So, this part already I have told you.

Now, we will demonstrate to you how the observations, parameters which I have told how they are to be determined, how to find out the emission uniformity, how the data should be collected? So, I am just giving you an experimental procedure and then we will operate one sprinkler head in the field that you will also study and learn from that. We want to perform an evaluation test so, a sprinkler system should be installed at a desired location in the field. Note down the specification of the pump coupled with the electric motor. Observation on the wind means that is a climatic observation we need to collect for taking the observation. With respect to a sprinkler system, and we want to find out, what is the capacity of the sprinkler system? What is the discharge of the sprinkler system? So, we need to conduct the test.

So, first of all, we will be dividing the whole field into square grids and then at the center of each grid, one plastic can will be kept. And then what happened, normally, these cans should be placed 2 meter apart for a smaller spacing in emitters or drippers or sprinklers whatever we say. So, means for a smaller set that is 2 meter apart it should be done when the spacing is 10 meter apart. 3 meter when we are putting it is for the larger spacing sprinklers.

Means when we are bought a larger farm area then we want to operate all the sprinklers at a stretch. In that case, such provision should be there if it is for a larger spacing. The grid should cover the entire area of the sprinkler area, theoretically, it should be. Otherwise, if there is no wind condition exist, this is done for the entire area. When there is wind or some kind of field is going means the data are going to be affected. So, it can be also done that we are taking half or one-quarter of the field. One-quarter of the circular field because the sprinkler rotates. So, it makes one particular circle that is 360 degree. Now, if you are putting a particular angle that is up to 90 degree, up to 180 degree we should evaluate.

So, the procedure, it remains the same. Process procedure will remain the same. Types of the data will remain the same. Only thing you will be getting the number of observations will be different. The number of observations will be half. Why we can do in the half. We assume that it is in the ideal condition. So, whatever data we are collecting such data will be replicated in the other side. The can grid should be covered the entire area.

We will note down the observation of the range as well as the sprinkler nozzle as their sizes, operating pressure, and then corresponding discharges. That relationship already you have studied that Q is equal to C into a into root 2gh. So, the operating pressure and discharge relationship is required. Pressure is measured by using a pressure gauge which is fixed on the riser pipeline, or, using a Pitot tube also these data are collected. That is the pressure and discharge data can be collected.

Now, discharge is measured by connecting the physical tube on both the nozzles which are sprinklers major range nozzle, as well as, the sprinklers spreader nozzle. So, this data which we are collecting with the help of a tube, the discharge is collected in a can and then for a given period, we will convert the discharge means precipitation intensity form that how much is the amount of water it has come out. So, either we can say in the volumetric form or in the depth-wise form also it can be converted. And then one can know, what is the precipitation intensity? Like this, we will collect the observation on radius and water spread area. Then we will repeat the observation for the different pressures to achieve desired uniformity coefficient of 85% or more. So, we need to operate for the other pressure till we are not getting the coefficient of uniformity more than 85%.

Now, these are the observations that we will be collecting. The observations on the pressure of the water at the nozzle, the discharge of a smaller nozzle, discharge from the large nozzle, the diameter of small nozzle, diameter of a large nozzle. These diameters are used to calculate the discharge from the smaller nozzle as well as the larger nozzle. So, this is a measurement we have done. Wind speed is measured by using the anemometer and then wind direction. So, we will note down, what is the wind direction? And then, the temperature, what is the ambient temperature? Relative humidity, pump size in hp, what is the inlet diameter of the pump? What is the outlet diameter of the pump? The discharge from the pump, all these data are useful. And this can be given.

So, like this for serial number one means basically it is the row and column. At the center of, these row and column that particular location, one Can can be kept and observation can be obtained. So, O1, O2, O3 are the lines on where the cans are placed. And O is the center of the sprinkler over which the sprinkler head is kept. So, after getting those data as I told you that we will find out the xi minus x bar, sum of xi minus x bar that though so, this sum will come total of all the values and then one can calculate, what is the emission uniformity?

Now, we are conducting a test in the field. Here, we are demonstrating to you a sprinkler irrigation system. So, the sprinkler irrigation system also uses a pump which creates an adequate amount of pressure. So, water is being lifted from the source since it is a demonstration unit and used for testing a sprinkler nozzle. So, here it is a small tank where the water is stored. And then there is a pump. You can see here at this place there is a pump.

And this pump is coupled with an electric motor. Now, at the suction end of the pump, there is a flexible pipeline where the water is being taken. At the lower end of the pipeline of the suction pipeline, there is a foot valve. So, the foot valve, the purpose of the foot valve is to retain water. So, first the suction pipeline it is filled up with water up to the filling the impeller so that it does not take the air.

Whatever air is available in the pipeline, will be removed when it is filled up with water and then water means it is used for priming. So, a foot valve you can see here at this end, there is a flap it has come out. And when we are filling water then this particular valve it gets closed this is the purpose of foot valve. Then the water is taken. This is the delivery end of the pump which is connected and then it goes to the main pipeline and at the appropriate location, sprinklers are attached. We have taken water from the delivery end of the pipeline. So, the main pipeline of adequate diameter, normally, these pipelines are of 2 inch, 2 and a half inch, or 3 inch in diameter. And each pipeline is of 3 meter, 6 meter or 9 meter long. So, here, we have taken water from the main pipeline and then with the help of a 90-degree bend, a lateral pipeline has been joined.

Now, as I told you that there is a coupler at an appropriate location. A coupler is used to attach sprinkler at a place where we want to give irrigation. So, this is one coupler in which one lateral pipeline will be attached with another lateral pipeline. And on this coupler, you can see here that on the coupler, there is a riser pipeline which is of 1-inch diameter, 1 meter long, and this end is connected with a pressure gauge. A pressure gauge is connected here to know, what is the operating pressure of a sprinkler head?

Now, a sprinkler head here you are seeing. This is a sprinkler head which is made up of an alloy where there are 2 nozzles. These 2 nozzles are discharging at a given pressure. And one nozzle is a range nozzle. Another this particular nozzle is a range nozzle. The other nozzle is the spreader nozzle. This is the counterweight and here there is a spring. So, when the water it comes, the spring compresses and then a torque is created. So, because of this torque, when the jet will come, it will hit. So, once it is hitting, then it deflects. And deflection causes the sprinkler head to rotate. So, this way, it takes the ones particular sense circle.

Now, we will be monitoring the pressure. At a given pressure, how much is the discharge coming out of the sprinkler? So, there is a relationship which I have already explained to you that discharge from a sprinkler nozzle is directly related with the operating pressure which is the square root of the operating pressure. So, we will find out, what is the total discharge? Means, discharge from this nozzle plus discharge from this nozzle, both the nozzles will be operated to know that how much discharge we are getting at a given pressure.

From that data, we will also find out the coefficient of discharge from these 2 sprinklers because we know the operating pressure. We know the discharge. We know the value of g. So, we can find out the coefficient of discharge. In order to measure the discharge from both the nozzles, 2 pipelines which were fitted with the nozzles. Now, the total volume of water is being collected in 10 seconds. And then, we will find out the volume of water collected in 10 seconds will give the discharge at 1 kg per square centimeter.

Yes, this is the discharge from another nozzle. So, individual discharges we have collected in 10 seconds, and then using this data, we will find out the coefficient of discharge for each nozzle. That is the range nozzle as well as the spreader nozzle. Now, we can see that in how much time it takes to take 1 round. So, the sprinkler revolution in per minute, it can be found out. So, this is one observation it is, to be used. Another observation what you see there are measuring cans. So, the depth of water which is collected in a given time, these depths of water will be used to find out the uniformity of water distribution. Then another observation which you can see here, what is the diameter of coverage?

So, a diameter, this is the radius. It is being measured that how much is the wetting radius from the nozzle which is, when the sprinkler nozzle, it is operating at 1 kg per square centimeter. So, we are measuring operating pressure. We are measuring the volume of water then discharge. Then, we are measuring, what is the diameter of coverage of wetting diameter? We are measuring the depth of water collected in the cans. These depth of water collected in each can is used to find out the coefficient of uniformity, that formula which already I have explained in theory class and we have worked out a problem in the tutorials.

Now, this sprinkler problem basically is a numerical example, it has been given where one can evaluate emission uniformity, one can evaluate pattern efficiency. So, from one particular sprinkler, it is placed over here. This is in another corner, another sprinkler is placed. There is one sprinkler it has been placed and at this. So, this particular sprinkler system is kept at an appropriate location. And then at the center of each grid, these data have been collected. These data can be in milliliter or simply one can say that these data are in millimeter depth of water which is collected in a can. So, volumetric form or it can be in the depth form, these data can be collected.

So, in this particular problem sprinkler heads which have been used these sprinkler heads the one particular observation is 4.365 into 2.381 millimeter. So, this is one range nozzle diameter. This is the spreader nozzle diameter which is operating at 2.8 kg per square centimeter. So, now the area is given, sprinkler diameter is given, one can find out what will be the operating pressure? Theoretically, what will be the operating pressure? So, area one can calculate. We have been given the operating pressure. So, Q is equal to Ca root 2gh. The value of C, it is ranging from 0.95 to 0.98. So, you can substitute the value and you can find out how much is the discharge at 2.8 kg per centimeter square?

The other data which are available, wind speed is given 3.5 kilometer per hour. And this is from the southwest side relative humidity is 42%. Test time is 1 hour. So, these data were collected from the field, and from these data, we want to evaluate the coefficient of uniformity.

So, these data we have kept in the descending order of magnitude. This means the highest value is 10.2. There is only one observation of 10.2. Now, you can see 9.9 is another value. This has also one, only one time it has occurred. But, 9.4 millimeter or 9.4 milliliter of water, it has been obtained from 2 cans. So, like this, if you see here, the highest depth of water which is 10.2, and the lowest is 6.6.

And then how many times these observations, so, there were 21 number of observations. And then, what we are doing? We are multiplying with the application rate multiplied by the frequency. So, this is the observation multiplied by the frequency. So, this means rather it is the depth of water application. So, the depth is multiplied by frequency. And then you are summing the value that is m into n. m is the average value multiplied by the number of observations. So, the number of observation is nothing but frequency. So, this value is the depth of application multiplied by the faculty. So, m into n equal to 178. Numerical deviation taking the observation, so, numerical deviation from the first observation that is 1.72, we will be getting the value of the frequency into deviation. So, this is coming as a summation of X. That is your deviation from the mean is 17.76.

So, we are getting the mean value. That is m mean m equal to the sum of all the observations divided by the number of observations. So, a sum of all observation is nothing but the previous value that is your depth of application multiplied by the frequency number of observations. So, this is 178 divided by 21 is 8.48 millimeter or mL whatever the unit which we can use. So, this is the value. And then, we will work out the emission uniformity.

So, emission uniformity is given by

$$C_u = 100\{1.0 - \frac{\Sigma X}{m \times n}\}$$

That is the deviation from the mean summation value divided by m into n. m is the average value. n is the number of observations. So, when we multiply, we get this value. And then, we found that the computed value of Cu from the data is 90.02%. It is highly satisfactory. And then, this particular setup of the pressure is giving the best performance.

Pattern efficiency is given by minimum depth divided by mean. So, minimum depth, if you remember, it was 6.6 millimeter and 8.48 is the mean. So, we are getting 77.83%, which is the pattern efficiency. This is also a very good indicator that this particular sprinkler system which we have taken from the field data, it is giving very good performance from the operational point of view.

Now, let us summarize this lecture. So, here we have got evaluated the different parameters which are the sprinkler head-discharge relationship. We have evaluated how the water distribution takes place, water distribution in the form of emission uniformity. We also worked out one example to make you more clearer about how to find out the uniformity coefficient, how to find out the pattern efficiency.

So, you learned about this. And, in the forthcoming lecture, we will work out numerical examples of sprinkler irrigation system. For this particular topic, you may refer to these books. So, thank you very much.