**Micro Irrigation Engineering**
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# Lecture-13
# Soil and Plant Water Monitoring Instruments

Dear participants welcome to lecture 13 on micro irrigation engineering subject, lecture 13 is on soil and plant water monitoring instruments. We learned about soil water, we learned about plant water, and how they are interrelated? When we are interested or we want to give irrigation to the crop, we need to know how much amount of water is available in the soil, how much water has been transported from the soil, root system, plant root system, from the soil to the plants. So, we need to install or in the laboratory, we should bring a sample and then analyze soil parameters, analyze plant parameters, accordingly, irrigation can be given to the plants.

So, this particular lecture will be covering different soil moisture measuring techniques, as well as soil water monitoring instruments. We will also learn what is plant water potential? And then what are the instruments that can be used to monitor plant water potential?

So, when we talk of soil and plant water monitoring applications, which are the areas where such monitoring is important? So, it is for agriculture, it is for hydrology, it is for meteorology. When we talk of soil water all 3 areas need soil water information, soil water data. When we are talking about plant water monitoring, it is relevant for agricultural water management, it is relevant to hydrology, hydrologic modeling, or several hydrologic parameters evaluation you need plant water monitoring also.

Now, in the case of agriculture, we talk of irrigation scheduling and its control. So, soil and plant water monitoring applications, it is applicable to irrigation scheduling and control which has relevance to agriculture. It has relevance or application in ecosystem and crop water balance. It is when we are interested to know, what the efficiency of irrigation system is? There also soil and plant water monitoring are important.

For hydrological monitoring or hydro-pedology, catastrophic event monitoring, the soil, and plant water-related parameters are important. So, when we talk of soil water, soil water is applicable to agriculture, hydrology, and meteorology. Whereas when we talk of plant water monitoring parameters, those parameters are applicable to agriculture and hydrology.

Now, when we are talking about soil water measuring techniques, so one of the very simple methods is gravimetric moisture content or another way that we want to express in terms of volumetric water content. So, how much a soil consists of solid particles, the soil solid particles it consists of pore space, these pore spaces could be partly filled with the air, it could be partly filled with the water or it can be solid.

So, when we are interested in a total soil volume, so some certain percentage of this from the volumetric point of view, it will have air, it will have water or when it is saturated, all the pores are fully filled. And then when we talk of soil water with reference to irrigation, so when the gravitational water is removed. So, water is available in the pores and then partly filled with the air. So, if we say 15% of the volume is air, 35% of the volume is water, or 50% of the water it is in the volumetric unit means we are telling that how much is the percentage of water content is available in a given soil column. Gravimetric moisture means we are expressing in terms of the weight, amount of water available per unit dry weight of the soil. So, the gravimetric method or technique is a direct measurement method that can be used to determine water, volumetric basis, or weight basis.

So, there are different methods to monitor, so gravimetric technique, tensiometer technique, then nuclear technique where radioactive materials are used, and then electromagnetic simple principles. These are applied to find out the soil water content, then remote sensing is another way of without coming in contact with the soil particles without coming in contact with exactly the object, we are monitoring the soil water status.

So, the gravimetric method as it says that and it is the oven drying method means bringing samples from the field. And then we find out what is the percentage of the dry soil versus the weight of the soil. So, we can express in terms of the moisture content by the percent that weight of water divided by the weight of the soil. So, this way one can find out what is the moisture content in the soil sample.

So, there are advantages, it is a direct measurement, it ensures accurate measurement, calibration of soil moisture, there are several other methods which are available which I will be talking about tensiometer method or radioactive material using that is neutron moisture probe or TDR. All these are calibrated by using the gravimetric way of finding moisture content. So, the gravimetric method, is independent of soil salinity, a particular type of soil, and one can easily calculate the value of moisture content, only thing is that it requires 24 hours. So, the soil sample taken 24 hours before that one can say it does not give the real-time, but there is a delay of 24 hours.

Tensiometer technique that is by using the tenacity, means we are measuring the capillary tension or energy with which water is attached or available in these soil pores. So, it is the capillary forces that are holding the water within the pore. So, this is the potential that we are measuring, this potential is matric potential when we are using tensiometers. So, a tensiometer consists of a porous cup connected to a continuous liquid column to a vacuum gauge or transducer.

Here on the right side what we are seeing is that there is a tube and this tube is filled with water. And the top of the tube is attached with a stopper that is a silicon stopper. And then there is a pressure transducer, so when we are piercing in the needle. So, pressure transducer gives the how much is the soil moisture suction or tension it is available? And these data can be read by the readout unit.

So, it is a simple device, the only thing that it has got a limited range of measurement. So, it has got a limited range of measurement that is 0 to 80 centibar, minus it is written that it is negative pressure or tension we are measuring. So, it is not when the soil is too porous it is not applicable or the other soil which is too porous. However, it gives a precision reading and if the soil water tension exceeds below 80 centibar or it goes below 80 centibar that is used for monitoring the irrigation or irrigation control. But when it exceeds the value of 80 centibar, then there is a chance that air which is available in the soil pores, may enter, so that may interrupt the observation.

Nuclear techniques, as the name it say that nuclear techniques means here it is using radioactive material. It gives a precise estimate. However, this method slowly has been discarded by the international community because of the use of radioactive material. So, it is a non-destructive means samples are not to be brought. And then access tube is to be driven in the field and for the entire crop season observation can be taken at different depths.

But it is a non-destructive indirect method and the commonly used for repetitive field measurement of volumetric content means for the entire crop season observation can be taken. It is based on how much is hydrogen nuclei means water content is available in the soil. So, water content in the soil, so fast neutrons which are emitted by an Americium and Beryllium which you just force that are thermalized slowdown by the hydrogen ion present in the soil sample.

It measures the slowdown of fast neutrons emitted into the soil. So, it consists of 3 components, one component this is on the top what you see this is the unit, it is a counter unit. So, it has got a counter and then there is a, here this part it is a probe and in this probe, there is a detector. Then what happened, when from this source fast-moving these neutrons they are emitted. So, that is causing the thermalization of the neutrons and this thermalization is practically dependent on the amount of water molecule available in the soil.

So, here the amount of moisture content and the number of counts which are there from this, it is counted there is a linear relationship. So, that is measured or this is calibrated and then moisture content is calibrated with the number of fast-moving neutrons, slowdown neutrons, and then this is a linear relationship it is obtained.

As such, there are some certain advantages of using the neutron scattering method. It is a non-destructive method, possible to obtain a profile of water content in the soil. Water can be measured in the dry as well as in the wet phase. It can be automated for one side to monitor the spatial and temporal soil water means the after the observation is taken, one can take it to another tube, so as such whole unit of measurement it can be shifted from one place. So, that is from the spatial point of view. And then the temporal multi-time data can be collected, measurement directly related to soil water content. So, if one can directly from the calibration curve, one can find out what is the amount of moisture content available.

There are some disadvantages or limitations that it is costly equipment, it is dependent on the bulk density and salinity. There is a radiation hazard; this is one of the major limitations of using this equipment, and particularly when we are taking observation from the first 15 centimeter of soil the fast emitting neutrons it may come above the surface. So, this is not recommended to use for shallow depth soil water monitoring.

Then another method is a nuclear technique, which is also gamma attenuation. This also uses radioactive techniques and changes in the wet density here what is the change in the wet density, it is measured and moisture content is determined from the density change. It is calibrated in terms of volumetric water content and it gives a very fast response, it is less than 1-minute observation.

There are some advantages, it gives mean water content in terms of depth and this particular device can be connected with the automated irrigation system. And then any temporal changes in the soil water can be measured, it is non-destructive, soil samples are not to be brought. It is in the field at the site itself the observation can be measured. It is restricted to soil thickness for the shallower depth the thickness of 1 inch or less. But with very high-resolution data are obtained. So, if someone wants to have data of less than 25.4, then one can get this particular device. It is affected by the soil density of the soil when it is changed then the observations are affected.

Then electromagnetic techniques, technique is based on the several properties of the soil that vary with soil moisture content. The observation can be measured in terms of the resistance that is the resistivity of the soil or in terms of the capacitance that is between the electrodes in the soil it measured for soil moisture content. So, resistance in terms of an ohm or sometimes the capacitance-based observation is measured.

So, a device which you are seeing this is a granular matrix soil moisture sensor. And there are porous blocks, gypsum blocks that are available, and this gypsum block which you are seeing here. This gypsum block inside there are 2 electrodes and these 2 electrodes are connected with the probe and then on the top, there is a readout unit, that readout unit gives the observation in terms of voltage or terms of the resistance, and that value is calibrated in terms of the soil moisture content.

Only there is a limitation that the calibration made it changes with the time because of the if continuously when irrigation is being given, and then if the fertilizer is given then soil salinity as well as the chemical content in the soil that as well as in water that changes the calibration curve. The response time means such devices are kept in the field for a longer period for the entire crop season it can be kept and then observation is taken. And those observations are interpreted what is the available moisture content? And these units are also used for finding out the moisture content and that can be attached with the automated irrigation system.

Now capacitive sensors are available. The effect of soil moisture sensors, here when I am telling about the capacitive sensor here it is the observations are affected by the dielectric constant. So, the measured parameter is brought in terms of volumetric soil water content. Respond time from such devices are instantaneous and this gives a relatively better response as compared to the resistive unit. And there is long term stability of such observations are also in question. And relatively as compared to resistive or granular soil moisture sensors, they are expensive.

Another important device is which has been now commonly used is time-domain reflectometry. So, in time domain reflectometry, the speed of an electromagnetic signal passing through porous media varies with the dielectric constant of the material. So, TDR in short form we say of time-domain reflectometry measures apparent dielectric constant of the soil surrounding the wave guideline.

At microwave frequency which is measured in megahertz or gigahertz, the propagation of velocity depends on the length of the electrodes and then how much is the length it is given and also how much time it takes? So, the propagation velocity (V) is given by

$$V = \frac{L}{2t}$$

Which is the function of soil bulk dielectric constant and this can be given by the equation that soil bulk dielectric constant ($\varepsilon_b$) is given by

$$\varepsilon_b = \left(\frac{c}{V}\right)^2 = \left(\frac{ct}{2L}\right)^2$$

Where V is the velocity of propagation through the transmission line of length L, t is the time when it is transmitted from the source and then how much time it returns back and c is the velocity of electromagnetic waves in vacuum ($3\times10^8$ m/s). So, t is the travel time for the pulse to transfers the length of the embedded waveguide in both directions that is a downward as well as backward direction.

So, this is the part which we are seeing that is a 3-rod probe where the electromagnetic waves are transmitted and then the observation comes. So, observations are monitored in terms of it is calibrated in terms of moisture content and it is expressed in the volumetric unit. So, so much water content is expressed so much volume out of volume it is given in cc by cc or that each cubic centimeter by cubic centimeter, sometimes it is expressed in percentage also.

So, the soil bulk density constant is governed by the dielectric constant of liquid water which is 80. And then the dielectric constant of soil is less it could be 0 to 4. So, a large disparity in the dielectric constant makes the method relatively insensitive to the composition of the soil texture. So, the measured parameter is volumetric water content, and response time is very fast it is less than 28 seconds. There are certainly advantages; the only thing that is quite expensive equipment and this system can be automated.

Then frequency domain reflectometry, this is another device, it is working in the same principle more or less as TDR, the only thing that here the frequency is high. The pulses are transmitted, so FDR measures the soil dielectric by placing the soil in effect between the 2 electrical plates to form a capacitor. And this explains the term capacitance, so which is used to describe what these instruments measure.

When voltage is applied to the electric plates a frequency can be measured, this frequency varies with the soil dielectric constant. So, that is another device and a simple device it gives considerably precise observation as far as but this device is also an expensive device that is used for measurement of soil moisture content.

Now, the other way of monitoring soil water content is remote sensing, and in remote sensing, we are using active as well as passive sensors. And the active sensors were from the radar or it means your side looking radar or synthetic aperture radar, pulses are being thrown, and then the reverse pulses are measured.

So, passive, when this measures in terms of the emission property of the material where active sensors are measured in terms of the scattering coefficient and then which is given by sigma 0 decibels. So, that depends on the sigma 0 depends on the dielectric property of the soil, geometric properties of how the soil if the rays are beams are transmitted from the source. And then another system parameter those are used.

So, this is what you see when it is an airborne radar and then the pulses are transmitted. So, this pulse it goes and this let us say these are the targets. So, these targets are when the pulse is transmitted, then it is transmitted back to the system and then these values are analyzed in terms of the moisture content. And then these are some of the sensors which are their synthetic aperture radar in the space.

So, Seasat, Almaz 1, that ERS-1, SIR radar set, so these satellites, so they have got the sensor where the active microwave remote sensing, where P-band, L-band, S-band, C-band antennas which are working in different frequency are utilized to monitor the soil water content, but it is limited to a certain depth.

Plant water monitoring is a very useful thing because the soil is an indirect way, it is we are getting a sample. But frankly speaking that we need to monitor plant water from an irrigation point of view, we are irrigating to plant. So if I know about the plant systems, we will be able to give water to the plants, so it is useful to determine water deficit. And irrigation needs, there are different crops and it has got different requirement. So, we need to give water to different crops which are having different water requirements. And then what happened? The water potential in the plant differs in many ways, and the atmosphere would provide energy, and then because of this energy with the plant through the process of evapotranspiration, through the process of transpiration, it extracts moisture from the soil.

So, this particular information when we are talking about the amount of transpiration it takes place that is the plant process, and the amount of water which is withdrawn from the soil that is soil water. So, both the system it works when the plant is grown in the soil media.

So, basically, it involves that water moves from the higher potential this is the basic fundamental involved, that water move from the higher soil water potential to the lower soil water potential or higher plant water potential to the lower plant water potential. And between points of equal potential means, there is no movement of water. So, when we say for the pure water the pressure, the water potential it is zero.

So, water potential values are always negative, because this negative is causing the gradient to flow, so from higher potential to the lower potential water will move. So, psi w increased by increase the pressure potential and it is a decrease by the addition of solutes which lowers the solute potential.

So, if we put total water potential, so total water potential ($\Psi_w$) is given by pressure potential ($\Psi_p$) plus the osmotic or solute potential ($\Psi_s$) plus the electrical potential ($\Psi_E$) plus gravitational potential ($\Psi_G$). So, these components the $\Psi_E$ when we say electrical potential these are very negligible if water is having zero concentration of the salt or this value is very small. So, it remains the same, there is not much change in the value and G is also when the plant is of a smaller height, this does not play a role. So, these 2 components can be taken as very negligible, and then the total soil water potential can be given by $\Psi_p + \Psi_s$.

Now, the plant water potential can be measured by using a pressure chamber, it can be measured by these cryoscopic osmometers, it can be measured by using a psychrometer. What is a pressure chamber? A pressure chamber is an instrument for estimating the water potential of a plant by reversing the negative hydrostatic potential or we say tension. So, plant water tension in a plant's xylem sap.

Now, using the pressure chamber the solute is potentially assumed to be 0. Since few dissolved solutes are in the xylem sap, what is xylem? Xylem is in intimate contact with the majority of cells in the entire plant because only 2 to 3 cells separate vascular bundles. Therefore, measuring the positive potential required to reverse the xylem sap flow will give us a good approximation or good estimation of the water potential of the plant.

So, pressure chamber operators, what it does? It assumes the solid potential is 0 since few dissolved solutes are in the xylem sap. The positive pressure required to reverse xylem sap flow estimates, the water potential of the plant because the xylem is in intimate contact with most of the plant cells. The water column in the xylem is under tension or negative hydrostatic pressure because during the transpiration process water is withdrawn through the plant from soil to atmosphere.

So, any pressure chamber operator, consists of a device which is a pressure gauge, there is a pressure chamber, there is a rubber gasket or holding the plants, leaves, or a particular part of the plant. And that creates the pressure and creating a pressure seal and a lid that hold the rubber gasket and seal the pressure. So, a hose connection attaches the pressure chamber to a compressed source. So, when the pressure is applied, what is the pressure applied it measured and then how much is the water which comes out then it is measured.

A cryoscopic osmometer is another device to measure the plant water potential, it consists of a temperature-controlled thermal stage attached to a microscope. So, a drop of plant sap is suspended in the depression. So, there is a depression in this particular, so it is a depression on the stage, and oil is included to prevent evaporation of sap, so water should not get evaporated, so oil is used. The cryoscopic osmometer measures the water potential of plant tissue by estimating the solute potential in a plant's sap.

The method is based on the colligative property of solution, which states as the solute concentration of solution increases, the freezing point decreases when the concentration increases the freezing point of the material available in the sap that decreases. So, when using this method, we assume hydrostatic potential if the cell is zero, because of the cell membranes, because cell membranes get damaged due to the freezing process.

So, this is kept below the microscope and these observations monitor what is the temperature and then how does it function?

So, the temperature is rapidly lower to reach the cell sap, and the temperature is then slowly raised. And it reaches when the temperature reaches then melting process is started. And then through the microscope under the last crystal in the plant cells melts, this temperature is noted and recorded. So, melting and freezing point are the same the solute potential of the sap is then estimated using freezing point depression.

As such, this is laboratory-based equipment, and this is expensive and it needs a skilled person who should operate. Another limitation is that anti-freeze compounds in the plant may affect the estimation of the solute potential.

A psychrometer is another device, which I have told psychro is brought from the Greek word, it means it is "to cool" and it measures water potential from a change in the temperature due to evaporation or condensation. Psychrometer consist of a shield chamber, this is the device which we are seeing that it consist of a sealed chamber with a thermocouple. So, there is a device that is connected with the thermocouple.

And this thermocouple is attached to a temperature gauging device that measures the temperature. So, a drop of standard solution with known water potential is placed on the thermocouple, and a piece of plant tissue is kept in the bottom of the chamber, this is what we see in the device. So, if the drop of the solution has higher water potential than the plant tissue, water will move from the drop of the solution towards leaf tissue causing the temperature to drop because of the evaporative cooling.

Now if plant tissue has a higher potential than the drop solution water will move from the leaf tissue and condense on the drop of solution that will cause a rise in the temperature. So, it is at the point where there is no net change in the temperature that the water potential of the drop of solution and plant tissue are assumed to be equal. So, this can be such type of relationship, it can be grabbed or it can be plotted graphically or it can be explained graphically that water potential is plotted on the x-axis. And then the change in the temperature is measured on the y-axis, and then the green line where it becomes 0 means no change. And then it gives that what is the solute potential of the thermocouple that is noted down. So, a green line which is shown here is 0 temperature change, so down to the water potential of the solution, this value is the water potential of tissue. It gives estimates of the water potential of excised and intact plant tissue and solution. Equipment is sensitive to temperature fluctuations and this particular thing is purely fully laboratory conditions. So it needs a control condition to observe the plant water potential.

So, in this particular lecture, I have tried to present here and explain to you the principle and operation of the various instrument to monitor soil and plant water, which are useful for irrigation purposes, which are useful for connecting with the automated irrigation system. Now, in the forthcoming lecture, you will be given exposure to the devices which are used for the measurement of irrigation water.

You can refer these books which are useful for this particular topic on soil water as well as plant water monitoring systems. Thank you very much, good day.