Soil Fertility and Fertilizers
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Lecture 04
Importance of Soil Nutrient Management and Basic Soil Plant Relationship

Welcome friends to this fourth lecture of week one of NPTEL online certification course of Soil Fertility and Fertilizers. And in this week we are talking about importance of soil nutrient management and basic soil plant relationship. Now in our previous three lectures we have discussed about the basics of plant nutrition, we have also discussed the criteria for essentiality we have classified the nutrient based on their relative amount required as well as based on their essentiality.

We have seen different types of deficiency symptoms of plants and we have also discussed the chelates and different aspects of nutrient cycling. We have discussed some important principles like law of minimum, law of diminishing return and also we have discussed about the law of maximum. Now in this week we are going to discuss the following concepts.

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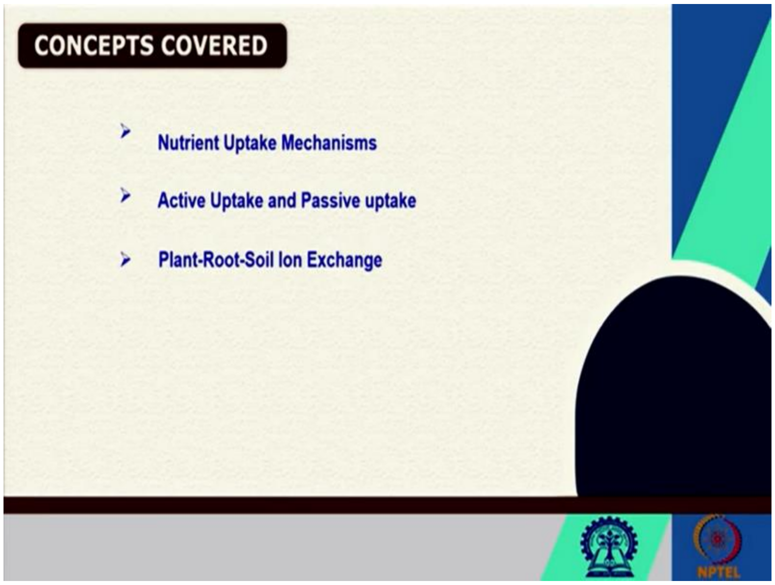

These are the nutrient uptake mechanisms we are going to discuss, also we have we are going to discuss the active uptake and passive uptake and finally we are going to talk about the plant root soil iron exchange. These are all important concepts as far as the plant nutrition is concerned.

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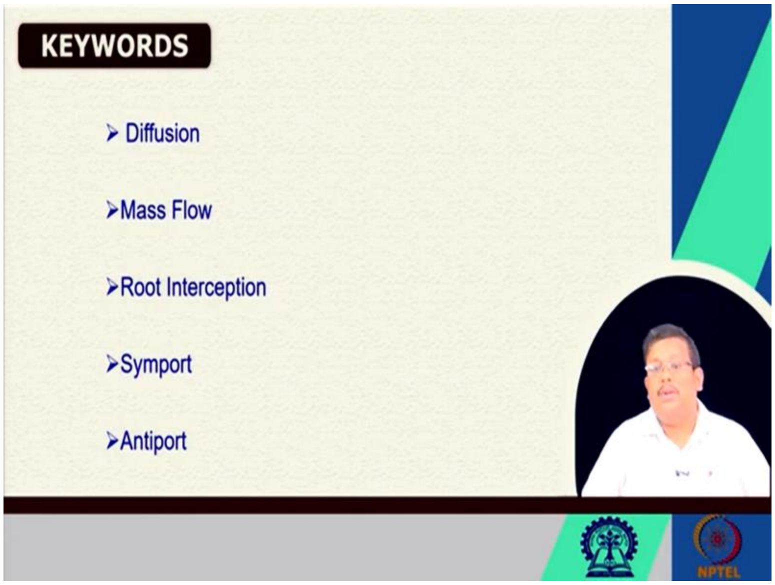

So these are some of the keywords which we are going to discuss in this lecture diffusion, mass flow, root interception, symport, antiport so we are going to discuss all these important terms in this lecture.

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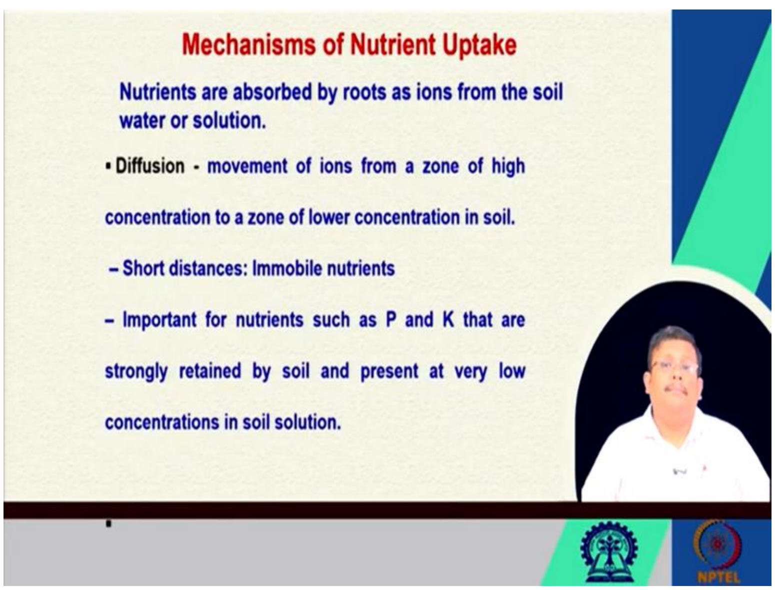

So let us start with the mechanism of nutrient uptake. Now you know that nutrients are absorbed by root, roots as ions from the soil water or soil solution. Now there are couple of ways through which these nutrients are absorbed by the plant roots. The first mechanism is diffusion, so diffusion is a process in which the that supports the movement of iron from a zone of high concentration to a zone of low concentration.

Now in case of soil the ions are generally, the ions show their movement from the higher concentration to lower concentration so they create a concentration gradient. And this diffusion process is mainly helpful for short distances and of course these are very useful for immobile nutrients. Now these diffusion process is very important for nutrients such as phosphorus and potassium that are strongly retained by soil and present at very low concentration in soil solution.

So the nutrient uptake by the plant roots for phosphorus and potassium is mainly governed through this diffusion process.

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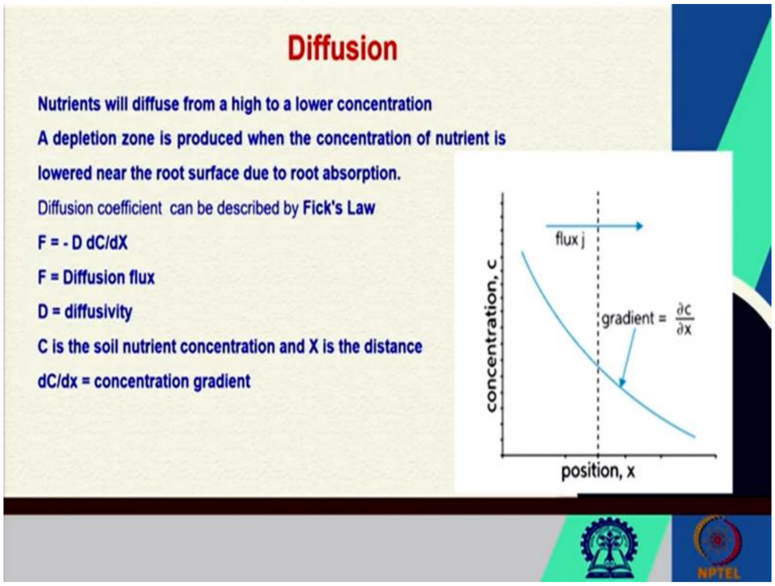

Now this diffusion process generally follows the Fick's law. So in soil the nutrients will always diffuse from a higher concentration to lower concentration and a depletion zone is produced when the concentration of nutrient is lowered near the root surface due to root absorption. So if we follow the diffusion I mean the Fick’s law it is clear that this is the Fick's law that is F equal to minus D into dC by dX where F is basically the diffusion of flux and D stands for the diffusivity coefficient and C is the concentration of soil concentration of nutrient and X is the distance and dc by dx is the concentration gradient.

So you can see, if you see this plot the x axis shows the distance between the ions as well as the plant root and here you can see that C stands for the concentration of ions in a soil solution. And here we see this concentration gradient that is the ions will always move from higher concentration to lower concentration. So this gradient is denoted by this dC by dX. And since the movement of ion generally occurs from the higher concentration to lower concentration we generally indicate it by a negative sign. So this is the diffusion law and given by Fick and so nutrients in soil follows this law for movement from soil solution to the plant root.

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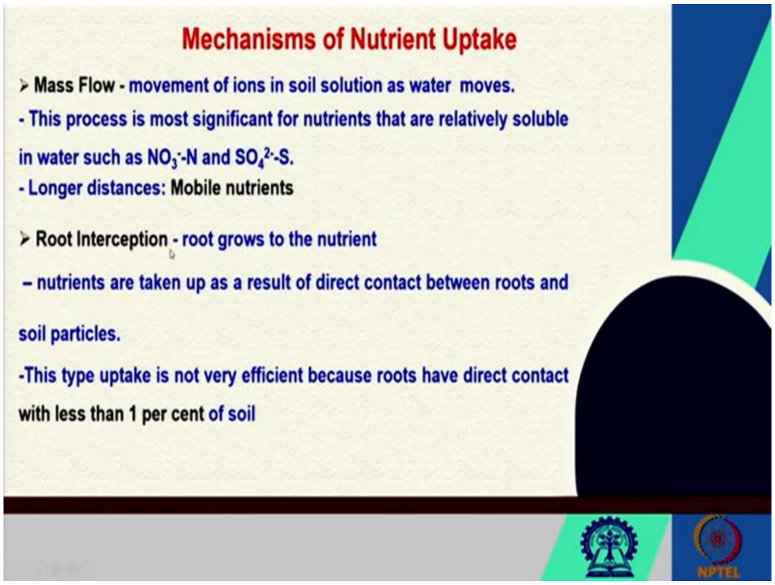

Now the next important mechanism is called the mass flow mechanism. Now mass flow is basically movement of ions in soil solution as water moves. Now this process is most significant for nutrient that are relatively soluble in water. So what are the nutrients which are highly soluble in water? Like nitrate, sulphate, you know that nitrate and sulphate are the two plant available forms for nitrogen and sulfur. So these two nutrients mainly move in soil in ionic form through the process of mass flow. The third I mean and another important point regarding mass flow is this mass flow generally is useful for longer distances and for mobile nutrients.

The third important process is root interception in the root interception process the root generally grows to the nutrient and nutrients are taken up as a result of direct contact between roots and soil particles. And this type of uptake is not very efficient because roots have direct contact with less than one percent of the soil. So these are the three major mechanism through which the nutrients are uptaken by the plant roots. First one is diffusion, second one is mass flow and the third one is new root interception.

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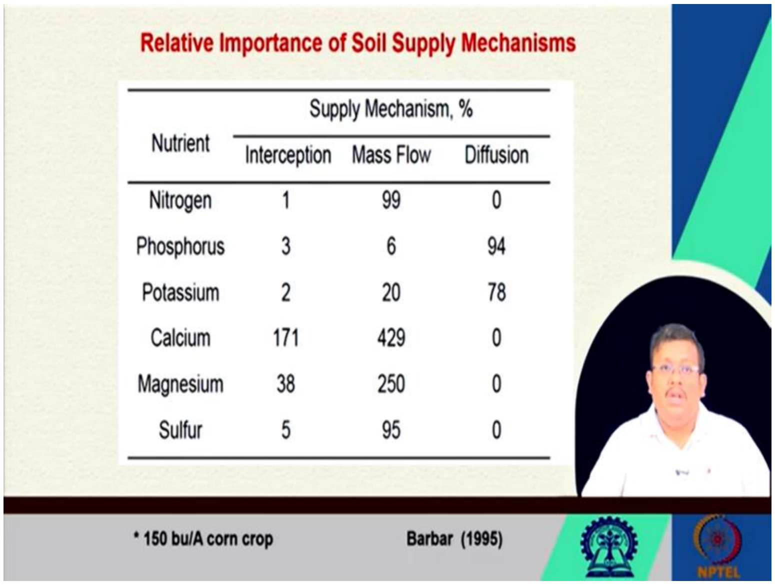

So if you see the relative importance of soil supply mechanism or this nutrient supply mechanism then you can see that for nitrogen majorly this nitrogen is supplied to mass flow and phosphorus is majorly or mainly supplied through diffusion process potassium is mainly through the diffusion process as we have discussed.

In case of calcium mass flow is important and at the same time calcium also shows you know considerable amount of root interception. Magnesium is mainly through mass flow and sulphur is also mainly through mass flow. So this table shows the relative importance of different mechanisms for supplying these plant nutrients to the roots.

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Now remember that when these nutrients are uptaken by the plants these nutrient ions must be dissolved in water we call it soil solution. Now they move from soil solution to vascular center of plant root passing through at least one cell membrane this is the skin that hold the cells liquid contents inside.

Now this movement across the membrane may be either passive or active movement. So these movement of nutrient based on how they are transferred across the membrane, we generally divide this process into two major categories one is passive uptake another is active uptake.

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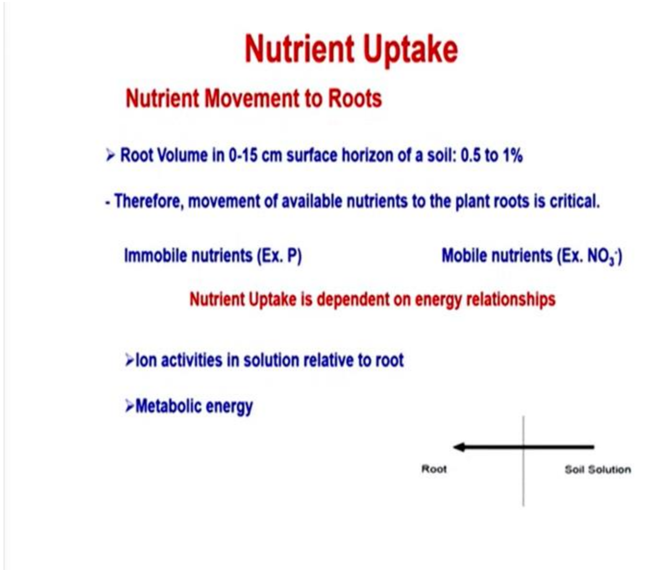

Now remember another important thing that root volume in 0 to 15 centimeter surface horizon of a soil is only 0.5 to 1 percent. So therefore movement of available nutrients to the plant roots is critical. Some example of immobile nutrients like phosphorus and mobile nutrients like nitrate and this nutrient uptake is dependent on energy relationship. And this energy relationship basically you know takes into account this metabolic energy as well as iron activities in solution relative to root. So we are going to discuss this in details in our upcoming slide.

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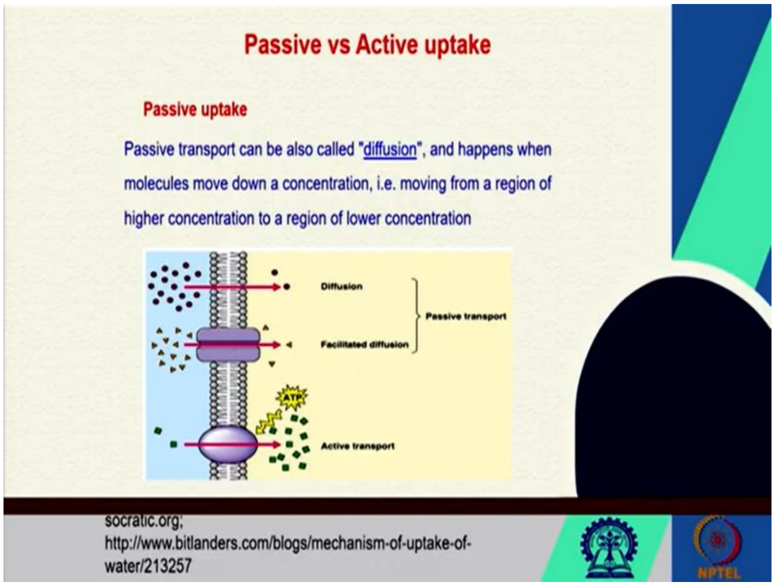

So let us start discussing with the passive uptake. Now passive uptake or passive transport can be also called the diffusion process. And happens when molecules move down a concentration that is moving from a region of high concentration to a region of low concentration. So just like the diffusion generally occurs along the concentration gradient this passive uptake always goes through I mean always also occur along these concentration gradient.

So here, in this picture it is quite clear that through this diffusion process the nutrients are moving across this plasma membrane. So this is a process of diffusion so this is a inside the plant root and this is outside the plant root. So here you can see the concentration of the nutrients outside the plant root that is in the soil solution is quite high and here through the diffusion process the movement of ions or nutrients can be seen so this is a diffusion process.

Sometimes this diffusion has to be facilitated through some carrier proteins. Now, in both these diffusion as well as this facilitated diffusion through carrier proteins are combinely termed as passive transport.

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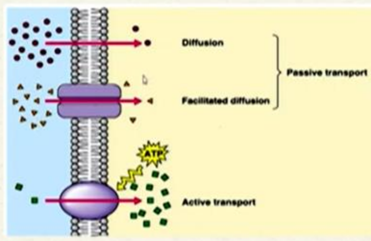
Passive vs Active uptake

Passive uptake

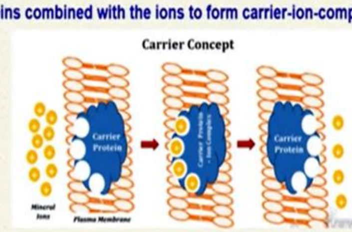
Passive transport can be also called "diffusion", and happens when molecules move down a concentration, i.e. moving from a region of higher concentration to a region of lower concentration



socratic.org;
http://www.bitlanders.com/blogs/mechanism-of-uptake-of-water/213257

Carrier Proteins

- The plasma membrane is completely impermeable to some ions.
- The absorptions of these ions is facilitated by some special proteins on the plasma membrane called "Carrier Proteins".
- Carrier proteins combined with the ions to form carrier-ion-complex.



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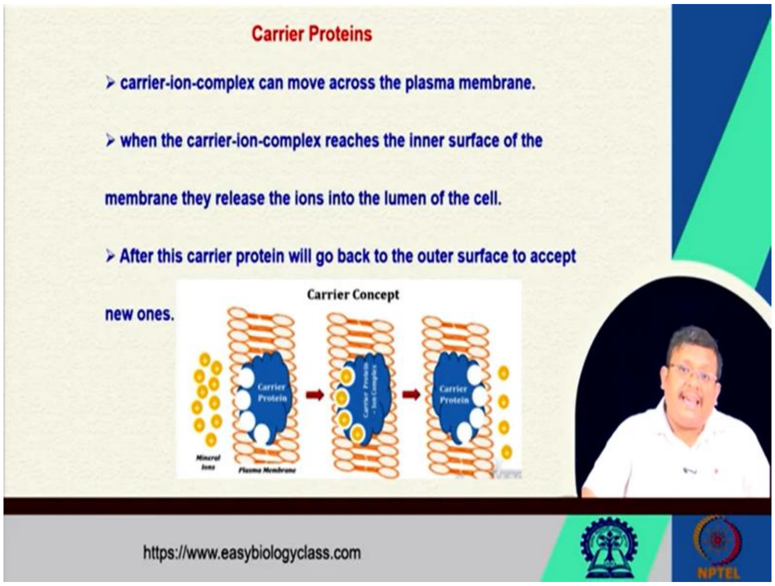

So let us discuss what are these carrier proteins. Now the remember that the plasma membrane is completely impermeable to some ions so here you can see although in case of diffusion simple diffusion process these nutrients can move freely from outside of the plant root to the inside of the plant root. However there are some elements or nutrients which cannot pass through diffusion simple diffusion process.

They need some you know they needs this facilitated diffusion. So because the plasma membrane is completely impermeable to these ions. So the as a result the absorption of these ions is facilitated by some special proteins on the plasma membrane and they are called carrier proteins. Carrier proteins generally combine with the ions to form the carrier iron complex.

So here you can see these are mineral ions and this is the carrier protein inside the plasma membrane and these are some of the binding sites, so these binding sides will bind these ions. So they will create this carrier protein ion complex and ultimately they will reach towards the inside of the plant root they will release these nutrients inside the cell. And then again they will go back to get more mineral ions. So these are the examples of this carrier proteins.

Now this carrier ion complex which we have seen can move across this plasma moment and when the carrier ion complex reaches the inner surface of the membrane they release the ions into the lumen of the cell. Now after this these carrier proteins go back to the outer surface to accept the new ones. So this is a cyclic process through which the carrier proteins continuously take up these mineral ions form this carrier protein ion complex and then release those ions to the lumen of the cell.

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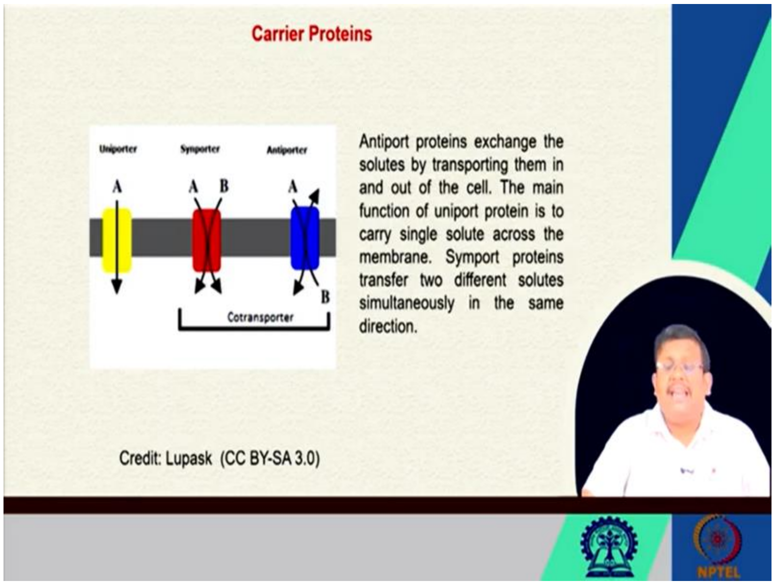

Now this carrier proteins can be based on their mechanism of transport. This carrier proteins can be differentiated into three major types one is uniporter second is symporter and third is antiporter. So here these antiport proteins exchange the solutes by transporting them in and out of the cell. The main function of uniport is to uniport protein is to carry single solute across the membrane. And simple proteins transfer two different solutes simultaneously in the same direction.

So symporter and deporter can shows the importance of co transporter. Because here two different solutes are being moved one in case of symporter we can see that they are moved in the same direction. However in case of antiporter they move in different direction.

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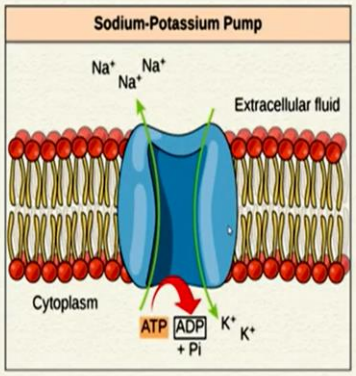
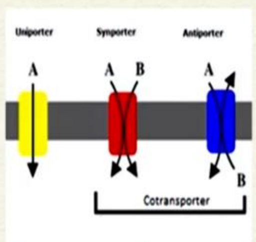
Active uptake



Active transport is a mode of transportation in plants, which uses stored energy to move the particles against the concentration gradient. In a plant cell, it takes place in the root cells by absorbing water and minerals.

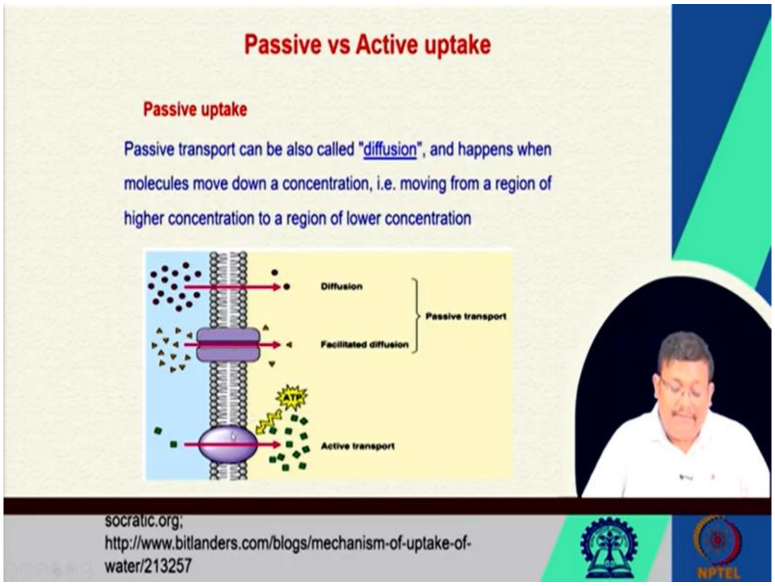
Credit: CNX OpenStax (CC BY 4.0)

Carrier Proteins



Antiport proteins exchange the solutes by transporting them in and out of the cell. The main function of uniport protein is to carry single solute across the membrane. Synport proteins transfer two different solutes simultaneously in the same direction.

Credit: Lupask (CC BY-SA 3.0)



The next important concept is active uptake. Now this active transport is a mode of transportation in the plants which uses the stored energy to move the particles against the concentration gradient. In a plant cell it takes place in the root cells by absorbing water and minerals. Now depending on the mode of operation these carrier proteins are of three types.

The first one is called the unipoter carrier protein, the second one is called the synporter carrier protein and the third one is called the antiporter carrier proteins. Now this antiporter carrier proteins exchange, these antiporter carrier proteins exchange solutes by transporting them in and out of the cell. And this main function of this uniport protein is to carry the single solute across the membrane. And synport protein transfer two different solute simultaneously in the same direction.

So we can see that in case of synport protein or antibody protein two different solutes are simultaneously moved together so these are known as also co transporters. So let us discuss what is active transport now active transport is a mode of transpiration in plants which uses stored energy to move the particles against the concentration gradient. Now in a plant cell it takes place in the root cell by absorbing water and minerals.

So here you can clearly see that this is the cytoplasm and this is the extracellular fluid. And the here in this case the active transport generally occurs by spending some amount of energy from the ATP and ultimately creating ADP plus pi. If you go back to the previous slide we can clearly see the difference between the passive uptake and active uptake.

In case of passive uptake we have seen that the concentration of the solutes are higher and the movement of the solutes you know generally goes from higher concentration to the lower concentration so this is a diffusion process. And also here in case of facility diffusion we also seen that the movement of iron was facilitated by some carrier proteins although the movement of iron was along the concentration gradient.

However in case of active transport we can see that the movement of ions against the concentration gradient. Here we can see inside the cell the concentration is more as compared to the outside the cell. So here they are moving against the concentration gradient and these movement is facilitated by some energy or ATP, so this is called the active transport. So just because of this active transport uses the stored energy to move the particles against the concentration gradient.

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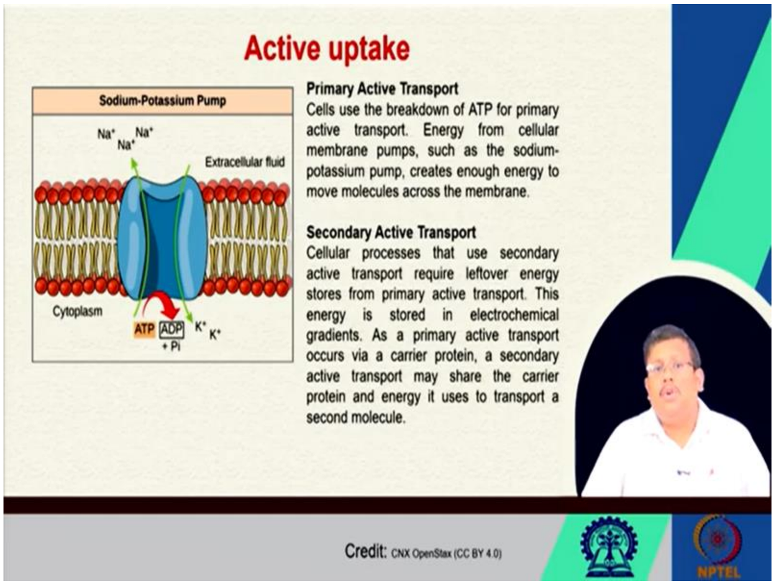

Now active transport is also of two types one is called the primary active transport and other is called the secondary active transport. Now in case of primary active transport the cells use the breakdown of ATP for primary active transport and energy from cellular membrane pumps such as the sodium potassium pumps. As you can see here this is called the sodium potassium pumps creates enough energy to move the molecules across the membrane.

So this is known as the primary active transport. What is secondary active transport cellular process that use secondary active transport require leftover energy stores from primary active transport this energy is stored in electrochemical gradients as a primary active transport as a primary active transfer occurs via carrier protein a secondary active transport may share the carrier protein and energy it uses to transport a second molecule. So this is the major you know features of these are the major features of active transport or active uptake.

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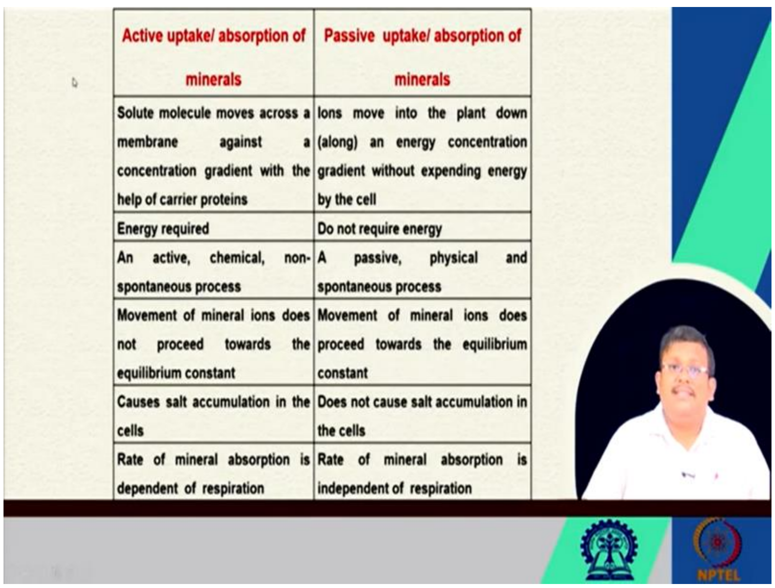

Active uptake/ absorption of minerals	Passive uptake/ absorption of minerals
Solute molecule moves across a membrane against a concentration gradient with the help of carrier proteins	Ions move into the plant down (along) an energy concentration gradient without expending energy by the cell
Energy required	Do not require energy
An active, chemical, non-spontaneous process	A passive, physical and spontaneous process
Movement of mineral ions does not proceed towards the equilibrium constant	Movement of mineral ions does proceed towards the equilibrium constant
Causes salt accumulation in the cells	Does not cause salt accumulation in the cells
Rate of mineral absorption is dependent of respiration	Rate of mineral absorption is independent of respiration

So let us see what are the major differences between active transport and passive transport. So in case of active transport the solid molecule moves across a membrane against a concentration gradient with the help of carrier proteins. And in case of passive uptake ions move into the plant down an energy concentration gradient without expending energy by the cell.

The second important point is in case of active transport energy is required however in case of passive transport there is no energy required. In case of active transport and active chemical non it is generally it is generally indicated it is a active chemical and non spontaneous process however the passive transport is a passive physical and spontaneous process.

In case of active transport movement of mineral ion does not proceed towards the equilibrium constant however in case of passive transport movement of mineral ions does proceed towards the equilibrium constraint. In case of active transport it causes salt accumulation in the cells however in case of passive transport it does not cause salt accumulation in the cells.

In case of active transport rate of mineral absorption is dependent on respiration however in case of acid transport rate of mineral absorption is independent of respiration. So these are some of the major differentiating characteristics between active transport or passive transport.

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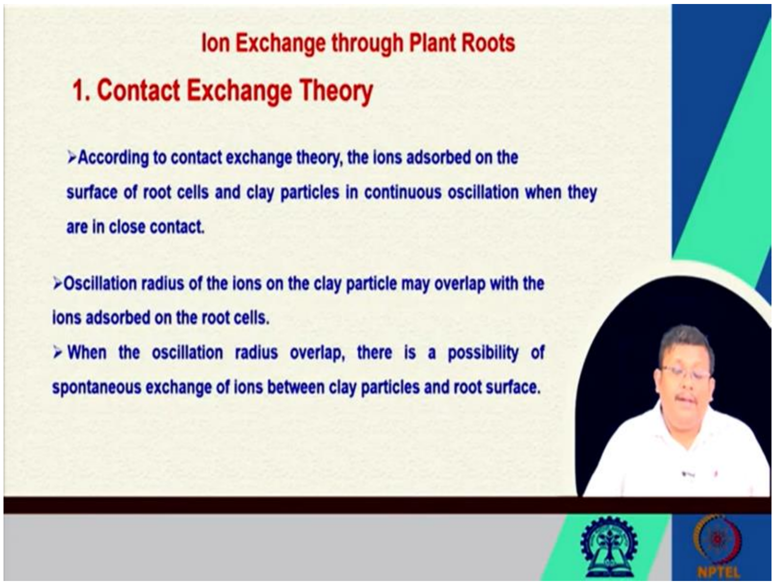

Now let us discuss the third important concept, third exchange, the third important process of nutrient uptake that is Contact Exchange or Ion contact or ion contact exchange. So this according to this contact exchange theory the ions adsorbed on the surface of the root cells and clay particles in continuous oscillation when they are in close contact.

So generally this theory believes that the ions which are adsorbed on the surface of the root cells and clay particles are continuously oscillating when they are when they come in close contact. An oscillation radius of the ions on the clay particles may overlap with the ions adsorbed on the root cells. And when the oscillation radius overlap there is a possibility of spontaneous exchange of ions between clay particles and root surface. So this is how these ion exchange you know occurs in case of contact exchange process.

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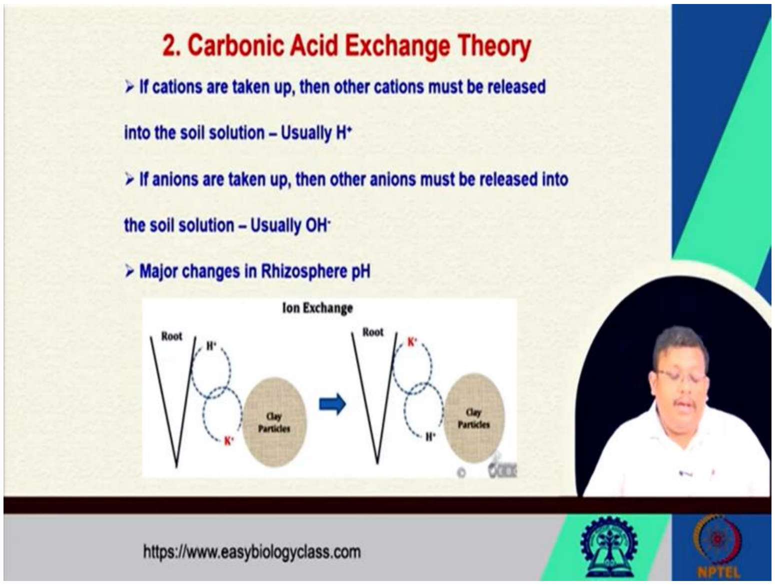

Now remember that another theory is it is called carbonic acid exchange theory where it postulates that if cations are taken up then other cations must be released into soil solution to maintain the balance generally it is H plus. So here you can see when the cation K plus is being taken up by the root they are releasing these H plus to maintain the ionic balance or charge balance.

So on the other hand if anions are taken up then other anions must be released into the soil solution generally it is hydroxyl. So due to the due to the release of these H plus and hydroxyl ions they we can see some major changes in rhizospheric ph. So this is carbonic acid exchange theory.

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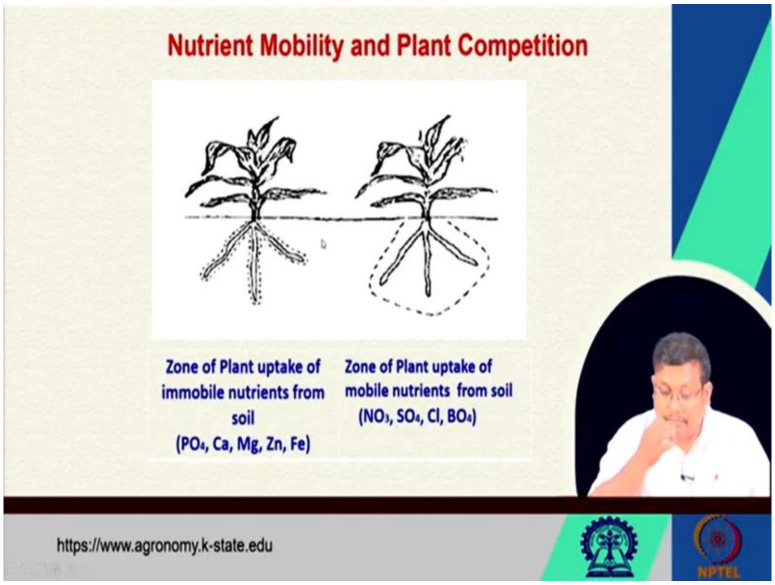

Now of course based on the nutrient mobility and plant competition the zone of plant uptake of immobile nutrients and immobile nutrients from the soil and mobile nutrients from the soil varies widely. So here you can see these is the zone of uptake of immobile nutrients from the soil however the zone of uptake of mobile nutrient from the soil is quite large. And these are for nitrate sulphate chlorine and also for boron. And in case of phosphorus calcium magnesium zinc and iron they are basically immobile nutrients so the zone of plant uptake is quite less.

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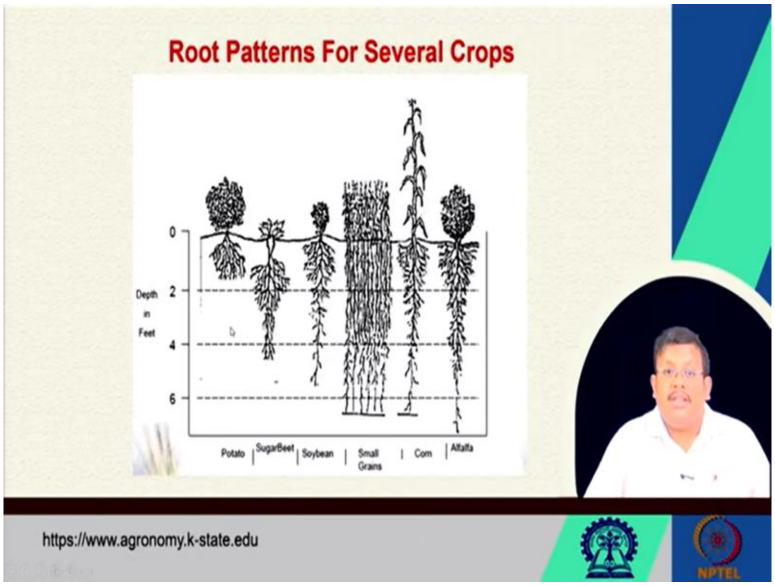

And based on that we can see the root patterns differ from one crop to another crop. So here you can see this is the root of potato then sugar wheat then soybean then small grains and corns and alpha, how they are changing based on these nutrient uptake mechanisms.

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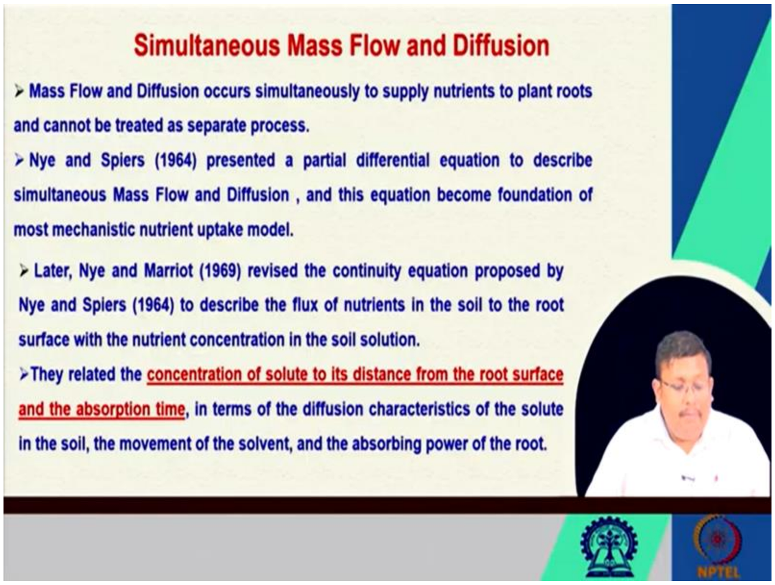

Now mass flow and diffusion can occur simultaneously. So mass flow and diffusion occurs simultaneously to supply the nutrients to plant roots and cannot be treated as separate process. Now Nye and Spiers in 1964 they first presented a partial differential equation to describe the simultaneous mass flow and diffusion. And this equation becomes the foundation of most mechanistic nutrient uptake model.

Now later the same two scientists revised this continuity equation proposed by them in 1964 to describe the flux of nutrients in the soil to the root surface with the nutrient concentration in the soil solution. So they related the concentration of the solute to its distance from the root surface and the absorption time. In terms of diffusion characteristics of the solute in the soil, the movement of the solvent and the absorbing power of the root.

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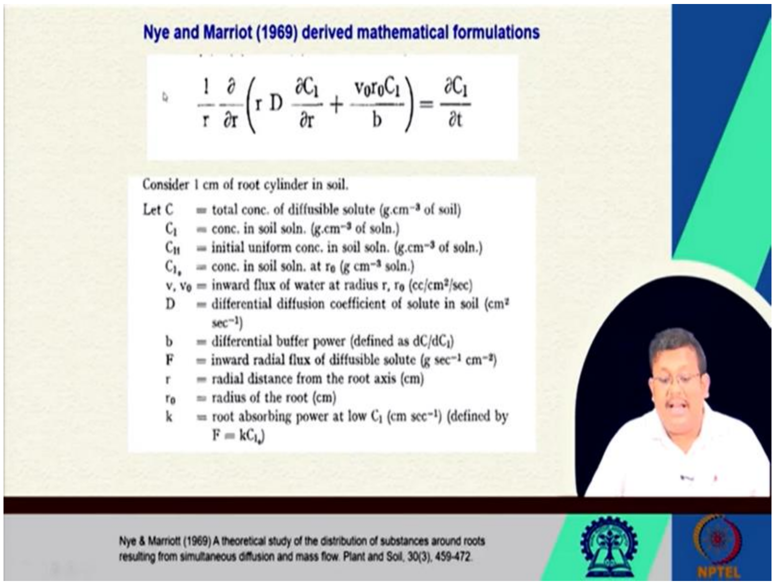

So this is the mathematical formulation given by Nye and Marriott in 1969. So here r stands for the radial distance from the root axis in centimeter and capital D stands for the differential diffusion coefficient of solute in soil and then C one stands for the concentration of iron in the soil solution. And here v 0 and v small v 0 stands for and also stands for the inward flux of water at radius r zero and so small b shows the differential buffer power. So this is how this mathematical formulation basically shows the simultaneous occurrence of diffusion and mass flow.

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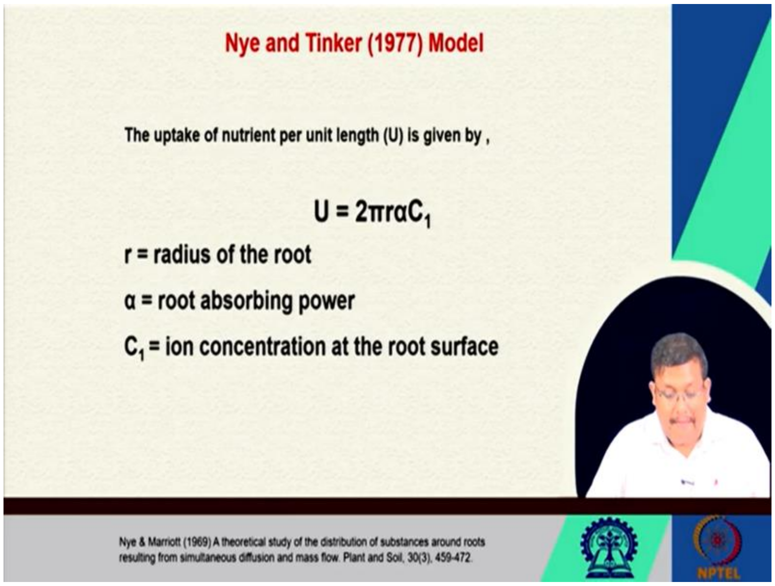

They Nye and Tinker in 1977 given a model shows you know which shows the uptake of nutrient per unit length. So this is basically given by this two pi r then alpha c one where these r stands for the radius of the root and alpha stands for the root absorbing power and c one stands for the ion concentration at the root surface.

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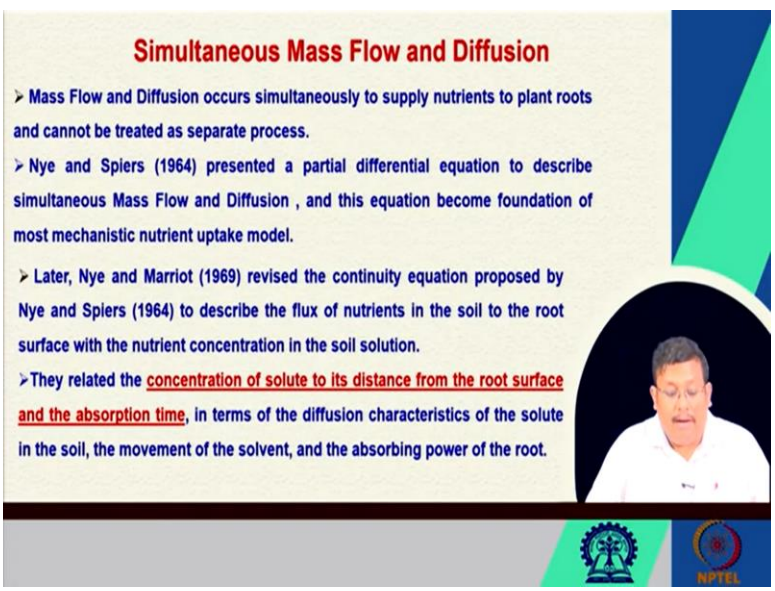

So these are some of the models which shows the mechanistic nutrient uptake models.

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So, guys let us wrap up this lecture here and we will discuss more about this mechanistic models and other aspects of plant nutrition in our last lecture of this week. Thank you very much.