Soil Science and Technology
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Lecture – 24
Cation Exchange Capacity (CEC)

Welcome friends to this new lecture of Soil Science and Technology, and this will be our lecture 4 for week 5. And we will cover in the next two lectures, we will cover 2 important topics that is cation exchange capacity and then we will be covering the absorption of different pesticides.

In the last three lectures, we have covered you know important aspects of soil chemistry, we have covered detail in details about the silicate clays, and we have also covered the sources of charge on clay colloids specially, the inorganic clay colloids. And today we will be starting a new topic, that is cation exchange capacity and also we will be talking about anion exchange capacity simultaneously.

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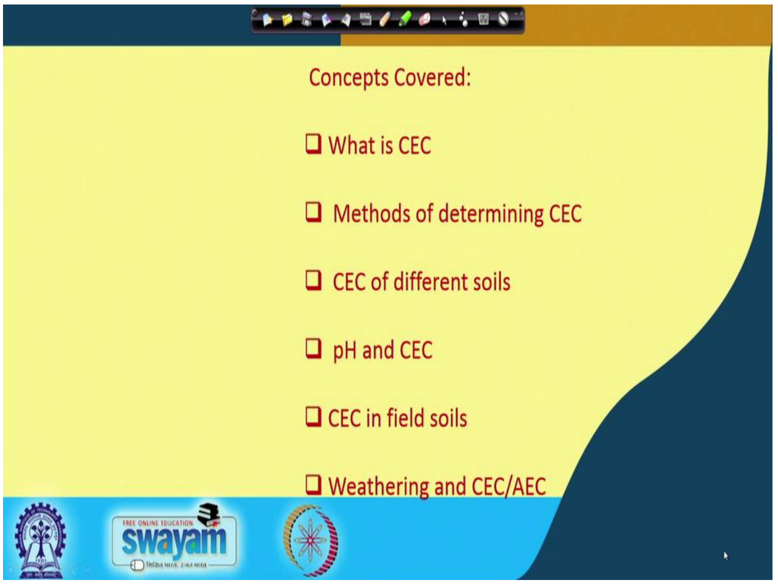

So, what is cation exchange capacity? The first question comes to our mind, what is cation exchange capacity? So, this is the first concept which, we will cover today and then the rest of the topics are methods for determining the cation exchange capacity then cation exchange capacity of different soils.

We will discuss: what is the relationship between the pH and the cation exchange capacity and then we will discuss about the CEC in field soils. And also we will try to see; what is the relationship between different weathering intensity and cation exchange capacity as well as anion exchange capacity.

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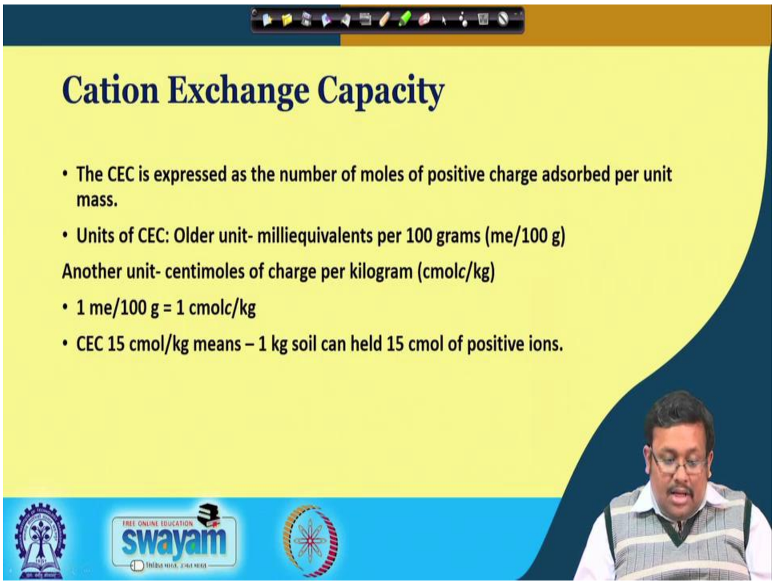

So, let us start our discussion. So, basically you know that in clay as well as in organic matter, which is present in the soil they are highly reactive, because of their charge distribution. And as I have told you that this clay minerals or silicate clays or crystalline silicate clays, you know create a huge amount of both positive and negative charges specially, the negative charges due to isomorphic are isomorphous substitution. And these negative charges are responsible for attracting different positive cations. So, basically the cation exchange capacity is the ability of the soil to exchange the cations from it is surrounding medium and attach and you know and adsorbing and help in adsorbing those cations over the soil surface or clay surface.

So, cation exchange capacity basically also indicates the, it also sometime indicate the fertility status or you know nutrient enrichment status of the soil. So, the cation exchange capacity basically, you know is expressed as the number of moles of positive charge adsorbed per unit mass of soil. So, unit of CEC or cation exchange ; obviously, the short form of cation exchange capacity will be CEC and units of CEC we know earlier, we use a unit called milliequivalents per 100 grams of soil for estimating the cation exchange capacity. However the recent unit for cation exchange capacity is centimoles of charge per kilogram or cmolec per kg of soil. So, basically these 2 units are same. So, 1 milliequivalent per 100 gram is you know is equal to one centimole of charge per kg of soil. So, in other words, see a soil with a CEC of 15 centimole per kg means 1 kg soil can hold, you know 15 centimole of positive ions.

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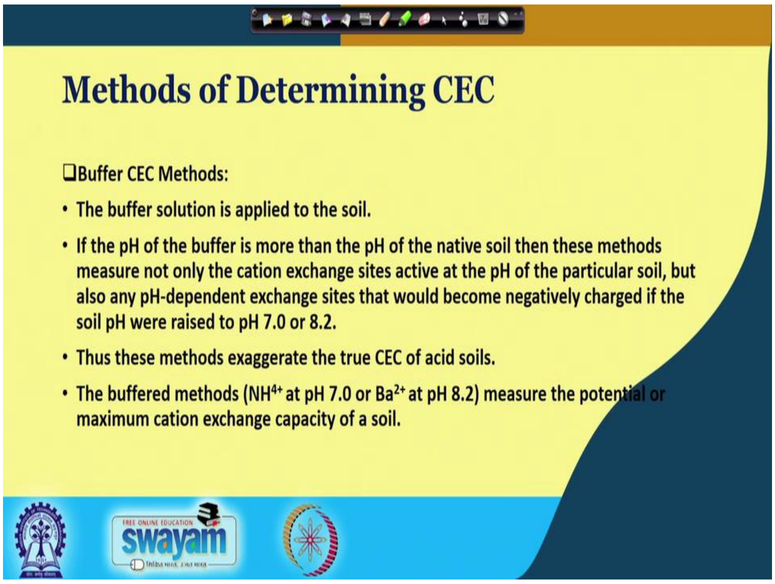

So, let us go ahead and see; what are the different methods of determining the cation exchange capacity.

Now, one of the method is called the buffer CEC method, now what is buffer? Buffer is any chemical that resist the change. So, some sometime, you will see that we use pH buffer for measuring pH. So, basically some standardized chemicals which generally resists the change of chemical status. So, here in the buffer CEC method, basically, we apply the buffer solution to the soil and if the pH of the buffer is more than the pH of the native soil, then this methods measures not only the cation exchange sites activate at the pH of the particular soil. But also any pH dependent exchange site that would become negatively charged, if the soil pH which were raised to pH 7 or 8.2.

So, anyway in summary these methods exaggerate, the true CEC of acid soils and the buffer method that is you know ammonium ions at pH 7 or barium ions at pH 8.2 measure the potential or maximum cation exchange capacity of soil.

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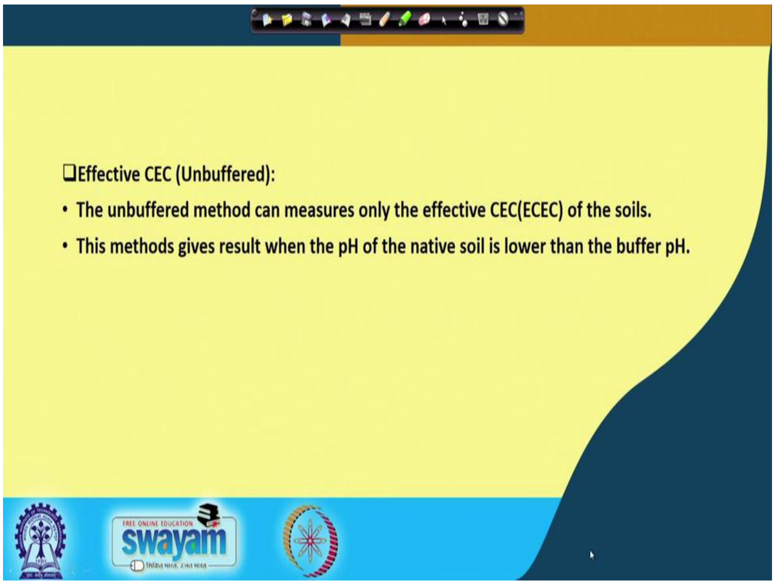

So, another term is called the effective CEC or ECEC this is basically unbuffered.

So, the unbuffered method can measure only the effective CEC or ECEC of the soil and these methods gives results, when p the pH of the native soil is lower than that of buffer pH.

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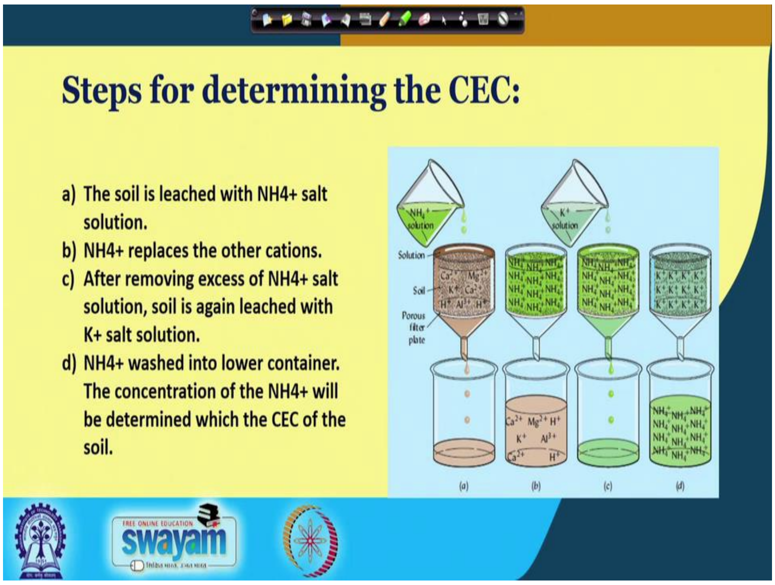

So, these are 2 general methods and what are the different steps for determining the soil CEC? Now you can see we are showing here 4 different beakers. Now, these 4 different beakers and we are describing the process of measuring the CECs in some sequential steps.

So, in the first step, if you can see we are basically pouring the soil in you know in some funnels and we are leaching the soils with ammonium salt solution sometime ammonium acetate. Now, this ammonium ions of this ammonium salt solution replaces the other cations. So, you know that the cations are calcium, magnesium, potassium and then you know other H plus, aluminium.

So, these cations are getting replaced by ammonium cation and as a result of that in the second step, you see in b means the second step all the cations are coming into this leach solution and ultimately all the exchange sites of the soil will be occupied by this ammonium cation. Now so, after removing, so the now in the second step, you can see all the soil has been saturated with ammonium. Now our duty is to remove this excess of ammonium salt solution, then soil is again leached with k plus salt solution.

So, to remove these ammonium attached or adsorbed ammonium cations, we further leach the soil with potassium salt solution. So, what happens this potassium basically replaces these ammonium ions and thus all the exchange sites is further occupied by this potassium. So, ammonium washed into the lower container and the concentration of the ammonium will be determined, which the CEC of the soil. So, that will basically gives you the CEC of the soil so again at the first step.

We will take the soil into a funnel and then we leach the soil with some ammonium salt solution basically, some you know ammonium acetate. And as a result of that you will see that all the ammoniums will replace all the cations in the leach solution, and ultimately, the ammonium ions will occupy all the exchange sites. In the third step, we will remove all the ammonium with the help of potassium salt solution by leaching with the potassium salt solution and finally, we will measure the ammonium in the container and that will give you the idea of the total CEC.

So basically, it is acting as a proxy for measuring the cation exchange capacity because these ammonium will replace all these cations calcium, magnesium, potassium and ultimately, it will show the total cation exchange capacity.

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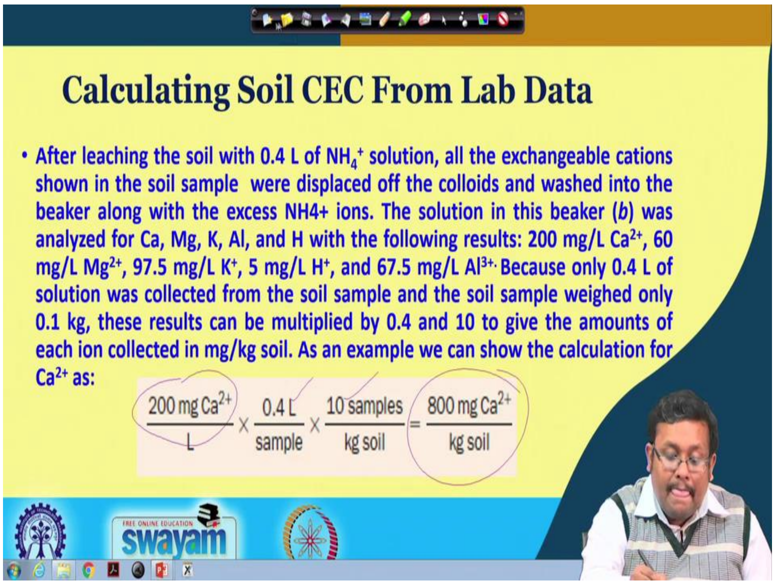

So, let us go ahead and see how we can calculate the soil CEC from lab data. So, after leaching the soil with 0.4 you know; let us assume that after leaching the soil with 0.4 litre of ammonium solution, all the exchangeable cation shown in the soil samples were displaced off the colloids and washed into the beaker along with the excess ammonium ions. So, the solution in this beaker b that is in the second step, was analysed for calcium, magnesium, potassium, aluminium and hydrogen or you know H plus ions with the following results and we are getting the following results that is 200 milligram per litre of calcium ions, 60 milligrams per litre of magnesium then 97.5 milligram per litre of potassium and then 5 milligram per litre of H plus. And 67.5 milligram per litre of AL^3 plus.

So because, only 0.4 litre of the solution was collected from the soil samples and the soil sample weighted only 0.1 kilo. So, we you can convert these results to by multiplying with 0.4 and 10 to give the amount of each ion collected in milligram per kg of the soil. So as an example, we can show we can see the example for calcium, we are getting 200 milligram of calcium per litre and then we are multiplying it with these 2 multiplication factor to convert it to make milligram per kg of soil. So, basically we are getting 800 milligram of calcium ion per kg of soil.

So, this is simple. So, let us see what is the next step.

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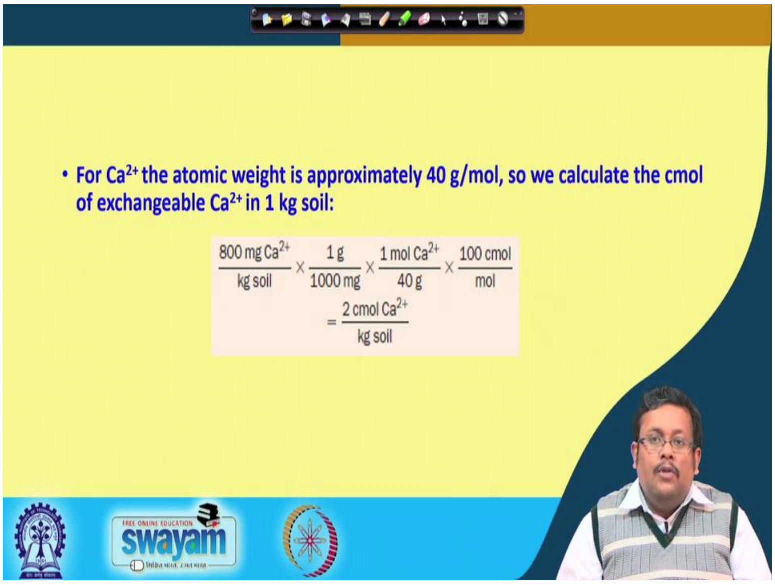

So, in the next step for calcium, you know the atomic weight is approximately 40 gram per mole. So, we can calculate the centimole of exchangeable calcium in 1 kg of soil. So, basically we have to convert this 800 milligram of calcium into a centimole of calcium. So, basically you know that 40 grams mean 1 mole. So, from there we can, we know we can calculate mill mole and centimole.

So basically, when we convert this 800 when we convert this 800 milligram of calcium, we will get ultimately 2 centimole of calcium ions per kg of soil. So, our next step for this calculation so once, we calculate these centimole.

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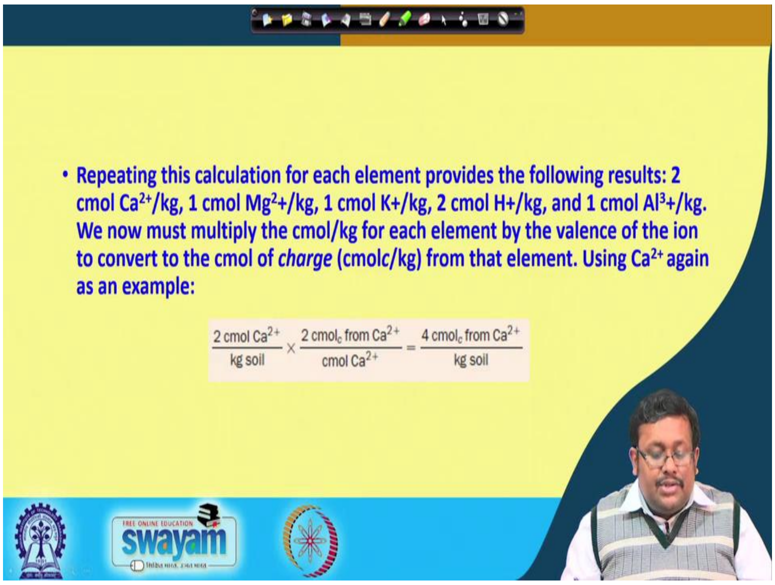

Now, next step is to repeating this calculation for each elements and ultimately providing for ultimately, which will ultimately provide the following results. So, we are getting ultimately 2 centimole for calcium per kg, 1 centimole magnesium per kg, 1 centimole potassium per kg, 2 centimole H plus per kg and 1 centimole of Al^3 plus kg.

So, we are getting the concentration of each of the cations, which were adsorbed previously and ultimately contributing to the CEC of the soil. So, we have measured individual concentration in centimole per kg of soil, we have covered up to this point. Now, we have to multiply the centimole per kg for each element by the valency of the respective ion to convert it to the centimole of charge. So, from centimole to centimole of charge, you have to multiply with their respective valency of the cation. So, you will get the c mole c per kg of soil.

So, for example, if we use the calcium again as an example, you can see we are here using 2 centimole of calcium per kg of the soil, and then we are multiplying it with 2 because, you know the calcium valency is plus 2. So, we are getting 4 centimole charge from calcium plus ion calcium 2 plus ion per kg of soil. So, for individual element we have to calculate this centimole of charge.

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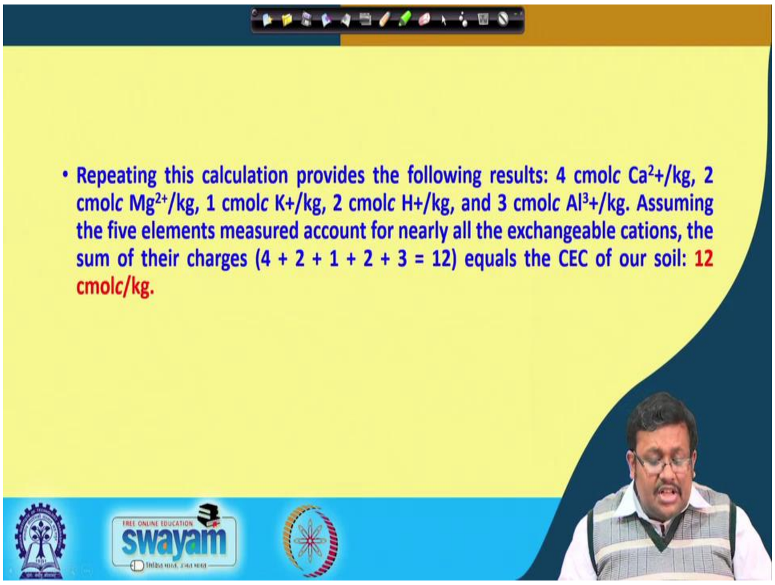

So, repeating we have to repeat this calculation and we will provide the following results like 4 centimole of calcium per kg, then 2 centimole of centimole charge of magnesium per kg, then 1 centimole charge of potassium per kg of soil, then 2 centimole charge per you know H plus per kg of soil and 3 centimole charge of Al^3 plus plus per kg of soil. Now assuming the 5 elements measured all the five elements measure account for nearly all the exchangeable cations, if we assume that there are no other exchangeable cation then the sum of their charges that is 4 plus 2 plus 1 plus 2 plus 3 that is 12 basically, equals to the CEC of the soil.

So, that is 12 centimole kg per centimole charge per kg. So, what are the steps? If you jot down, if you summarise first of all, we have to leach the soil with the ammonium salt, which will replace all the adsorbed cations into the soil solution into to the leachate solution ultimately, we will be leaching this ammonium with the help of potassium and then these further leached down all the ammonium can be calculated and it will basically you know, it will basically indicate the cation exchange capacity.

Now, once we calculate the so, for estimating the cation exchange capacity we have to measure the concentration of individual cation, which were replaced by ammonium after we calculate them then we have to multiply with some multiplication factor to convert it to milligram per kg. And after we convert it to milligram per kg of soil then you we have to convert it to centimole because, we know the amount or gram of individual element per mole and from the centimole, we have to convert it to centimole of charge per kg of soil. So, repeating all this thing for all the elements then we have to submit to get the total cation exchange capacity.

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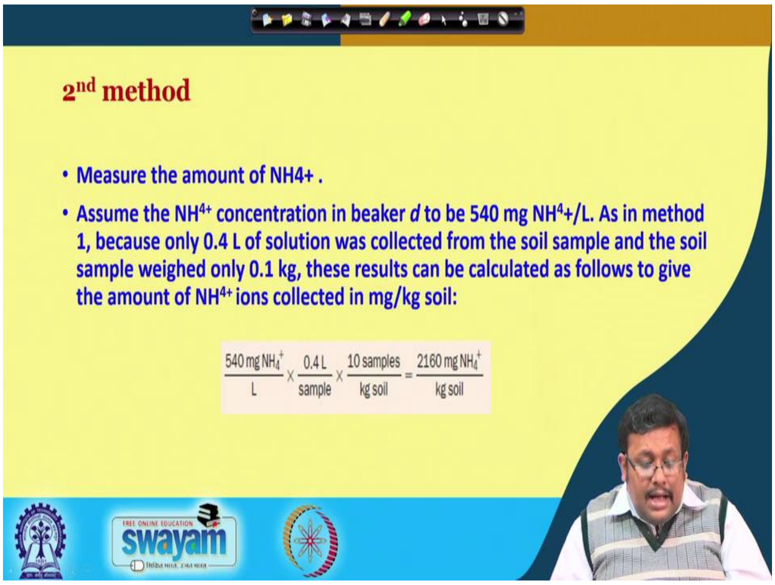

So, another method: if you remember you know in the previous method, what we did we basically measured the concentration of all the cations, which were leached in the first beaker with the help of ammonium salt solution. However, if you remember the total process at the end, we are further leaching all the adsorbed ammonium with the help of potassium solution.

So, by measuring the total ammonium concentration also we can also measure the CEC there are 2 methods one method says that you measure all the cations, which are previously replaced or in the first stage the cations, which were replaced in the first stage with the help of ammonium. So, you measure them individually their concentration covert them into their centimole, and further centimole of charge and then add them, it will finally, give you the total centimole total CEC.

Another method, the second method says that you measure all the ammonium, which were leached by the by the potassium in the last stage. So, you assume that ammonium concentration is beaker d that means the last stage to be 540 milligram per litre. So, as in the method one because of 0.4 litres of solution was collected from the soil sample and the soil sample weighted only 0.1 kilo these result can be further just like the previous.

These results can be calculated as follows to give the amount of ammonium ions collected for mg per kg of soil. You can see we are multiplying with the same multiplication factor that is 0.4 and 10 to get a milligram of ammonium ions per kg of soil.

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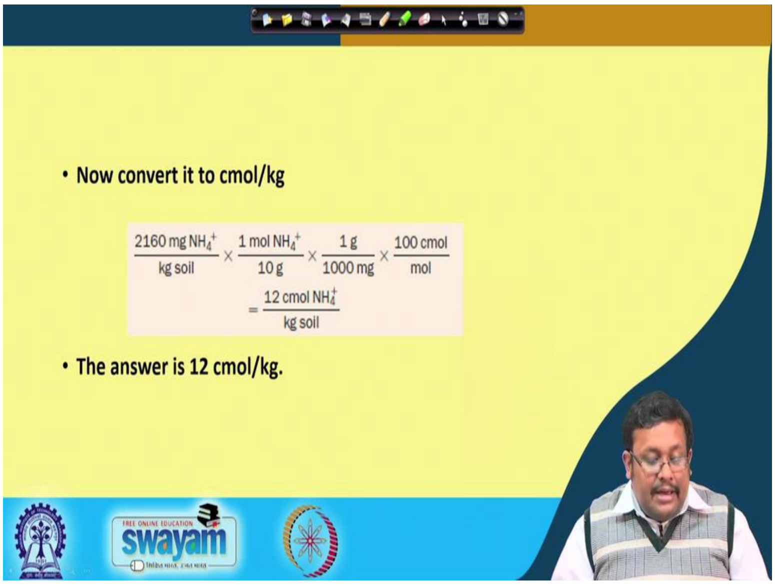

And ultimately we are getting, And now in the second stage we are converting it to centimole, we are ultimately getting 12 centimole of ammonium ions per kg of soil and then these centimole will be since ammonium has a single valency. So, further we will be getting that answer is 12 centimole per kg.

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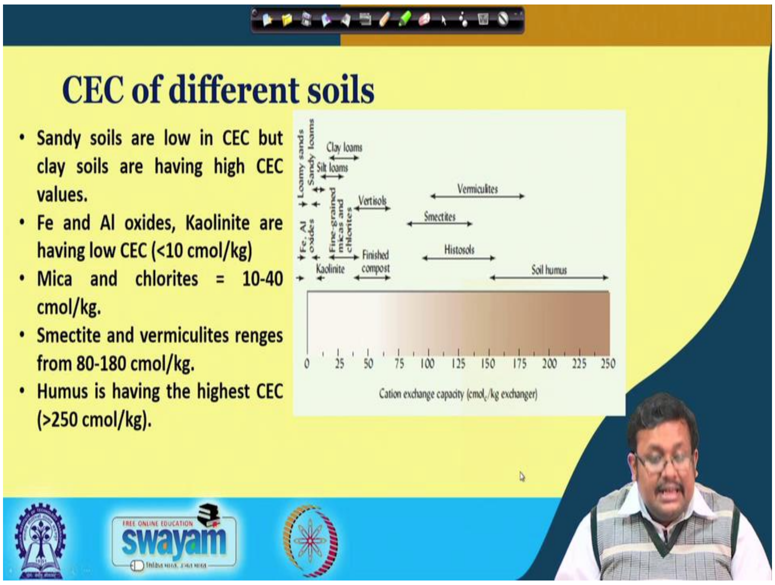

So, final our results is CEC 12 centimole c or 12 centimole, you know 12 centimole charge per kg of soil. Now what are the CEC of different soils? Now the CEC of the different soils also varies widely from one soil to another soil, depending on their chemical composition. So, sandy soils are low in CEC, but clay soils having high cation exchange capacity varies why because, you know the sandy soil are basically composed of sands and sands are chemically inert whereas, the clay soils are made of these crystalline clay minerals, which are chemically reactive, because of their negative charge development. So obviously, a clay soil will have higher CEC then that of a negative that of a sandy soil.

Now iron aluminium oxides, kaolinite are having low CEC that is low less than 10 centimole per kg and whereas mica and chlorites has 10 to 40 centimole per kg, and smectite, and vermiculites ranges from 80 to 180 centimole per kg, and the humus. Remember that humus is having the highest CEC that is more than 250 some you know most of the time it is more than 250 centimole per kg. So, remember that among the clay minerals, if you compare clay minerals as well as the humus, humus is showing more cation exchange capacity than rest of all the clay minerals. So, humus is much more reactive than the clay.

So, you can see based on the clay mineral nature or clay mineral type the cation exchange capacity is wearing and you know the reasons behind this because, you know that in case of kaolinite there is no isomorphic substitution. So, as a result of that there is you know very less amount of negative charge development, when there is a very less amount of negative charge development; obviously, their cation exchange capacity will be low all similarly. So, in case of smectite and vermiculites obviously, you will be having high amount of isomorphous substitution.

In that octahedral layer if you remember from our last lecture then obviously, there will be high amount of negative charge. And these negative charge high amount of negative charge will ultimately, contribute to the high cation exchange capacity mica you remember that both the layers, the inter layer space has collapsed by the small potassium cation. So, there is no space for adsorption of the potassium ion. So, as a result it is also have intermediate ranges of cation exchange capacity. So, we have an basic idea about the cation exchange capacity of different soils.

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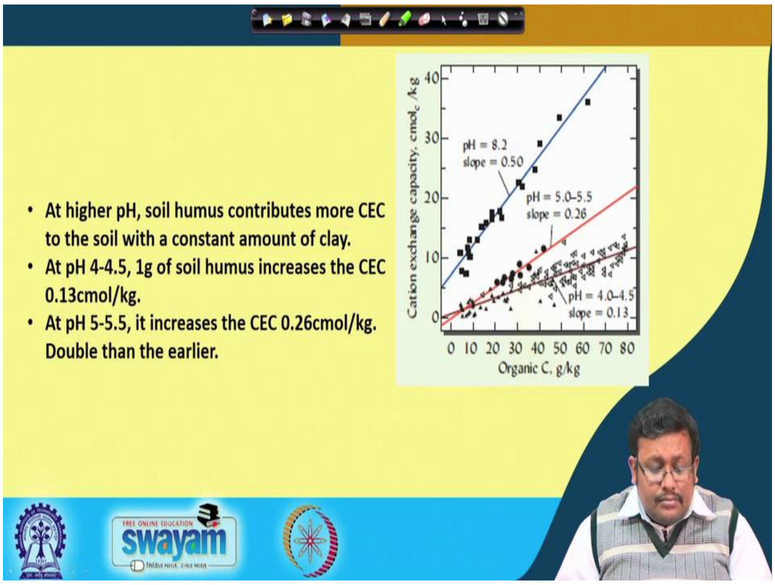

So, remember that at higher pH soil humus contributes more cation exchange capacity to the soil with a constant amount of clay. So, if you see this is the relationship between organic carbon in gram per kg and cation exchange capacity, which is being expressed in terms of centimole of charge per kg. So, if you go back to the previous, you know previous couple of slides, you will see that here, you should replace the cmol that cmolc obviously it should be centimole of charge.

So, please you know replace this c mole with centimole c, I will try to change this while I will be distributing the ppt with you ok. So, it will be centimole of charge per kg of soil. So, let us move ahead and see so, what I was talking about the relationship between organic carbon and cation exchange capacity in centimole of charge per kg of soil. So, you can see that at pH 4 to 4.5 in this line; obviously, at pH.

You know 4 to 4.5 1 gram of soil humus increases the CEC of 0.13 mole per kg. So, if you increase 1 gram of soil humus because, we are getting a slope of 0.13. So that means, so, in this case for this line, we are getting a slope of 0.13. That means, if you change the you know the organic carbon by 1 unit that is 1 gram per kg you will get an increase CEC of 4 to I mean of increase CEC by 0.13 centimole charge; however, at pH 5 to 5.5.

We are getting you know a slope of 0.26. So, slope is higher. So, one the slope is higher; obviously, that interpretation will also change. So, we are getting at pH 5.5, when we are increasing the organic carbon 5.5 concentration with by 1 gram per kg the pH will increase 0.26 centimole charge per kg. So, you can see at higher pH soil humus contributes more CEC. So, higher pH we are getting here 5 to 5.5 and here 4 to 4.5, we are getting a CEC increase of 0.13 centimole c per kg here for 4 to 4.5.

However, in case of 5 to 5.5, we are getting an increase of 0.26 centimole charge per kg, which is double than the earlier. That means, again it is re establishing the fact that at higher pH soil humus contributes more CEC in the soil with a constant amount of clay that is a you know prerequisite that your clay has to be constant in both the condition.

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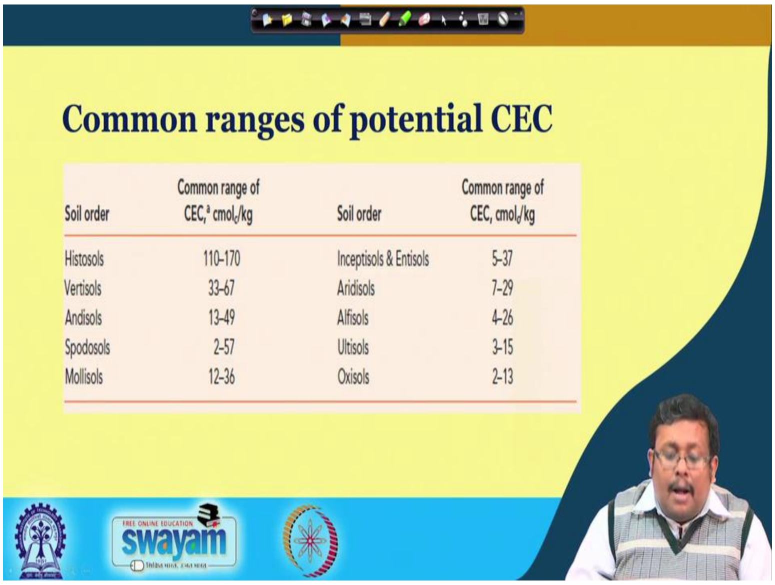

So, let us see some common ranges of potential common ranges of potential cation exchange capacity, if we, I am trying to show you the important soil orders and their corresponding CEC. So, if you consider histosols; obviously, we are getting the highest CEC because, it is dominated by organic matter. So, we are getting you know c mole 100- 110 to 170; 170 c mole c per kg of soil and in case of vertisols, we are getting 33 to 67. And obviously, in case of aridisol, which is dominated by sand we are getting lower somewhat lower spodosols, we are getting lower in case of oxisols, which is basically dominated by iron and aluminium oxides.

We are getting very low which is 2 to 13. So, you know that in case of iron aluminium oxides kaolinite, there is low amount of CEC. So, that is the reason that you know we are getting low amount of cation exchange capacity in case of this oxisols. However, in case of histosols, we are getting high amount of you know cation exchange capacity.

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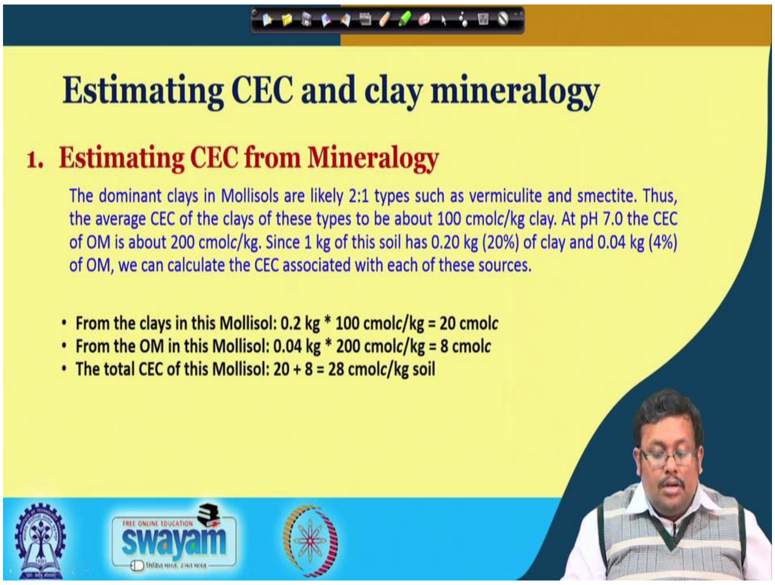

So, let us do some you know let us solve some problems. So, you know we want to estimate the cation exchange capacity and clay mineralogy.

So, we want to estimate the first step, we want to estimate the cation exchange capacity from soil mineralogy or clay mineralogy. So, the dominant clays in mollisols are likely 2 is to one type such as vermiculite and smectite thus the average CEC of the clays of these types to be about you know 100 centimole per kg of clay 100 centimole charge per kg of clay. So, at pH 7 the CEC of organic matter is about 200 you know that I showed you in the last couple of slides the ranges of you know CEC for organic matter.

So, it will be we can assume it by you can assume it as 200 centimole per kg, since 1 kg of this soil has 0.20 kg that is 20 percent of clay and 0.04 that is 4 percent of organic matter we can calculate the CEC associated with each of these sources. So, let us see what is the CEC from each of these sources. So, from the clays in the mollisols we are getting 0.2 multiplied by hundred centimole charge per kg.

So, that is 20 centimole charge per kg. So, basically we have to multiply the respective cation exchange capacity with the fraction of that mineral, which is present into the soil. So, you know that here it is 0.2 kg per clay mineral we are getting in 1 kg of soil. And from organic matter of the mollisol, we are getting 200 multiplied by 0.04, which is 4 percent. So, we are getting 8 centimole per charge. So, ultimately the total CEC from the mollisol will be 20 plus 8 that is 28 centimole charge per kg of soil.

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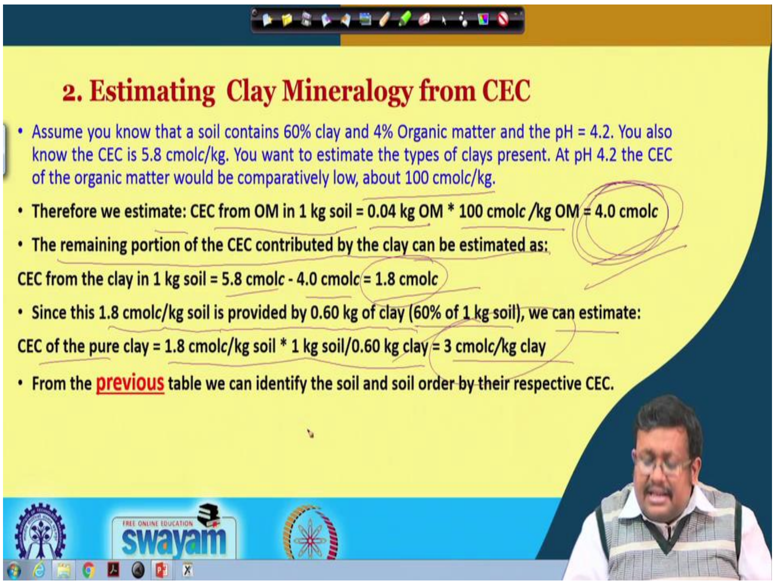

So, it is a one type of solution and if you try to estimate the clay mineralogy from CEC, you know we assume that is soil contains 60 percent of the clay and 4 percent of organic matter and you know at the pH 4.2. So, you also know the CEC is 5.8 centimole charge per kg. So, you want to estimate the types of clays present. So, at pH 4.2 the CEC of organic matter would be comparatively lower about 100 centimole charge per kg. So therefore, let us estimate.

So, we estimate that is CEC from organic matter in 1 kg of soil; obviously, it will be we know 0.04 kg organic matter that is 4 percent multiplied by 100 centimole, we have assumed that 100 centimole charge. So, it will be 4 centimole charge, the remaining portion of the CEC contributed by the clay can be estimated as so, the total CEC is basically contributed by both clay mineral as well as organic matter; however, we have already calculated the CEC, which is being contributed by the organic matter.

So, the rest of the CEC will be automatically contributed by a clay in 1 kg of soil. So, the rest of the CEC will be 5.8, we know the total CEC and we are subtracting the centimole charge, which is coming from organic matter; so 1.8 centimole charge. So, this 1.8 centimole charge has to be you know has to be contributed by the clay. So, since 1.8 centimole per kg of soil is provided by 0.60 kg of clay that is 60 percent of 1 kg of soil.

We can estimate the CEC of the pure clay is basically 3 centimole per kg of clay. Now from the previous day which I showed you different order, if you can compare that previous table, we can identify the soil and the soil order by the respective CEC. Now we are getting 3 centimole charge per kg of clay. So, if we go back to the previous table. So, basically we will be ultimately getting a CEC, which can be contributed by either oxisols, either ultisols or spodosols because, they have the range which covers that 3 centimole charge per kg of soil. So, from that you can calculate, you can as identify the soil order not only the soil order, but also you can get a hint about the clay mineralogy.

So, guys I hope that you have got some, you know basic ideas about the cation exchange capacity and how we calculate, how we estimate the cation exchange capacity in this lecture. And we will try to finish this lecture, we will try to finish this topic rather in this coming lecture and then we will be covering also the anion exchange capacity and then we will go to around next topic.

Since then, thank you very much.