Water Management

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Lecture 06

Soil, Water, Plant Relationships (Continued) & Infiltration

Okay, in the last lecture we had started looking at the closed volume of a field and with respect to that we had looked at what are the various components of the water balance. We had also seen what are the importance of the components like which are concerned with the crop and we had seen some of the characteristics namely the root zone depth, what do we mean by root zone depth? And we had also looked at what is the moisture extraction pattern of different crops?

How the moisture is extracted from this root zone depth which varies for different crops? There are still some more characteristics which govern the (mois) moisture extraction as well as the sensitivity of the moisture availability to these crops. So today we will start with the aspects of what is the sensitivity of crops to water shortages. There are some crops which can survive with a low level of moisture availability.

There are some crops which are very sensitive to the moisture deficit in the soil and those crops will be decaying under the deficit conditions very fast. That is what will decide how long you can wait for the irrigation water to be applied and that is going to be a very important aspect to be considered while designing the irrigation systems. Now if you look at these different categories, most of the crops are broadly divided into four groups.

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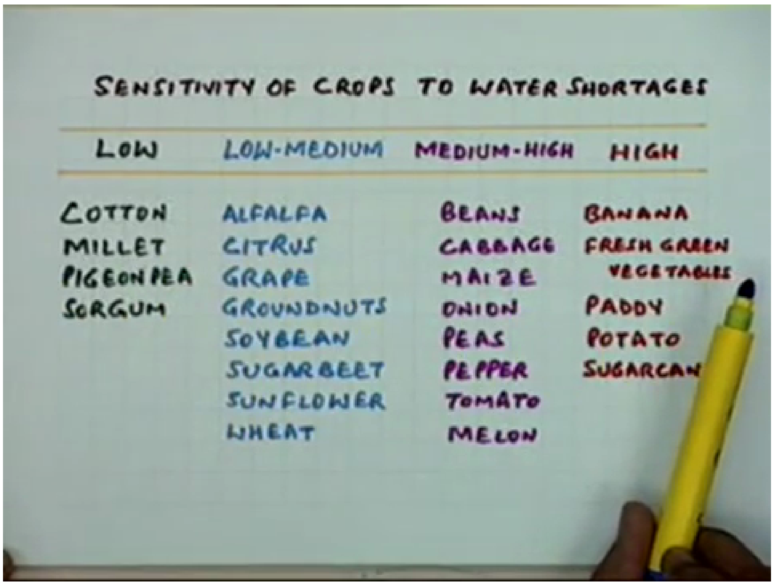

The crops which are having low sensitivity to the water shortages can be cotton, millet, pigeon pea, sorghum. There are some crops which are not as lowly sensitive, their sensitivity is higher than these crops. They come into the category of low medium sensitive crops and these are alfalfa, citrus, grape, groundnuts, soybean, sugar beet, sunflower, wheat. Similarly the next category is the next higher level having the medium high sensitivity and the crops with the maximum sensitivity or the highest sensitivity are the banana, fresh green vegetables.

Most of the fresh green vegetables crops are very sensitive crops. They cannot tolerate the deficit in the soil moisture levels. Paddy is there, potato, sugar cane. So likewise all the crops can be put under one of these four categories and while deciding on how the deficit conditions can be, you can say when you think of the water management ultimately these aspects will be having importance because you have to find out from where you can save moisture?

So all those crops which are very lowly sensitive or where sensitivity is very low, you can let those crops wait for the moisture availability or the irrigation can be delayed in those crops and you might be in a position to wait for the natural rain to occur or some other similar situations can be looked into. So these various aspects are important from that angle. Now this is as far as the crops in general their behaviour are concerned that is what is the situation.

But when you talk of the individual crops every crop has some critical stages which are very important from the moisture availability point of view. How do you define the critical stage of crop growth? The total growth period of the crop is known starting from the sowing time to the harvest time. That is what is the total growth period. So if I know that my crop, this is the sowing time or the sowing date and this is the time when you harvest. This total is the growth period, the crop growth period.

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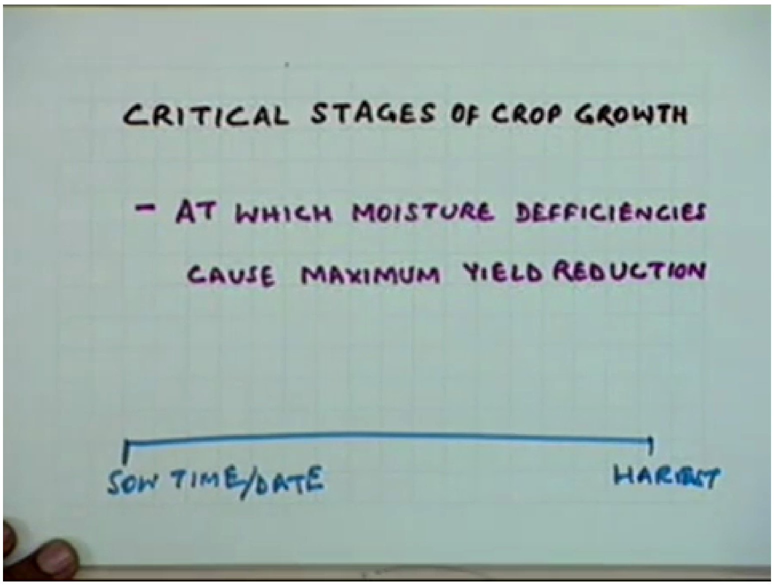

Now this total crop growth period can again be looked at in terms of different periods of or different stages of growth. There are some stages which are more sensitive than the other stages. So all those stages which are having lot of effect because of the moisture deficiencies or if the moisture deficiency is encountered you will have the yield reduction to the maximum. Those stages are the critical stages of the crop growth. And these critical stages of the crop growth they vary from crop to crop.

As you have seen that the sensitivity of the crops as a whole varies from one crop to another crop. Similarly for each crop or each individual crop within the crop growth period there are stages which are more critical than the other stages and the knowledge of those stages, which stages are more critical? That knowledge is again very essential when you want to schedule the irrigation, when you want to plan the scheduling of irrigation or in other words to know when to irrigate?

That knowledge will require this knowledge in turn that which are the critical stages and at what time of the crop growth period that stage is active, okay. So from just to give you an example for or before that if we try to look at which are those stages? Now these are the generic growth stages which have been identified and in all the crops these four stages in general you can say that these four stages are there.

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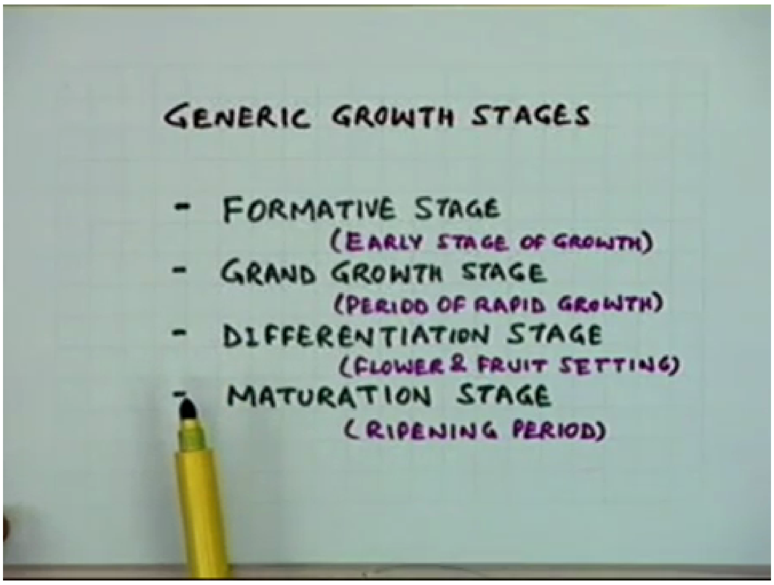

Similar to human being you can say that the human beings have different stages of growth. You are a child at one time in the beginning then the adolescence starts then you have the next stage when you are a mature man and then you are old man. So all those stages in general you can identify similarly in the case of crops and these are those four generic stages.

The formative stage which is the early stage of growth then the next stage is stage of rapid growth which is termed as grand growth stage and then the next stage is a stage where the flower and the fruit setting is predominant is known as differentiation stage and maturation stage which is the ripening period. Now these four are the generic stages. Their duration will change from crop to crop.

Their sensitivity as we have just mentioned, their criticality will change from crop to crop. In this categorisation somehow it is slightly difficult to identify or correlate it with the crops in general. FAO which is the organisation, Food and Agricultural Organisation based in Rome which is a body under the UN, they have lot of work which is being produced all over the world.

They keep on compiling that work. So they keep on coming out with various suggestions, various methodologies which can be used by the agriculturist or by the irrigation or the water management people all over the world. So these are the stages which have been recognised by the FAO.

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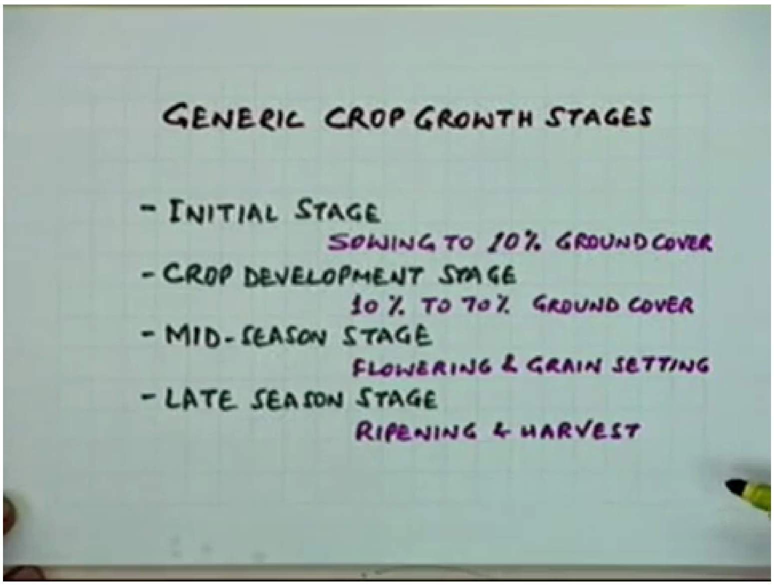

Now the same things but they have tried to quantify these stages slightly better than what has been done earlier. Now these stages the way they are defining is the initial stage where from sowing to 10 percent of the ground cover when you get that is the demarcation of this particular stage. Approximately again it might change from crop to crop to an extent but if you talk in general terms the stages. The crop development stage when your ground cover is from 10 percent to 70 percent.

The mid season stage when the flowering and grain setting is as we have said earlier in the case of the previous nomenclature. It was the differentiation stage. The late season stage is the ripening and harvest. All these stages later on we will look at what are the variations? How the consumptive use changes when you go from one stage to another stage? Let us look at some examples in some of the crops, which are the critical stages?

Where, if you do not take care of the moisture availability is going to affect the yield of the crop. So in the case of wheat, the crown root initiation, the flowering and the milk stage these are the critical stages. In the case of maize tasseling to silking and the grain filling these are the critical stages which are identified. Yes please.

Student: Can you explain milk stage please?

The milk stage? There is a stage when in the grain you are having the milk formation before it is dried. Have you seen the corn which you normally roast and eat? There you must be finding that the corn is having lot of milk. So that is if it is a raw form you will find that the milk formation is there. And when it dries out then that is the time when it is totally ripened.

So all these different stages people who are from the agronomy they will identify all these different stages, they will know that what they exactly mean. You can refer to any specific book and these are quite the names themselves they suggest what do they mean. For example in the case of (sor) sorghum, flowering and the grain formation these are the critical stages.

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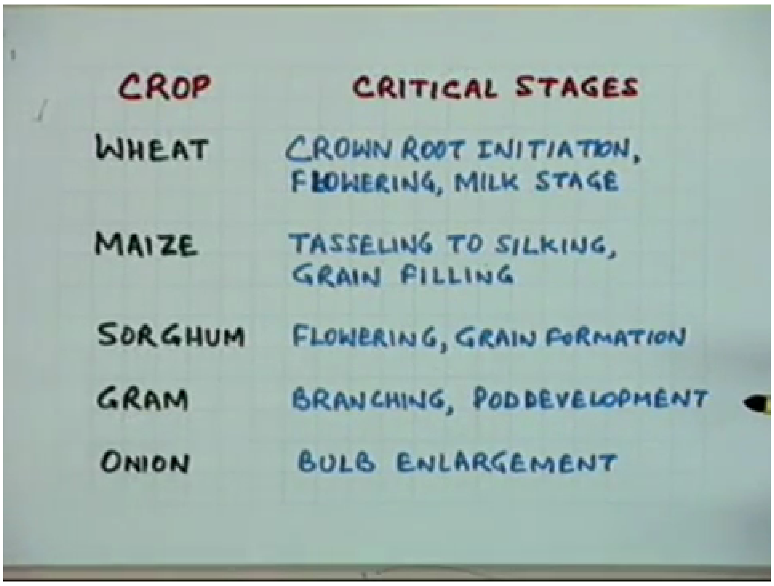

So if you do not ensure the supply of sufficient moisture at these timings then you are going to have problems. Your ultimate yield of the crop because that is what we are interested in. We are not interested in what happens in between to the crop. We are ultimately everything we are assessing with respect to the final yield. So if the yield is going to be affected, maybe that that yield is you are only going to know about that effect on the yield ultimately when you do the harvesting.

But it is the yield only with which you can assess all these impacts because that is what is your interest. Whereas in the case of fodder your crop is only for the function of providing fodder to the animals where the yield is fodder itself. Whereas if it is a grain crop, then the yield is grain. That is what your ultimate aim is. If it is a vegetable crop how much is a production in terms of the vegetable.

So the shape of the yield can vary but the yield with which you are concerned with, that will be predefined, okay. So it means that if we look back till now we have tried to look at all the aspects which are relating the soil, the water and the plant, these three major items which are actively involved in the overall crop production.

We have looked at their interrelationship and we have done that with respect to this close volume which is the close volume of the field because from now onwards we are going to look at some of the individual aspects in details. For example we have not gone into the details of what happens to the water which is spread over this surface.

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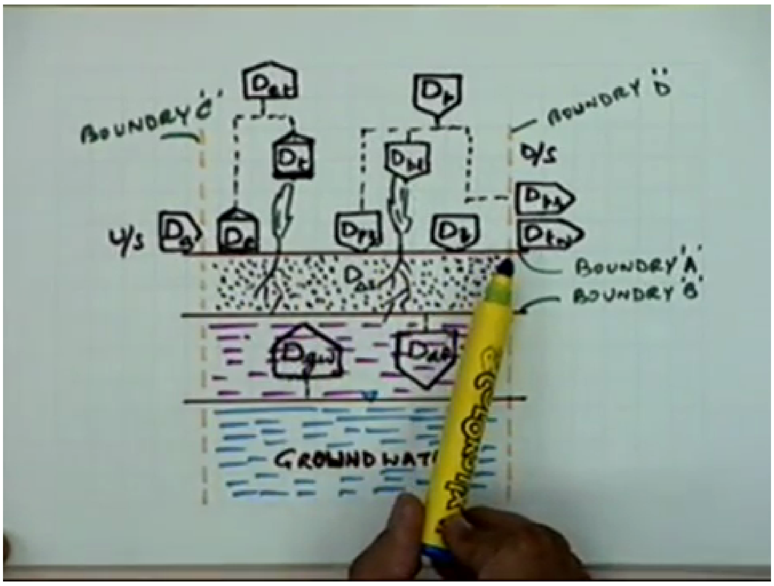

That is the next topic of our discussion, the process of infiltration. Similarly we will also look at what are the various ways and means by which the evapotranspiration is taking place? What are the various factors which are actively involved in that process of evapotranspiration? What are the various methods with which you can evaluate the evapotranspiration? That will be another topic which we will be going into before we actually going for the design of the various methods of irrigation, okay.

So with that we conclude the topic on soil, water and plant relationships. Is there any specific questions related to this topic we can take up before we go to the next topic? Okay, then in that case we will start with the topic of infiltration.

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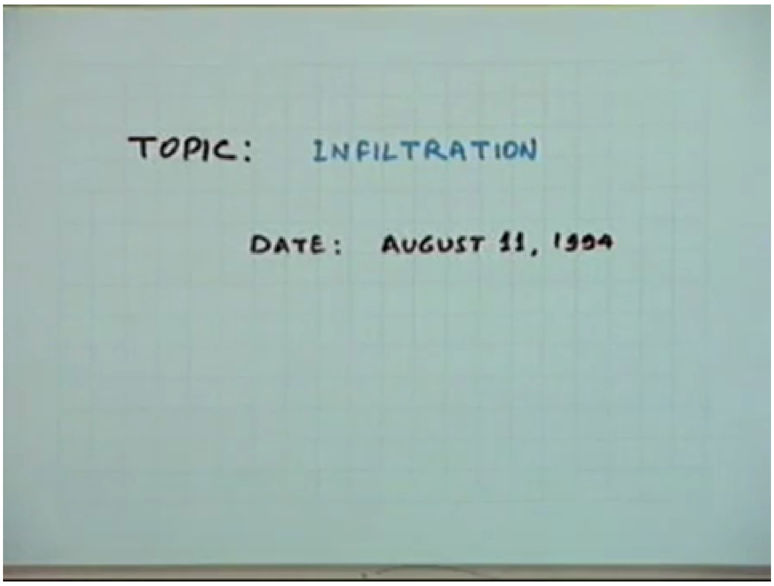

Let me put the same slide again. Here in this particular case we had seen that when we apply this depth of application, the irrigation water D A, the water is moving from this end which is the upstream end of the field to the downstream end and there is some water which gets infiltrated into the soil in the process of this movement. Then secondly we also saw that because of the precipitation which is falling over the total area there is some component of that rainfall which also gets infiltrated into the soil.

So as we had earlier also mentioned once from the beginning in one of the situations where we had tried to look at what do we mean by infiltration. We had said that infiltration is a process of the entry of water from the ground into the soil and is also controlling the water entry into the soil. Besides the water entry into the soil is also controlling the advance rate of the overland flow.

At what rate the overland flow will move that is also decided by the infiltration because when you are getting some water move from this end of the field to the downstream end, now is a case of spatially varied flow and the discharge is also reducing as the water is moving in the forward direction because some component of that water is moving into the soil.

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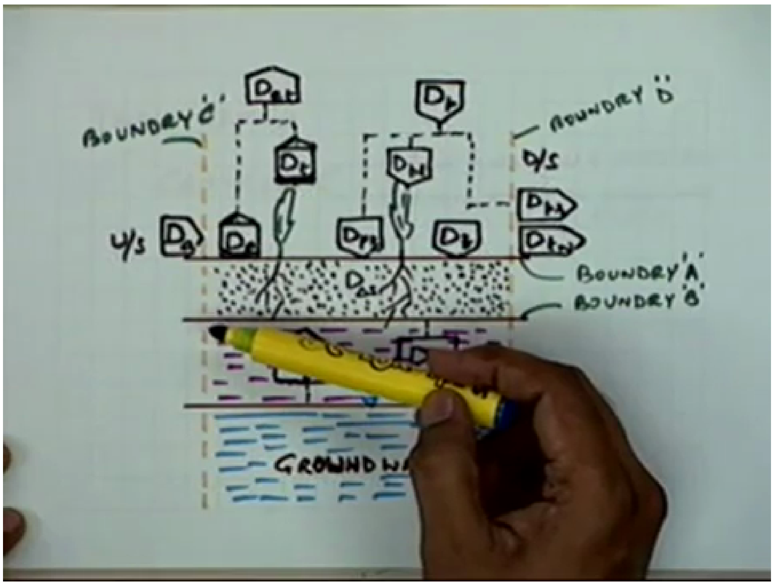

So in all those methods this particular aspect the advance rate of overland flow will be only applicable to those methods where you are having the entry point at the upstream end and the water flows to the downstream end. And those are the methods where you are using the gravity flow.

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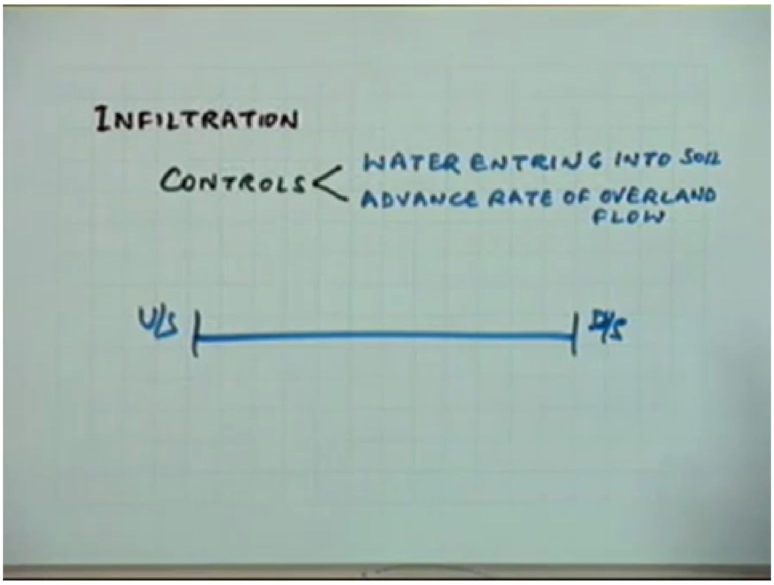

These are the methods which are the surface irrigation methods or the flooding methods normally known as. But the methods where you are sprinkling water those are not affected as far as this second component is concerned. The advance rate of overland flow is not because there is no overland flow in that situation. There in the case of sprinkles irrigation you are controlling the irrigation to the extent that there is no generation of any surface runoff.

That we will come to later but at this stage when we say that the advance rate of overland flow is also governed by the infiltration we are only confining ourselves to the irrigation methods where we are using the gravitational flow. Let us have a look at the definitions concerning the infiltration. There are various ways by which we measure these or we represent the infiltration. One is in the form of infiltration rate which we normally represent in terms of centimetres per hour or it can be any other depth unit per time unit.

The infiltration rate which is mentioned here is the instantaneous infiltration rate. At a particular time what is the rate? So it can also be called as the instantaneous infiltration rate.

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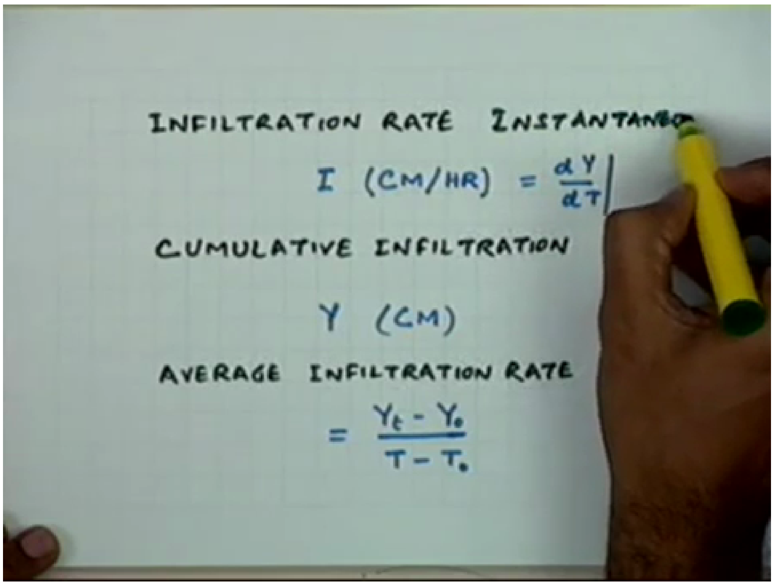

So if you want to know only what is the depth at a particular time or up to a particular time then you can represent the infiltration in the form of cumulative infiltration which is the accumulative depth over a particular time. So this has to be over a particular time because this does not belong to instance, this belongs to duration of the time.

So in a particular duration how much water has infiltrated into the soil at a particular location that can be represented in the form of accumulated infiltration which is represented as Y, normally is expressed in centimetres or any other depth unit. Similarly another term which is sometime used the average infiltration rate. When you want to look at the averages over some duration so you can always find out what is the accumulated depth at a particular time?

What is the accumulated depth at some previous time? So within that interval how much is the infiltration and what is the duration over which it has occurred? That way you can always represent (instant) instead of instantaneous infiltration rate you can find out what is the average infiltration rate over some different successive intervals.

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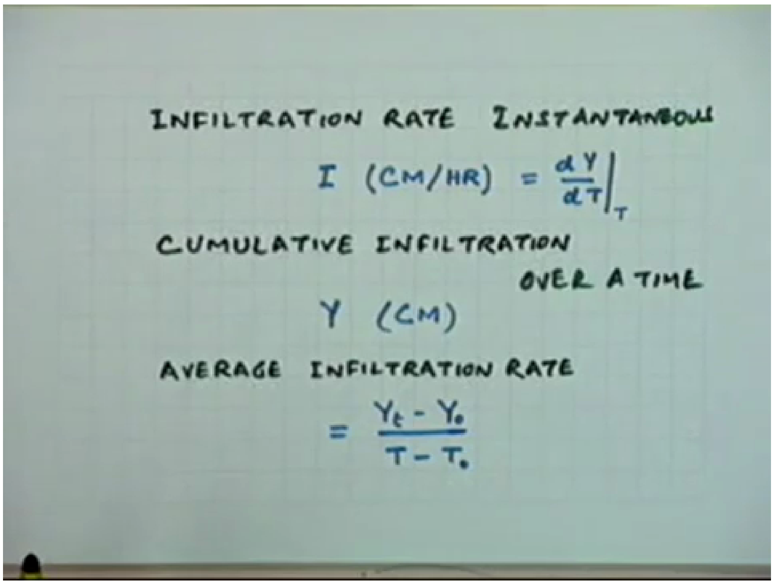

So that is sometimes it is expressed in this form. But one thing is there that out of these two forms as far as the irrigation is concerned it is accumulated infiltration which is more useful because at anytime you are interested in how much moisture has been stored into the soil or in particular in the effective root zone of the crop? That is what you are interested in.

But if you look at the typical curves, now this is the curve which gives the infiltration rate I or the instantaneous infiltration rate you can say and this is the very typical curve, the infiltration curve is also known as sometimes the infiltration capacity curve.

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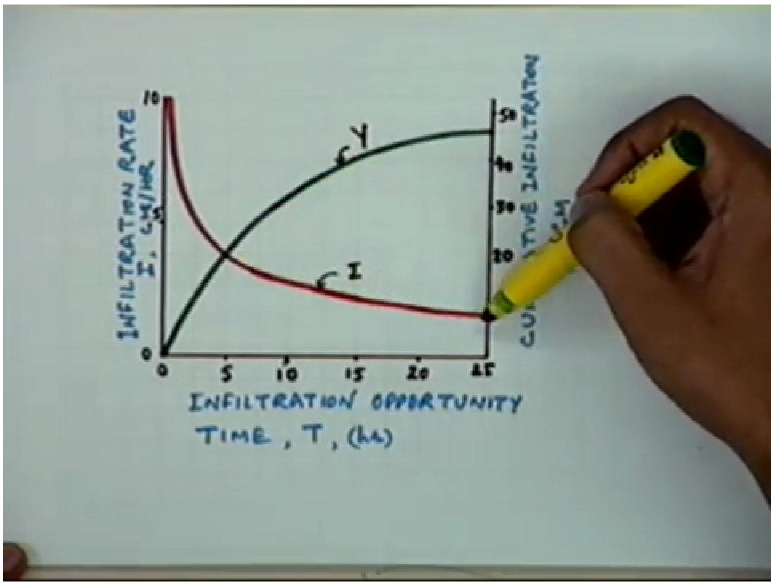

Why it is called infiltration capacitive curve? Because at any time what you are getting? You are getting the infiltration capacity of the soil. The infiltration capacity why it is known as because it is the maximum infiltration which can take place at that particular time and since it is a function of the soil conditions it becomes a unique thing for the soil. For those moisture contents the infiltration capacity will be similar.

If the moisture content changes then the infiltration capacity curve will also or for example let me say that this specific curve is a curve when you started the infiltration at a specific moisture content of the soil.

If the moisture content would have been more than that next time when you start the infiltration or when you start creating that depth of water over the top of the soil surface, the moisture content was higher than what it was at this time then the starting infiltration rate will be different. It might be somewhere here. It might start somewhere here.

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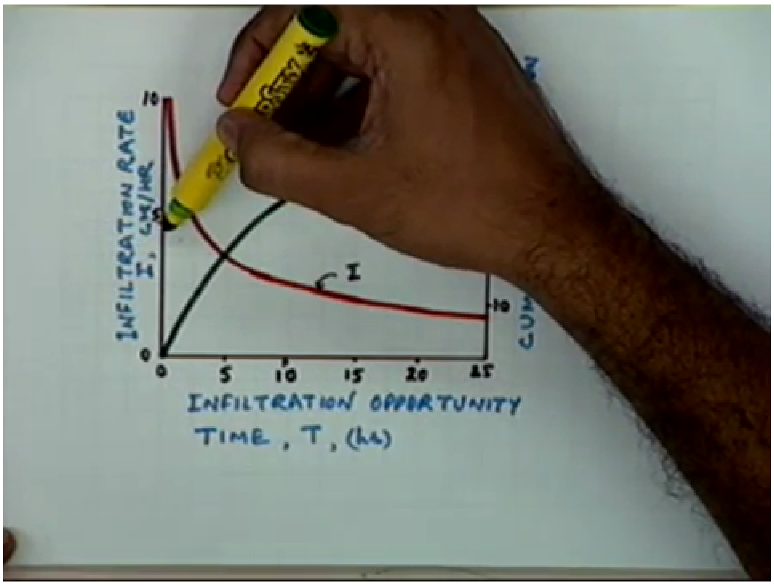

Or let me just put that in that case. You might get something like. This might become the infiltration capacity curve. For those conditions the infiltration capacity curve will remain fixed and is called capacity curve because is not constrained with the availability of water at the top. If the moisture is more than what is infiltrating into the soil at the top of the surface then you will always be getting the infiltration capacity which will be prevalent at that particular moisture condition.

If your moisture availability is less then what can infiltrate then the filtration rate will be constrained with the availability of moisture obviously. So in that case it may not be a capacity infiltration rate. It may be a rate which is less than what can happen. That is why normally when you talk of the infiltration curve it is always infiltration capacity curve. It is the maximum capacity of the infiltration which is prevalent under those moisture conditions.

That is a very important aspect because many a times you will get mixed up with that. So it is because of the reason that the availability of moisture is much more than what is the filtration rate. Now there is another property of this that after sometime if you let this infiltration continue there will be a stabilized infiltration rate which will be observed and that is called sometime you also term it as basic infiltration rate. That basic infiltration rate is also the characteristic of the soil.

Irrespective of where you start, with which moisture condition you start you will ultimately reach that stabilized infiltration rate which represents, what it represents? It represents the saturated hydraulic conductivity of the soil. What it represents? Saturated hydraulic conductivity of the soil.

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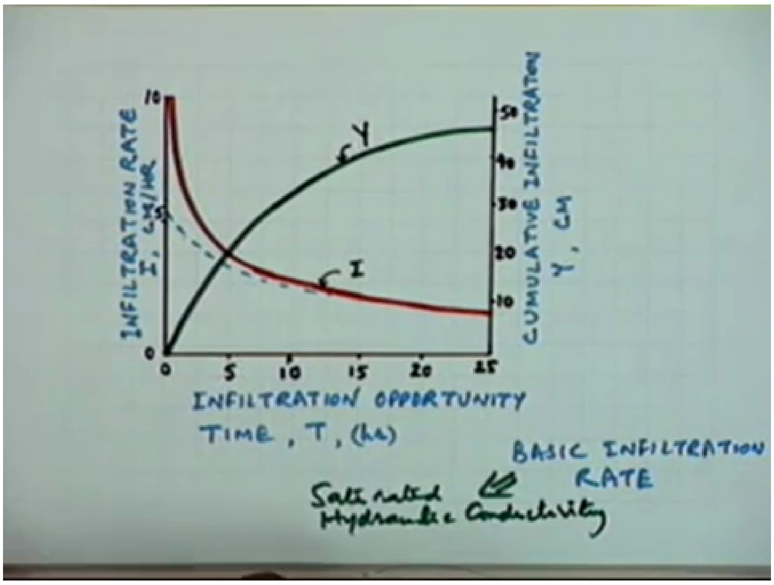

Now the other curve which has been drawn here, that is the cumulative infiltration curve. So if you integrate this, the filtration rate curve, you will get this cumulative infiltration curve. And it will be dependent on where you have started infiltration? What was the starting point? So from which time to which time you are talking about? In this particular case after 5 hours the accumulated infiltration is this much, 20 centimetres. After 10 hours it is around more than 30 centimetres.

So you have to look at which interval is always with respect to the time for which then filtration has been taking place and that is known as I will introduce that term here, it is called infiltration opportunity time. That time for which the filtration is taking place or the time for which the infiltration is under consideration that is what is the infiltration opportunity time.

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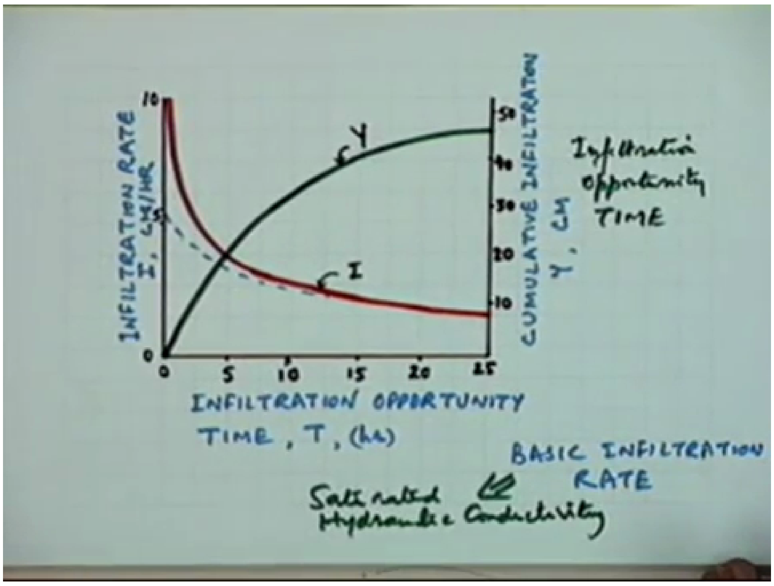

Let us look at the moisture profile under ponded infiltration. How the moisture moves into the soil when you have the ponding conditions created on a dry soil? It has been observed that there are five general zones which gets established under that situation and these zones are saturated zone which is just the top layer around 1 point 5 centimetres. A very small layer of the soil which will be under saturated conditions and the moisture content will be the saturation moisture content in that particular layer.

Then the transition zone which is around 5 centimetres below the saturation zone and under this particular zone this transition zone the moisture content will be changing very rapidly. The change of moisture content is very steep is very rapid. Then the next zone is the transmission zone. This is the zone in which the moisture content varies very slowly with depth as well as with time. And then you have the wetting zone where again you have a very sharp reduction in the moisture content.

And the wetting zone will be having a wetting front where you can make out clearly what is the moisture? You can see that the change of moisture content actually taking place. In a laboratory setup you can visually see that the region where the moisture gradient is visible.

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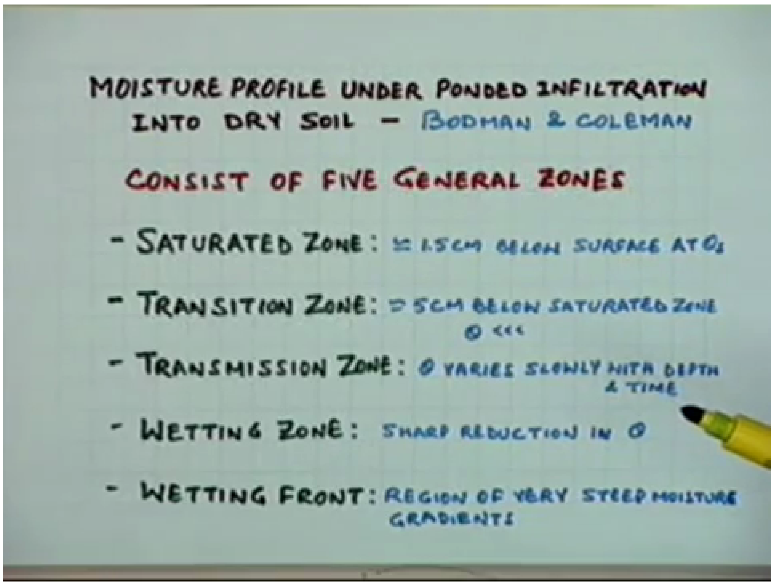

The same thing when you depict in the form of these different zones, now this is the soil depth, this is the soil profile and the way it is has been depicted is that this is the variation of water content on the x axis which is depicted just to show that how the moisture content changes. In the case of saturated zone if this level is the initial water content and this level is the saturated water content, if between these two levels over the profile how the moisture content varies.

Now this is not a demarcation. You do not take it as a demarcation. This is only a representation of what is happening in terms of these different zones in terms of the moisture content changes. That is depicted through this. It is not a profile as such, okay.

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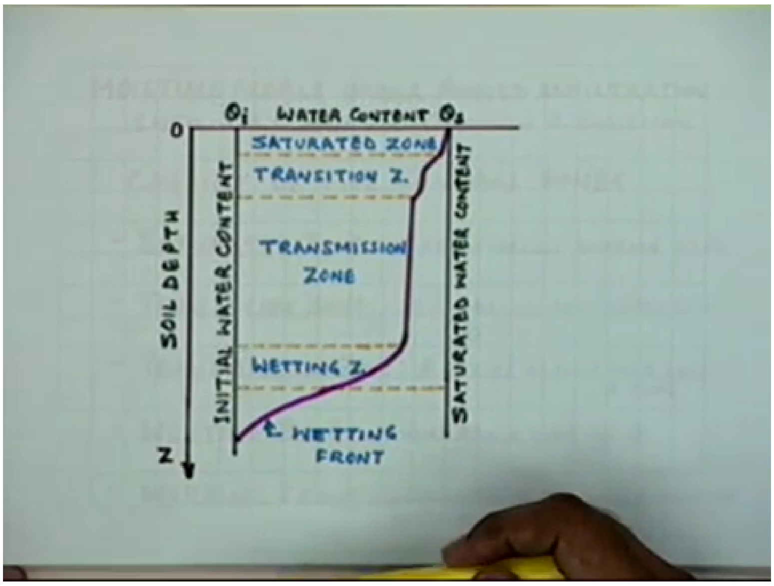

You can see here that this in the transition zone the change of moisture is very steep but this zone the transmission zone, this is the zone which is having a very slow moisture change and considerably in terms of the size of the zones this zone is the one which is having the major extent of the total moisture availability. And this wetting front again is not within this you will find that the wetting front is there. After the wetting zone you can see that how the wetting front is moving.

This also changes with if you keep on going in for the infiltration, the extent of these zones will also vary. This is only a depiction to bring home the point that there are variations. The moisture distributions also changes within the profile of the soil. So this can help ultimately because you are seeing the moisture extraction pattern of the root zone. In the root zone the moisture extraction pattern is such that the top soil is contributing the maximum to the availability of moisture to the plant. Sorry.

And that is the layer which needs the moisture availability more rapidly. If you can take care of that moisture availability or if you can cater to that moisture deficit without looking at the lower levels where the moisture extraction is much smaller and even if you know that the time which the water takes to reach that zone is also very large. You can even ignore that zone when you schedule your irrigation.

That is where you can use all this knowledge in managing your limited resources of water and we will come to that later on when we will look at those aspects. But at this juncture this knowledge is essential to at least have a complete knowledge about what happens to the moisture which is applied on to the soil and it infiltrates into the field.

The next thing which we are going to look at is that what are the various methods by which you can find out the infiltration characteristics of the respective soils. There are various methods available. For example you can use numerical techniques where you can solve the equations analytically and analytical solutions are available or you can have the numerical formations which can be used.

But most of the times those techniques are very cumbersome and many a times you do not have the data. In general for irrigation water management we are using the empirical relationship or some approximations to the physical processes which are used and they are found to be quite reasonably good. We will like to have a look at those various empirical relationships available which can be used to represent the infiltration process.

Now these infiltration equations, the earliest one which was as early as 1932, the Kostiakov equation was introduced at that time and this is the equation which represents the accumulative depth of infiltration and T is the time of infiltration or the infiltration opportunity time shown in minutes and a and b are the empirical constants.

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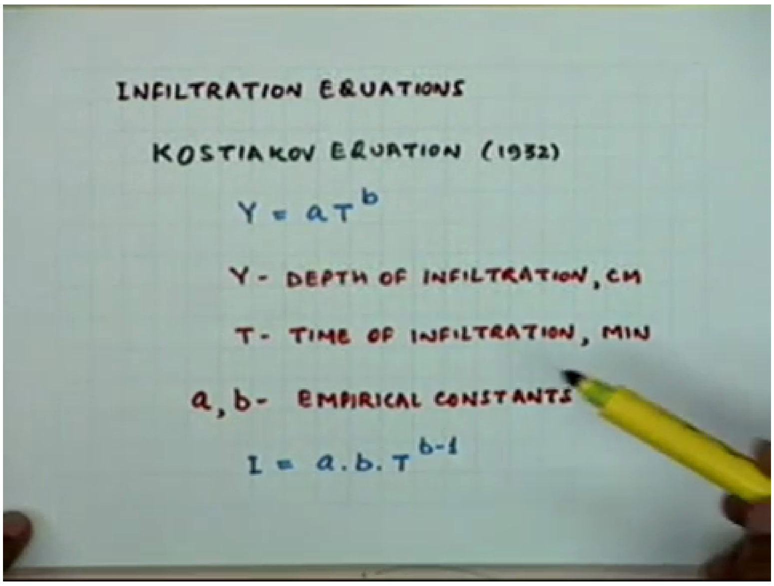

Now the same thing you can also express in the form of infiltration rate by differentiating this particular equation. The only problem in this equation was that when the time is very large the infiltration will tend to become zero. So you are not in a position to get the basic infiltration rate which you know that is prevalent. The infiltration rate which is applicable at the time when the soil becomes saturated, it stabilizes. That is the steady state infiltration rate.

That is not possible in this equation. So one way of some people even try to put a constant f 0 which is the steady state rate and improved upon this specific equation. But there were other equations which have come into picture and they have also been used. One of these is Horton equation. In the Horton equation the infiltration rate is expressed with respect to the initial infiltration rate and the final infiltration rate which is the f 0 and a constant C. So in this particular case you have to provide what is initial infiltration rate.

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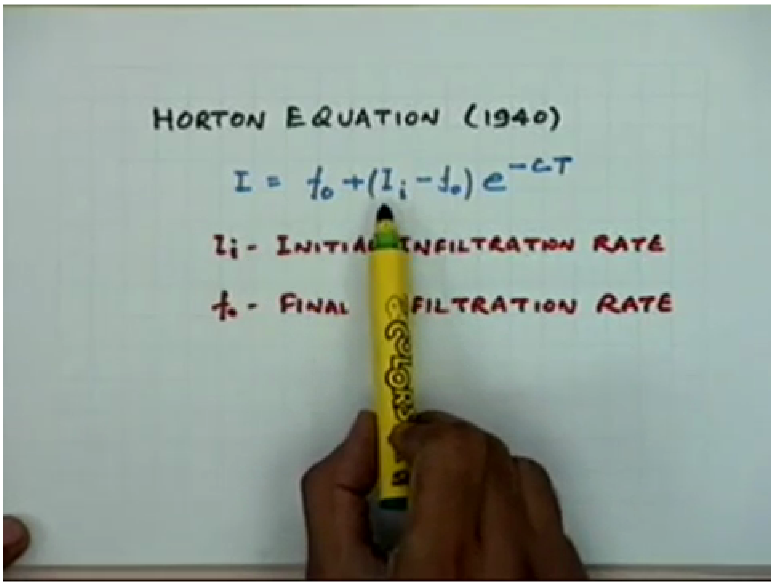

So having the initial infiltration rate known then you can find out what is the infiltration rate at any specific time. Then there is another equation which is the Philip equation where there are two terms. One is the sorptivity term and one is the conductivity term which have been used. The sorptivity term is more predominant in the initial portions of the infiltration curve and sorptivity is defined as proportional to the moisture content at the beginning of the infiltration minus the (satura) saturation level moisture content.

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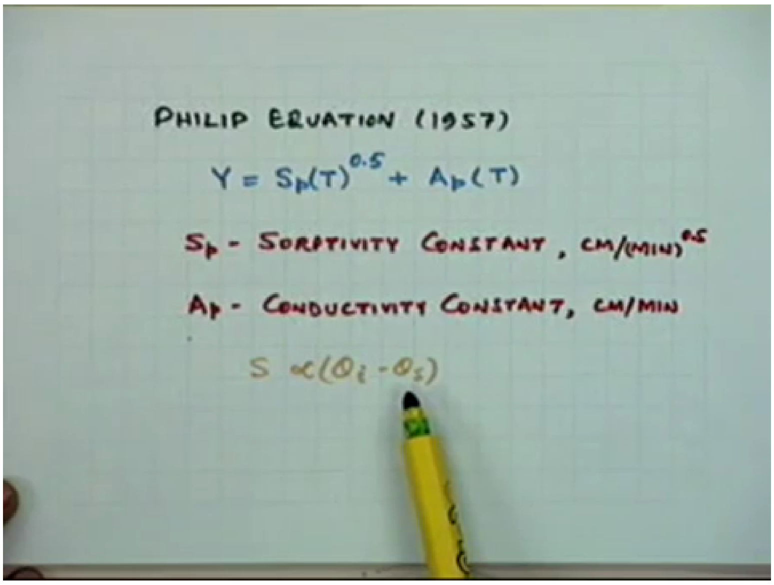

So when this difference will be high, S will be more predominant. Whereas in the situation when the infiltration is persistent, is looked at a longer time period, this conductivity term will become more predominant. The only problem in this particular case is that in many situations this term does not represent the steady state infiltration rate. It might be slightly different than that. Whereas in the case of sorptivity you again will have to give this initial moisture content.

So it can be adjusted with respect to the initial moisture content. There is another relationship which is quite often used. It has become very popular at least in America. It is the soil conservation service equation which is nothing but is the approximation of the first equation which was given by Kostiakov.

In this only this term C has been added in the Kostiakov equation and this C has been taken as a constant value when your infiltration is in centimetres. There is another value when the infiltration is taken in inches and these constants also at the constant a it varies depending upon the unit you are using.

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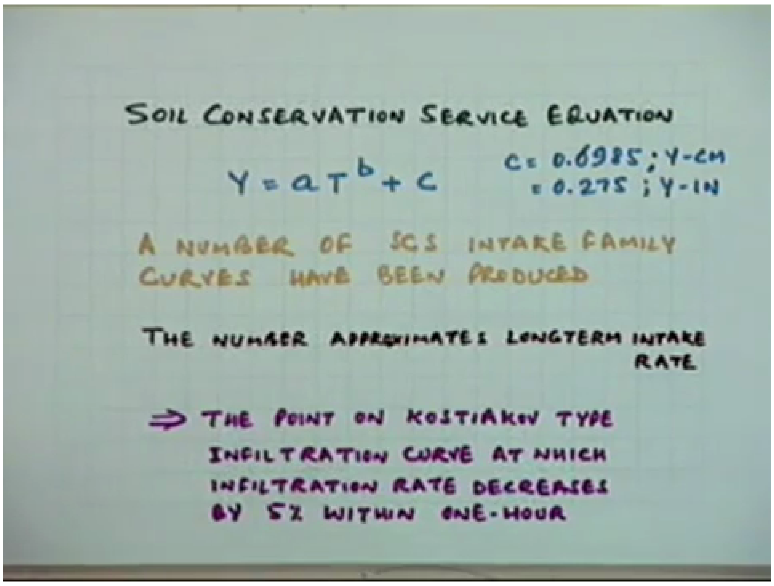

So there are curves. What they have done is that they have constructed a number of family curves for different types of soils. So for a range of soils they have constructed a range of infiltration curves which are known as they are calling it as the family of intake curves and the number of that curves normally designates what is the steady state infiltration. So the steady state infiltration represents the number of that curves.

They also found out some approximate ways by which they can construct those curves. The point on Kostiakov type infiltration curve at which infiltration rate decreases by 5 percent within 1 hour that has been found out and that is taken as the steady state value of infiltration. That has been approximated with respect to this assumption.

And if you look at it can be represented in this form because what you are saying is that you are using this curve and this is the change in 1 hour that multiplied by d Y by d T and you can also find out what is the time at which the long term intake rate occurs that can be approximated by either of these two equations, okay.

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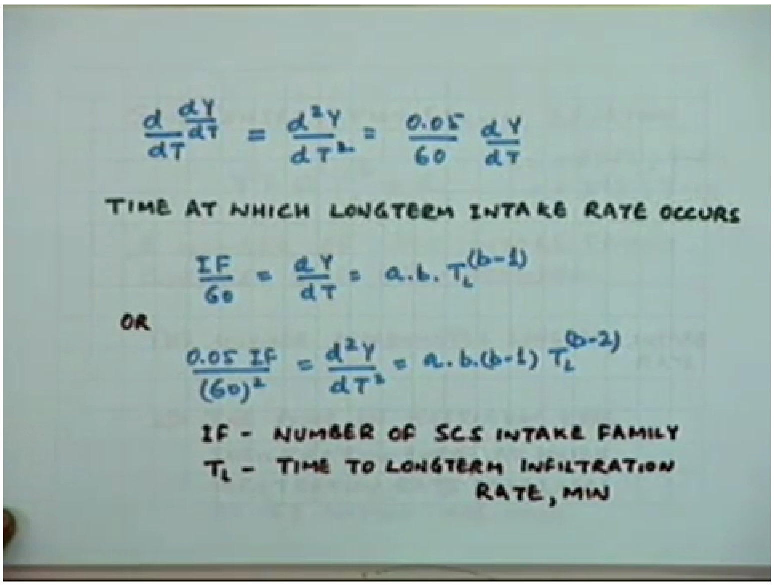

Where IF the number of soil conservation service intake family. Let me show you, these are the various intake families which have been. Is it visible? These are the various index families. You can see here this is the cumulative intake in millimetres and this is the time in minutes or it is the opportunity time.

Now for each type of soil for example this is the soil which has 1 point 25 millimetres of steady state infiltration whereas this is the soil which is having 50 millimetres of steady state infiltrations. So all these soils they are different soil and these are known as the family curves.

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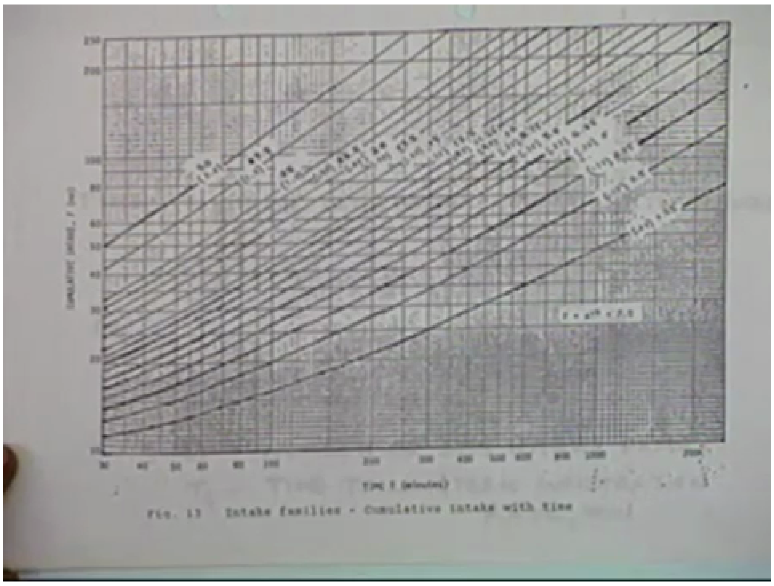

Once you know this family curve then knowing the opportunity time you can always find out how much is the accumulated infiltration. The method of measuring infiltration in the field you use cylinder infiltrometer. So it is a very simple equipment. It is a set of two concentric cylinders. Inner one and the outer cylinder which are used to observe the infiltration rate. Now these cylinders earlier to start with if you look at this it was only single cylinder which was used for this purpose.

This cylinder is (diven) driven in the soil and then you put some known quantity of water and take the observations on that change of level with respect to time. Now what was the problem was that the infiltration which was taking place there was lot of movement of moisture in the lateral direction because of the fact that the soil which is in this area this was having less moisture content.

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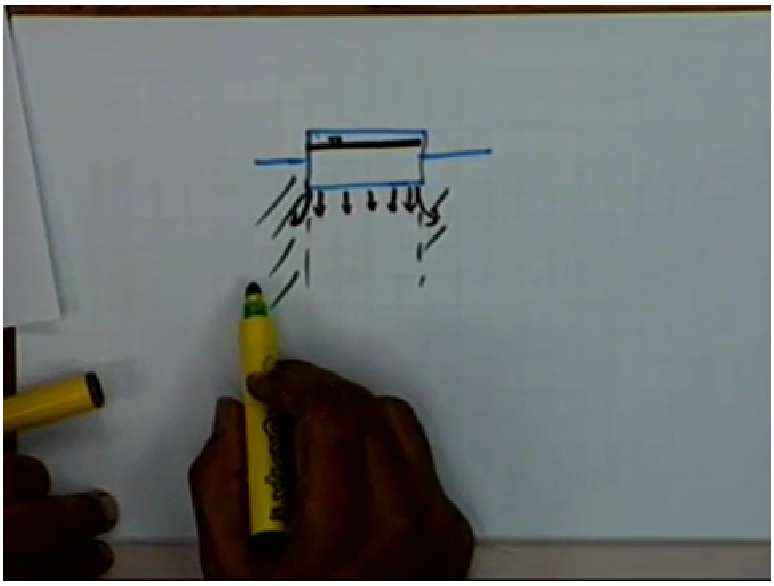

So there was a deficit of the moisture content in this adjoining soil. Lot of water had the tendency to move in the lateral direction. Because of that it was not a representative of what should have moved if the water was available in throughout the field. So because of that to avoid that loss the two concentric cylinders were used in which case you will still have the same tendency that some water will be moving from this area into the lateral direction. This tendency will still be there but most of the water which is coming from the inner cylinder will have the vertical movement.

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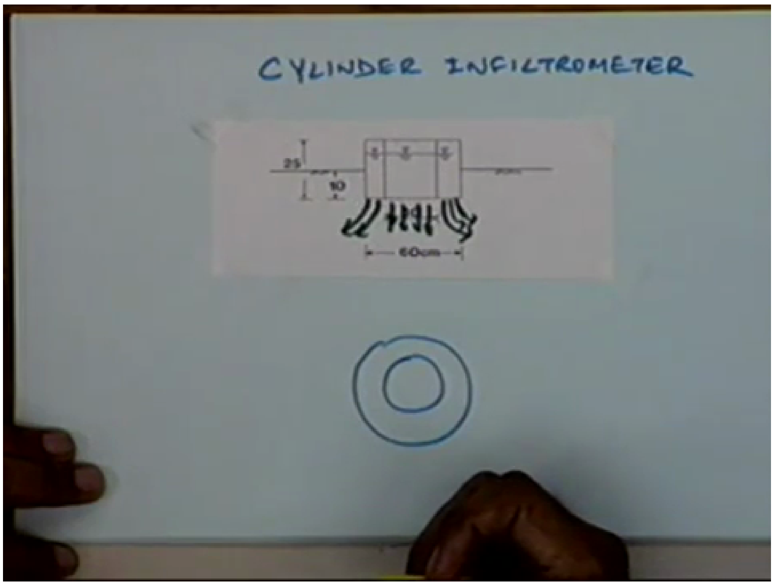

So all the additional amount of moisture which is going in the lateral direction is coming from the outer cylinder which is not part of the cylinder where the observations are being made. And these are the dimensions, the two cylinders are inner one is 30 centimetres diameter, the outer cylinder is 60 centimetres diameter and you have the depth of these cylinders is around 45 centimetres and is driven into the soil up to around 10 centimetres.

So if you look at the various steps which are performed while making these cylinder infiltrometer readings, these are the steps which also include the various other operations which you have to start and which we have to take before you lay the cylinders in the field and also before you start observing the various readings.

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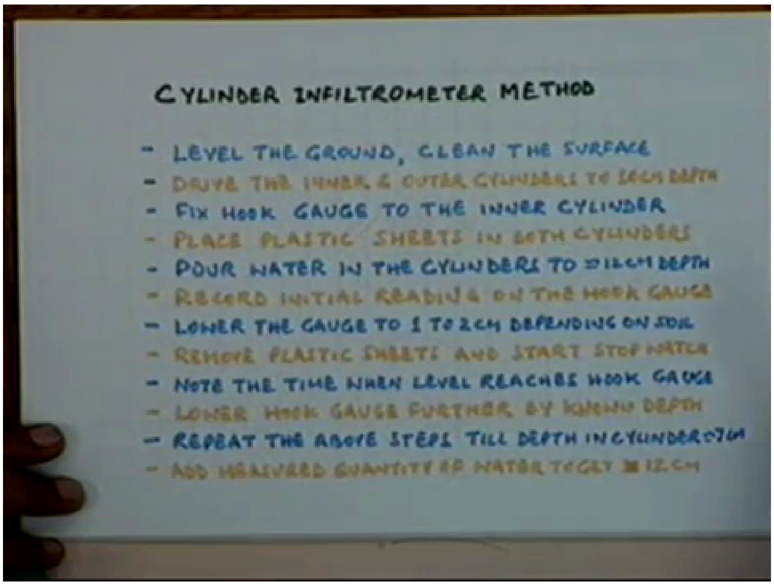

These steps include level the ground, clean the surface so that there is no undulations in the surface itself because at times you will like that throughout this area the level of water is uniform. Those are very small area which you are covering through the cylinders. Then you drive both the inner and then the outer cylinders up to a depth of 10 centimetres in the soil. You will have to fix a hook gauge which will be used to make the measurements or record the levels of water in the inner cylinder.

So for that purpose the hook gauge will be installed. You will have to place a plastic sheet as when you pour the water you want the observations to be taken with respect to time. So when you are pouring the water if you are not ready you will like the water to stay and for that purpose you will like to use plastic sheets so that you can start the time when you start the observation.

Pour water in the cylinder up to a depth of around 12 centimetres and this has to be done in both the cylinders so there is no connection in between the two cylinders. You will have to put the known quantities of water in the inner cylinder but as far as the outer cylinder is concerned you should maintain approximately similar level in the outer cylinder also without making any observations. Record initial reading on the hook gauge. Then the next step is that lower the gauge to 1 to 2 centimetres depending on the soil.

If the soil is very light soil, the filtration rates will be very high. So then it that case you can adjust the gauge up to a level which may be higher level, maybe 2 centimetres because it will take very small amount of time to reach that level. Remove the plastic sheet and start the stopwatch because you want to observe the time when the infiltration starts taking place. Note the time when the level reaches the hook gauge. That means you had set the known difference of level.

How much time it takes to reach that level? That is what you have observed. Lower the hook gauge further by a known depth. Repeat the above steps till depth in the cylinder is reduced to around 7 centimetres. So you are trying to be within a range which is from 7 to 12 centimetres and after you have reached this depth of around 7 centimetres you can add measured quantities of water so as to replenish the depth up to around 12 centimetres again.

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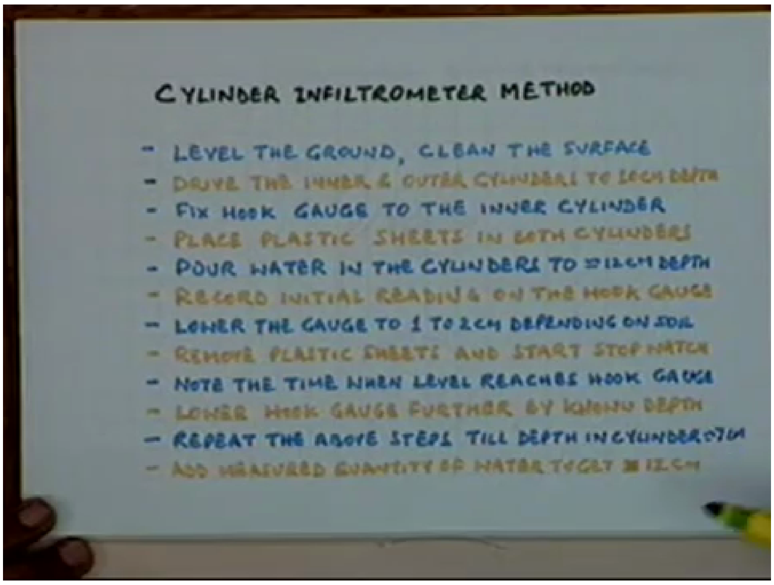

So that is what is the procedure. The whole procedure is there to record the movement of moisture in the soil with respect to time. That is what is going to give you the rate. That is one way. There is another possibility also. In this case you are trying to find out the time which is taken for the water to move a known depth of quantity of water into the soil. You can do the other way around. You can keep on taking the readings at a regular interval and then find out what is the depth at that particular time.

So in any case ultimately you can make a plot where you can transfer these observations and then use that to find out what is the accumulated infiltration depth curve. So that is the procedure which is very simple and that is what is observed. Only thing is that you should try to ensure that the depth is approximately between these limits because in actual practice when you are using the actual irrigations the range is almost similar.

The irrigation is also very strong. These 7 centimetres or 5 centimetres to around 10 centimetres or 15 centimetres depending on again the type of soil which we will come to those things later. And secondly you can make these observations at different locations in the field so as to take the average value because there might be some variations in the soil type, okay.

So with that we will conclude this topic and I will give you a tutorial sheet which will give you some exercises which you can use. Those exercises based on the actual data which has been collected over the field and then you can try to use those data to get infiltration curve, okay.