Forests and Their Management
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Module - 02
Basic of Silviculture
Lecture – 02
Plant Growth Factors

[FL] In today's lecture, we will have a look at Plant Growth Factors. Now, a major aim in silviculture is to have a good growth of plants. We want to have plants that are sequestering a huge amount of carbon dioxide from the atmosphere and are depositing them in the form of biomass in their bodies. So, you would want to have plants that are putting up a very good height and are also increasing in girth, or in other words the plants that are showing a very good amount of growth.

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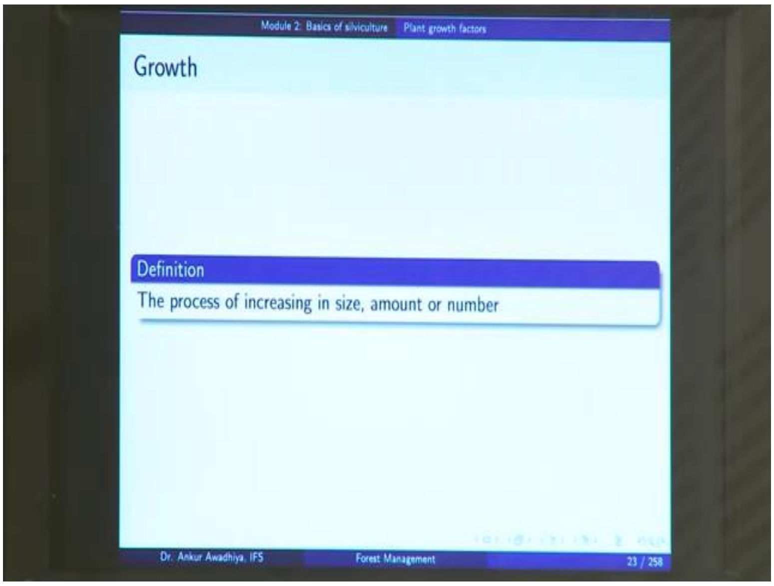

So, what is a growth? Growth is defined as the process of increasing in size, amount or number. So, essentially when we are doing silviculture, we want to have our plants that increase in size - they become taller, they become more stouter.

They increase in amount or number, which means that we want to have a good density of plants. Now, when we talk about the growth of plants, there are two processes that are occurring at all times, and the ratio of both of these processes determines whether the plants are growing or not.

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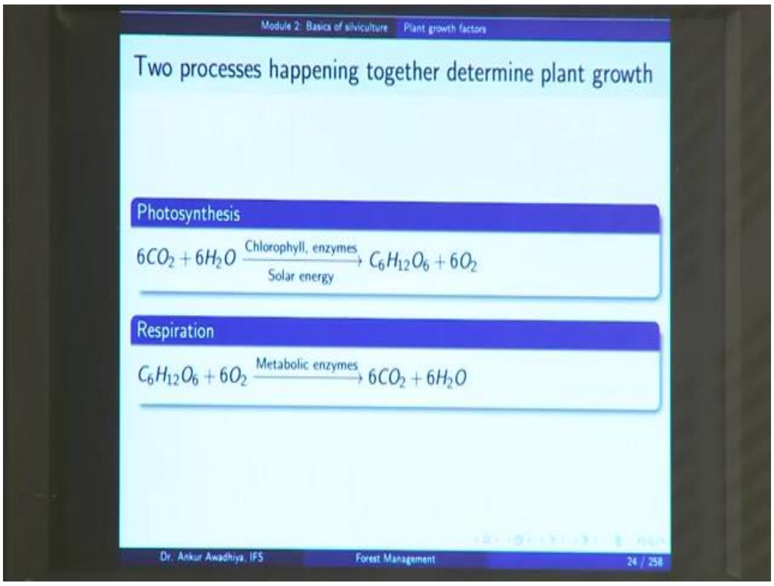

And, these two processes are the processes of photosynthesis and respiration. Now, photosynthesis as we know is the process in which the plants use sunlight to make their own food – "photo" is "light", "synthesis" is "to create". So, plants are using light to create something, and in this case, the creation of food.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

So, this is photosynthesis, but at the same time plants are also using energy for their own sustenance, and when they use energy, it is through the process of respiration. So, in respiration you have the opposite of this process; $C_6H_{12}O_6$, which is the sugar combines with 6 molecules of oxygen, in the presence of metabolic enzymes, it gives you 6 molecules of carbon dioxide and 6 molecules of water.

So, what we are saying here is that, in the process of photosynthesis carbon dioxide is being taken from the atmosphere and deposited in the bodies of the plants, whereas, in the process of respiration, the sugars that are there in the bodies of the plants are being burnt; they are being utilized or used for energy, and in this process carbon dioxide is being released back.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

So, if you have more amount of photosynthesis and less amount of respiration, in that case, the plant will show a positive growth, because more and more materials are being taken out of the atmosphere and deposited in the bodies of the plants.

On the other hand, if you have less amount of photosynthesis and a greater amount of respiration, in that case, material from the bodies of the plants is being converted into carbon dioxide and being released back into the atmosphere. So, in that case, the plants will show a negative growth, or in this case the size or the volume of the plants will reduce.

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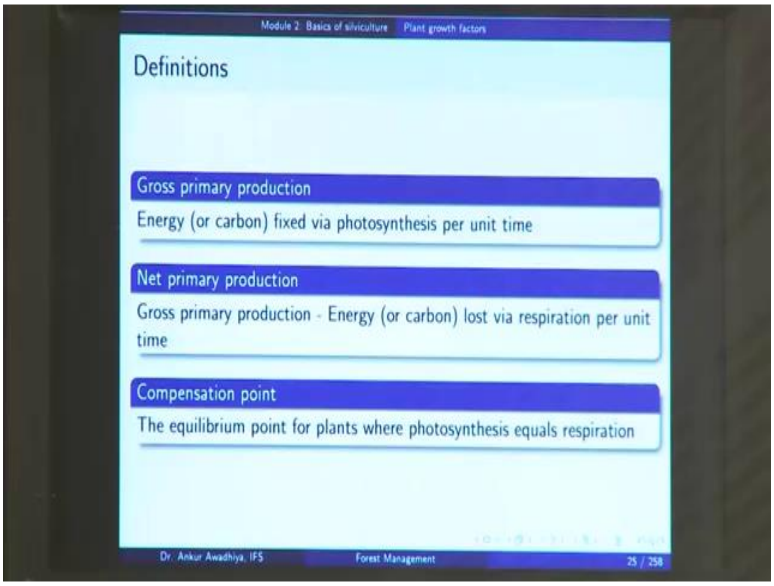

Now, we define these two terms - gross primary production and net primary production. Now, gross primary production is defined as energy or carbon that is fixed via photosynthesis per unit time. So, if you only consider photosynthesis, so, the amount of energy or the amount of carbon that is being fixed or that is being deposited in the bodies of the plants per unit time, it is generally expressed this per unit time, that is known as the gross primary production.

But then out of this energy or carbon, some energy or carbon is also being utilized for the sustenance of the plants in the form of respiration, and if you subtract that from the gross primary production, we get the net primary production. So, net primary production is gross primary production minus energy or carbon that is lost via respiration per unit time.

So, the net primary production will give you an idea of how much amount of growth is happening in your stand or in a particular plant.

And we also define the compensation point, as the point where at the equilibrium point for plants where photosynthesis equals respiration. Now, what is this compensation point? Because photosynthesis requires light, so you will have photosynthesis in the daytime; but respiration does not require light, and respiration is going on both during day and the night time.

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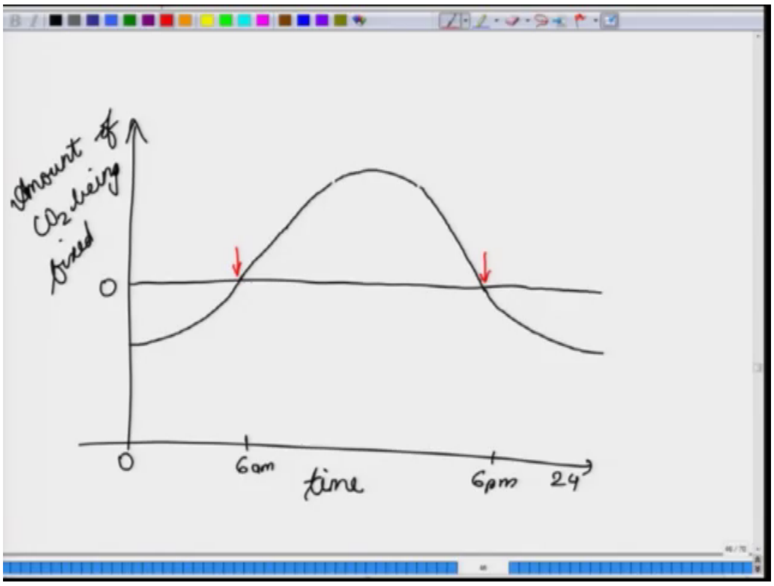

So, if we plot a curve of amount of CO_2 being fixed versus time. And, let us represent it as a scale from 0 to 24 hours. And in this scale, let us say that this is 6 am and this is 6 pm. Now the amount of carbon dioxide, and let us say that, on this axis this is your 0 point.

Now the amount of carbon dioxide that is being fixed by the plants will increase during the day time; probably reach a maximum and then it will go down. And in the night time, you will have that there is no carbon dioxide being fixed, but the carbon dioxide is actually being released by the plants. So, there is a net release of carbon dioxide.

And these two points, where the amount of carbon dioxide that is being fixed is equal to 0; because the amount of respiration and the amount of photosynthesis is one and the same. So, both are cancelling each other out. These two points are known as the compensation point. So, compensation point is the equilibrium point for plants where photosynthesis is equal to respiration.

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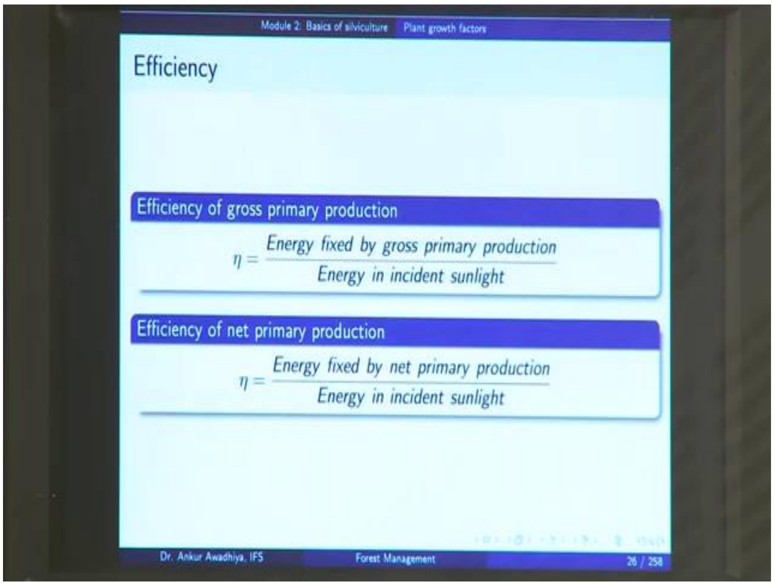

Now, apart from production, we also defined efficiency. So, efficiency is the amount of energy that is being fixed by the plants divided by the amount of energy that was present in the sunlight that the plants are using to convert carbon dioxide and fixing it. So, we define efficiency of gross primary production as the energy fixed by gross primary production divided by energy in the incident sunlight.

And, we define efficiency of the net primary production as an energy fixed by net primary production divided by, in by energy in the incident sunlight. Now, different species will have different efficiencies. So, if there is if there are two plants of different species - A and B, and the plant A is having more efficiency.

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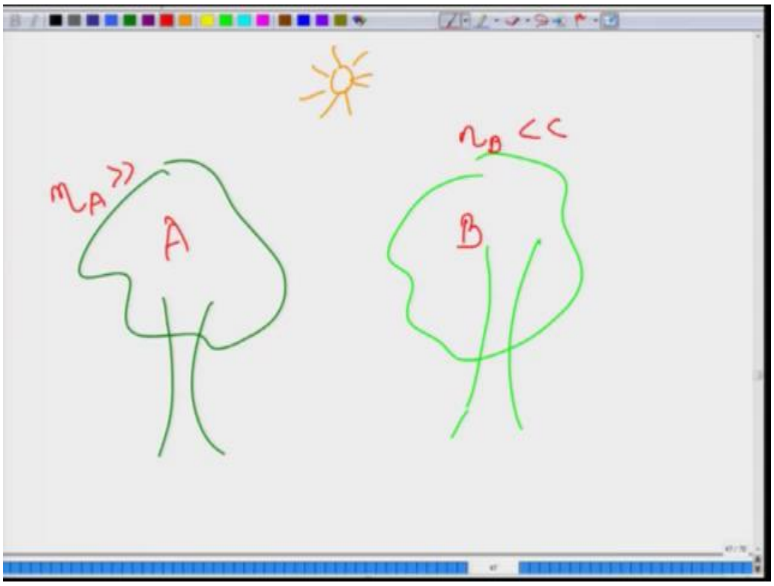

So, what we are saying here is that, you have two trees, and both these trees are in the same location. Let us call this - A and B; both that the trees are getting equal amount of sunlight, but the efficiency, in the case of A is very high, and the efficiency in the case of B is very less. So, in this case, A will be fixing much more amount of carbon dioxide using this energy that is being available and will show a greater amount of growth as compared to the species B.

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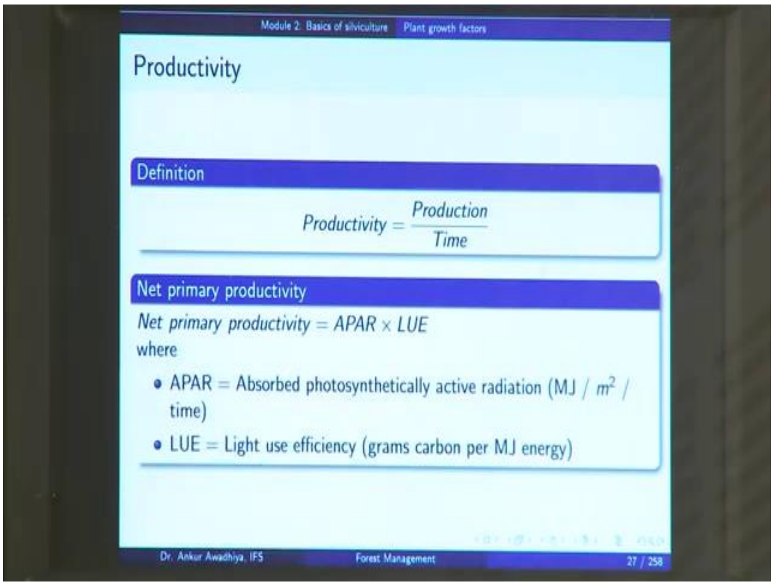

Now, apart from efficiency, we also define productivity. Productivity is defined as production per unit time.

Productivity = Production / Time

So, if you have gross primary production, so, in if you express it per unit time, you will get the productivity or the gross primary productivity. Net primary productivity is can also be represented as APAR into light use efficiency.

Net primary productivity (NPP) = APAR x LUE

Now APAR is the Absorbed Photosynthetically Active Radiation, and LUE is the light use efficiency.

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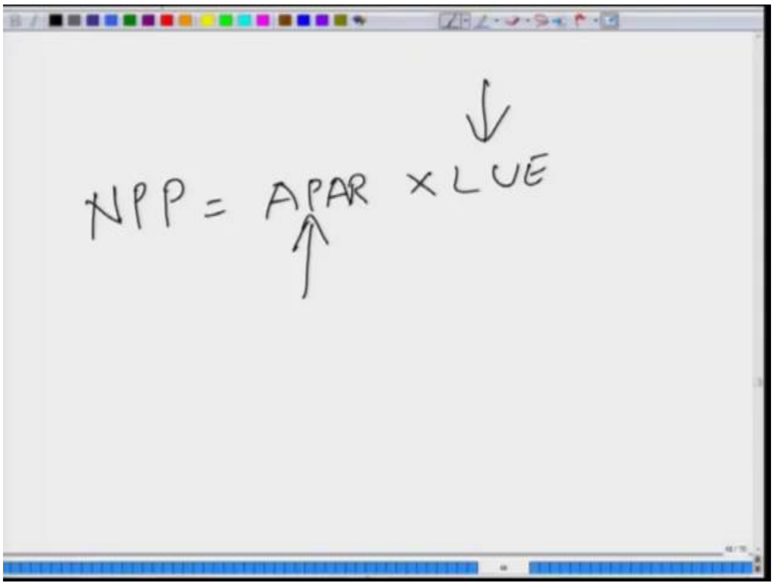

So, what this equation is telling you is that, if you talk about the net primary productivity - APAR into LUE. Now APAR is the Absorbed Photosynthetically Active Radiation. Now, as we know that sunlight is comprised of different electromagnetic radiations and not all of them are useful for photosynthesis. So, typically light in the reddish zone and in the bluish zone are useful for photosynthesis, whereas the green colored light is reflected out, because of which the plants look green in color.

Now if you talk about the photosynthetically active radiation, some part of it will be absorbed by the plants. So, the part of the photosynthetically active spectrum that is absorbed by the plants is known as APAR or absorbed photosynthetically active radiation. Now, light use efficiency, on the other hand, is the efficiency of the plants to convert this absorbed photosynthetically active radiation into biomass.

So, what we are saying here is that, if the amount of photosynthetically active radiation that is present in an area is less, so the net primary productivity will be less. Or if you are having enough amount of radiation, but it is not getting absorbed, so in that case also the NPP will be less. Or if you have sufficient amount of absorb photosynthetically active radiation, but the light use efficiency of that particular plant is less, probably because it is not of a very good species, or probably because this particular plant is diseased, or probably because it is not getting sufficient nutrients. So, if the light use efficiency is less, then also the net primary productivity will be less.

So, net primary productivity is equal to APAR into light use efficiency. Now, APAR is represented as mega Joules per - unit meter - per square meter per unit time. So, this is the amount of energy that is being absorbed per square meter divided by per unit of time. And, light use efficiency is given as grams of carbon that is converted or that is fixed per mega Joule of energy that the plant is getting.

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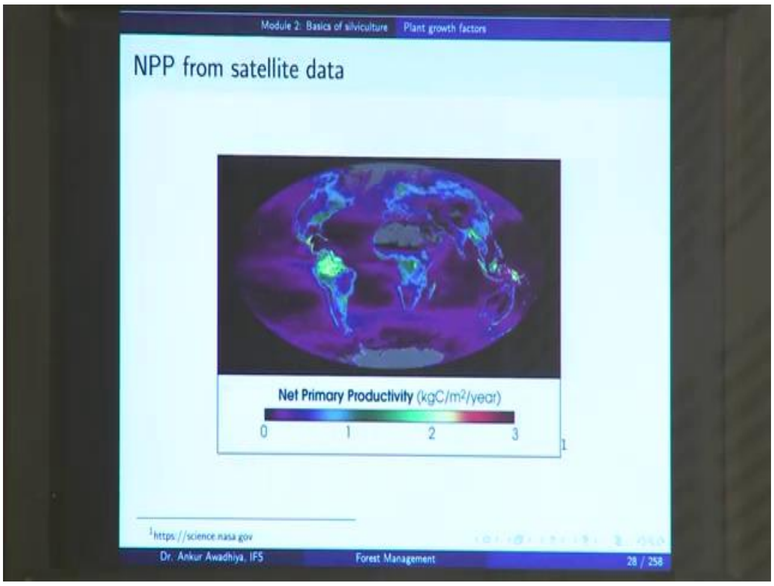

Now, the net primary productivity can be discerned from satellite data. And in this satellite data what we are seeing is that, in these areas, like in Brazil you have a high amount of net primary productivity, as compared to the ocean. In the oceans, the primary productivity is less, and we can also see there that in the polar areas, the primary productivity is less as compared to the sub-tropical areas.

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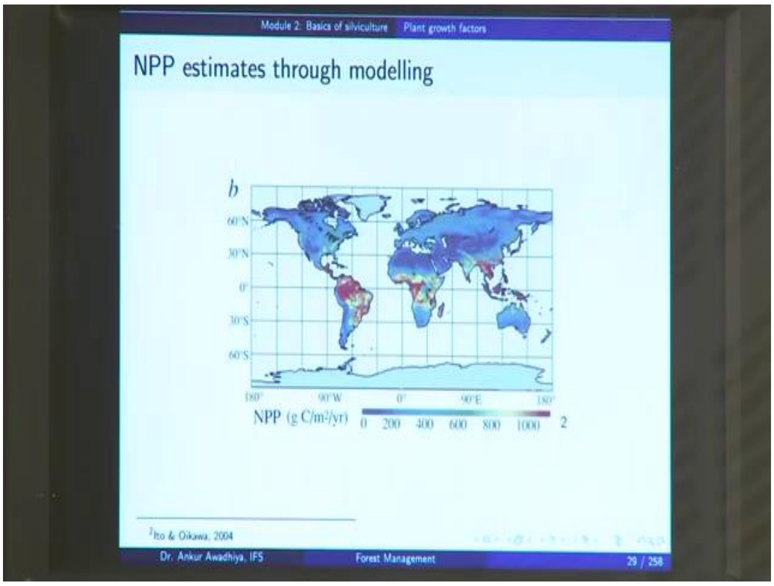

You can also do, or you can also figure out the net primary productivity using computer modeling. So, for every area for every region, we know that, we know that the latitude, we know the inclination of the earth, and with that we can figure out how much is the amount of light that is reaching into that area. How much of the photosynthetically active radiation is reaching into that area? and then, we can make use of our knowledge of which species are found in which areas, which will give us an estimate of the light use efficiency. And using both of these, we can compute the net primary productivity of different regions of the earth.

So here also what we are seeing is that, in the tropical and the sub-tropical regions the net primary productivity is very high, whereas in towards the poles it is less. In the desert areas also the net primary productivity is less, because even though you are getting sufficient amount of sunlight, but because of a lack of moisture, because the plants are not having enough amount of water, so they are unable to convert the carbon dioxide or the energy into biomass.

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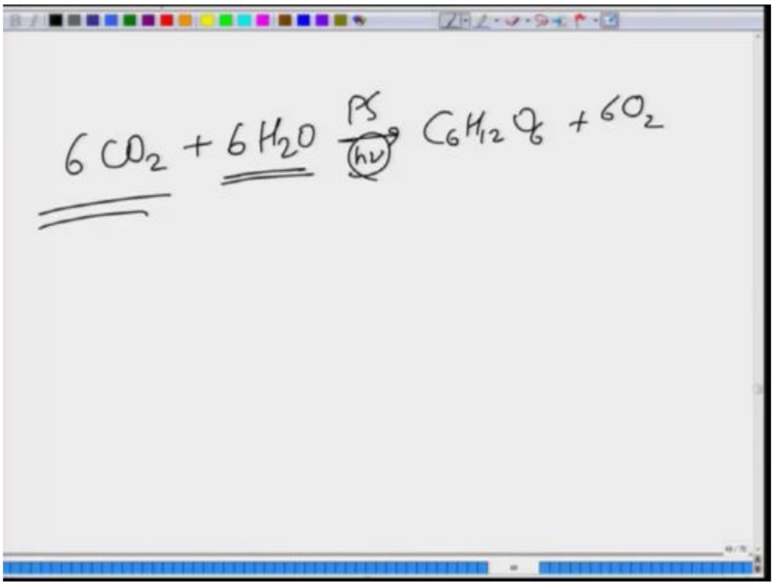

Because as you remember, in the case of photosynthesis,

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

we were having $6CO_2$ together with 6 molecules of H_2O, which during photosynthesis will give you $C_6H_{12}O_6$ plus $6O_2$. So, though you are having CO_2, though you are having light, but because you do not have sufficient amount of water, so you are, so the plants are unable to convert or fix the carbon dioxide into biomass. So, the NPP will be less, if the amount of water in an area is less.

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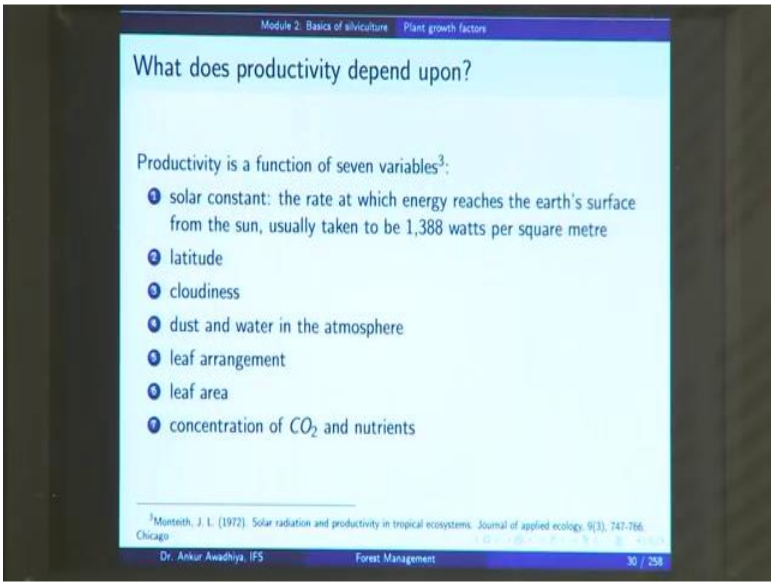

So, given all these fundamentals, what does productivity depend upon? So, productivity, now it has been determined that productivity is a function of seven variables. The first variable is the solar constant or the rate at which energy reaches the earth surface from the sun, and this is usually taken to be 1388 watts per square meter.

Now what we are telling here is that, the primary source of all the energy is the sun, and so if the amount of energy that is being released by the sun is less, in that case the energy that will reach the earth will also be less. And if we have less energy to begin with, the plants will not get enough amount of energy, and so the amount of or the productivity of the plants will also reduce.

But typically, the solar constant does not vary very much, it is more or less constant. So, we take it to be a constant at, as 1388 watts per square meter. However, the actual amount of light that will be received at any particular location, will then depend on the latitude of that location. So, if there is a location that is near the equator, so the sun rays are directly falling overhead in that region. And so, more and more amount of energy will be made available, whereas, if we go move towards the poles, then the light will be incident at a very oblique angle. And so, the amount of energy that will be available to the plants will be less. So, productivity also depends upon the latitude of the area.

Then, productivity depends on cloudiness, because if you have clouds then the sunlight is not directly able to reach the plants; because the clouds reflect the sunlight back into the space. So, the amount of cloudiness will also determine the amount of productivity in an area. Then, the amount of dust in water in the atmosphere will also determine the productivity in that area, because this dust and water also some amount of energy will be reflected back.

Then, it also depends on the leaf arrangement of the plants. So, typically we find that plants arrange their leaves in such a manner that, they are able to absorb the maximum amount of sun light. But then with different species, there can be different leaf arrangements, and one leaf arrangement could be more efficient for a plant than some other leaf arrangement.

It also depends on the leaf area that is available with your species. So, some plants that have larger size leaves will be able to show larger productivity, as compared to some other plants that do not have large sized leaves. And, it also depends on the concentration of carbon dioxide and nutrients, which are the raw materials for photosynthesis. So, if you have a sufficient amount of carbon dioxide and nutrients, the plants will show a better productivity as compared to a location in which the amount of carbon dioxide and or nutrients is less.

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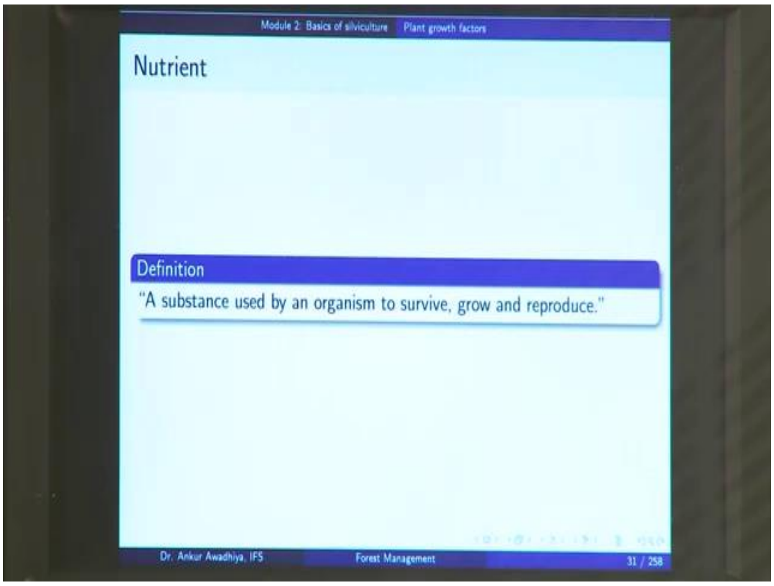

Now, this nutrient does not only include the mineral salts, but is it also includes water. Now, how do we define a nutrient? A nutrient is a substance that is used by an organism to survive, grow and reproduce. So, a nutrient is a substance, it can be a chemical element; it can be a molecule; but it is a substance that is used by the organism. In our particular case, we are talking about plants, so it is a substance that is used by plants for what - to survive, to remain alive, to grow, to show, to increase their biomass and also to reproduce.

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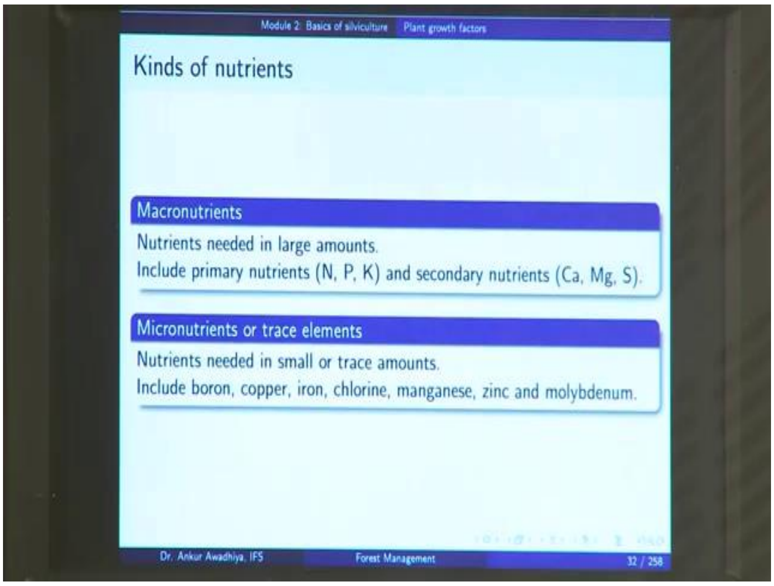

The nutrients are divided into two different categories - the macronutrients that are needed in larger amounts, and the micronutrients or trace elements that are needed in smaller amounts. Now, macronutrients include primary nutrients and secondary nutrients. The three primary nutrients are N P K - nitrogen, phosphorus and potassium. And, the secondary nutrients include - calcium, magnesium and sulfur. The micronutrients are the trace elements include boron, copper, iron, chlorine, manganese, zinc, molybdenum and so on.

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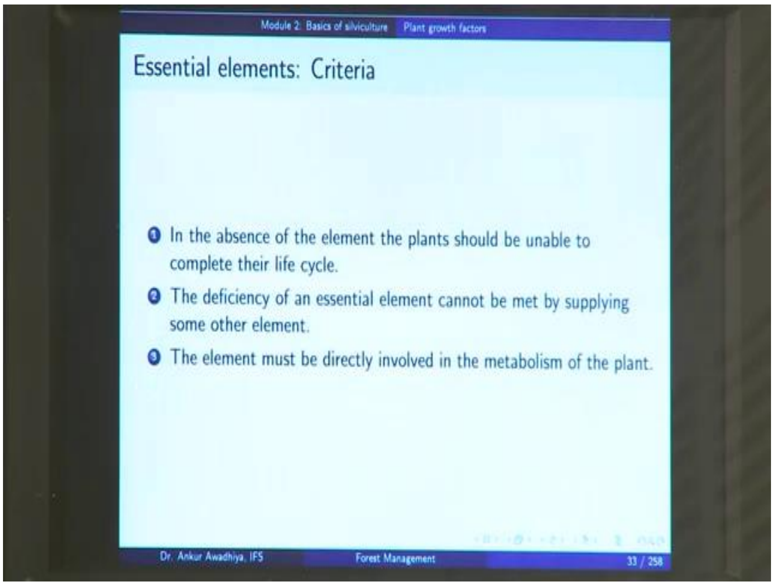

Now, out of these nutrients, some nutrients will be called as essential elements, and we define essential elements using three criteria. In the absence of the element, the plants should be unable to complete their lifecycle. So, if you do not give the essential element to a plant, it will not be able to complete its life cycle, it will die off; or probably, it will be unable to produce the next generation.

The deficiency of an essential element cannot be met by supplying some other element. So, you cannot replace an essential element with any other element; it has to be there, it has to be given to the plants. And, the element must directly be involved in the metabolism of the plant. So, these are the three criteria to define an essential element.

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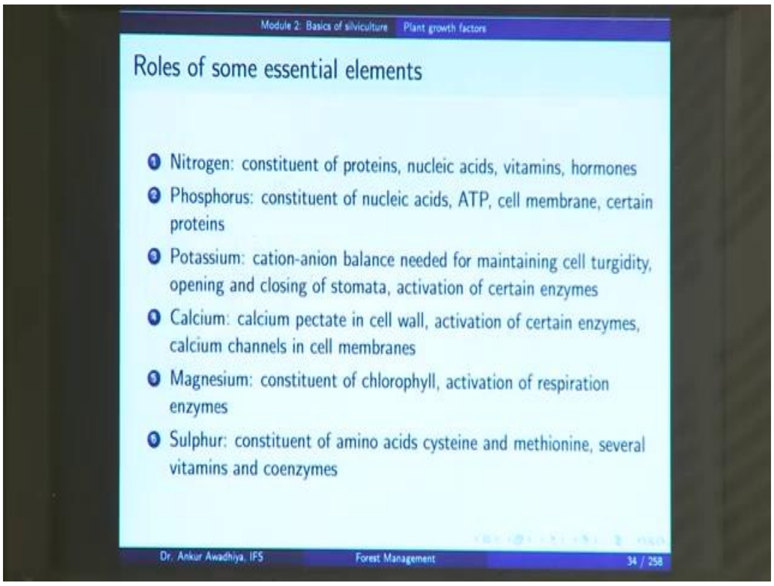

So, what are the essential elements? So, here we have the essential elements along with their roles. So, one essential element is nitrogen. So, as we know a major part of our atmosphere is comprised of nitrogen; nitrogen is a constituent of proteins, nucleic acids, vitamins and hormones. So, nitrogen is an essential element, because if you do not give nitrogen to a plant, the plant will die off very quickly, it cannot be replaced by any other element. And, this element is directly involved in the metabolism in the formation of proteins, nucleic acids, vitamins and hormones.

Similarly, phosphorus is a constituent of nucleic acids, ATP - which is the energy currency of cells, the cell membrane and certain proteins. So, the plants require phosphorus. Potassium is required for cation-anion balance, which is needed for maintaining the cell turgidity. Now, turgidity refers to whether your, whether the cell membrane of the cell is stretched or whether it is flaccid.

So, if a cell has a lot amount of water inside it, then say it will bulge and the cell membrane will become stretched, and in that case, we will call it a turgid cell. Now with, why do the cells, why is there a need to alter this the cell turgidity. In the case of plants, it is essential for the opening and closing of the stomata. Now, stomata are those cells that are present in the leaves and they provide an opening for the entry of air. They are typically kidney shaped cells.

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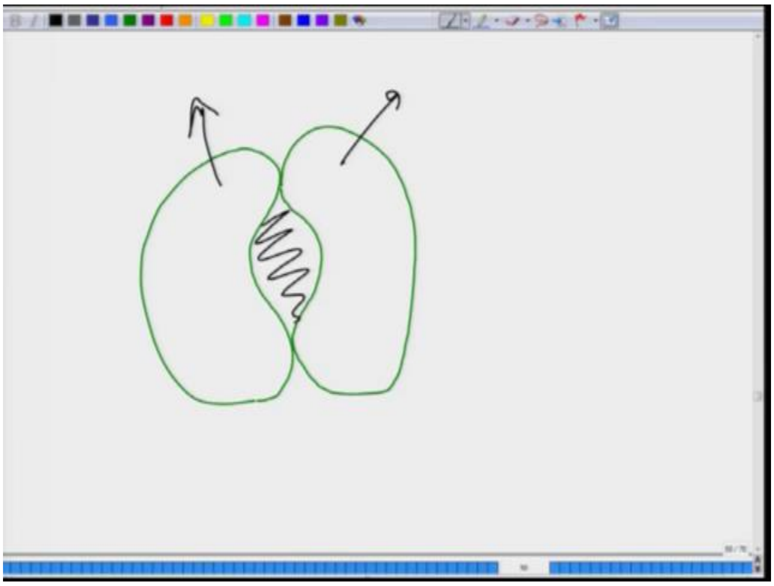

Now, the hole that is formed in between these two cells, is the place from which air will get inside or outside. Now when a plant opens it is stomata, it is able to get carbon dioxide inside and it is able to throw out oxygen, during the process of photosynthesis.

But then if you when you are throwing out oxygen, you are also throwing out water; because there will be some amount of evaporation, there will be some amount of transpiration. So, in the case of plants, it is much more beneficial that during the daytime when photosynthesis is happening, you should open this hole; when you are and when there is then the night time, you should close this hole, so that because photosynthesis itself is not happening, when you close this hole you are able to conserve water.

Now, the opening and closing of the this hole, or the stomata, depends on the turgidity of both of these cells. So, when these cells become turgid, the hole becomes larger, when the cells become flaccid, the hole reduces in size. And, this mechanism, of opening or closing of the holes, is determined by the cation-anion balance that is there in the cells. So, if you have more amount of salts in inside the cell, in that case, through the process of osmosis more amount of water will reach inside, and the cell will become turgid.

If you have less amount of salt, if the cell is able to throw the salts outside, in that case, water will also go out through the process of osmosis and the cell will become flaccid. Now, this intake and release of the salts is maintained through the cation-anion balance, which is done through the use of potassium. Potassium also plays a role in the activation of certain enzymes.

Another essential element is calcium. Calcium is present in the form of calcium pectate in the cell wall. It is required for the activation of certain enzymes, and it is also useful in the case of calcium channels in the cell membranes. Another essential element is magnesium. It is a constituent of chlorophyll. So, if you do not have magnesium, you do not have chlorophyll, and the plants will not be able to perform photosynthesis.

So, it is very much necessary for photosynthesis. It is also required for the activation of respiration enzymes. Another essential element is sulfur, which is a constituent of amino acids cysteine and methionine, several vitamins and coenzymes. So, these are some essential elements that the plants require and these cannot be substituted.

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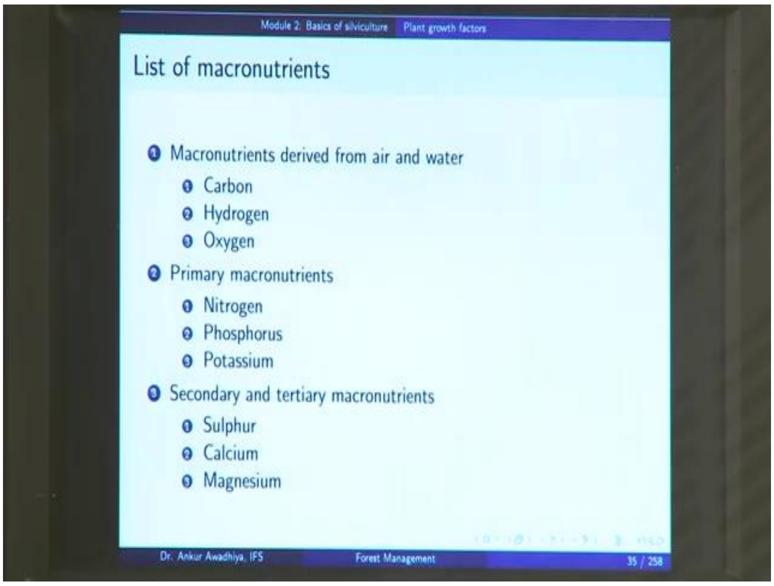

Now, we looked at macronutrients, and a macronutrient is defined as a nutrient that is required in large quantities. So, we can divide the macronutrients list into three categories - the first is the macronutrients that are derived from air and water. So, you get carbon, hydrogen and oxygen from air and water; carbon in the form of carbon dioxide, hydrogen in the form of water, and oxygen from both carbon dioxide as well as water. So, these are the macronutrients that you are getting from air and water.

Then, you have primary macronutrients, which are nitrogen, phosphorus and potassium - N P K. So, when we talk about fertilizers for either silvicultural uses or for agricultural uses, we are always looking for the ratio of N, P and K in those fertilizers, because these are the primary macronutrients. Then, you have secondary and tertiary macronutrients such as sulfur, calcium and magnesium.

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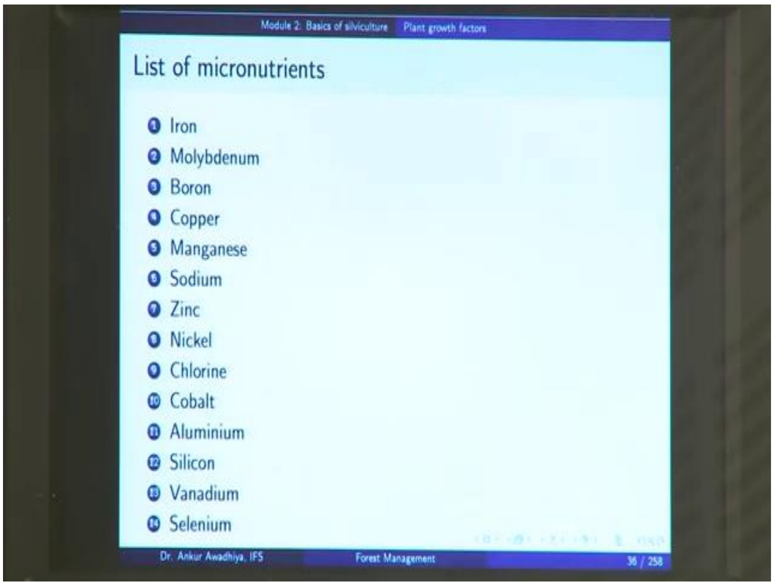

And, the list of micronutrients is very large. You have iron, molybdenum, boron, copper, manganese, sodium, zinc, nickel, chlorine, cobalt, aluminum, silicon, vanadium, selenium, and the list goes on. So, these are some prominent micronutrients that the plants require. Now if we talk about plants, they are getting - this nutrients - from either air or water and primarily from the soil.

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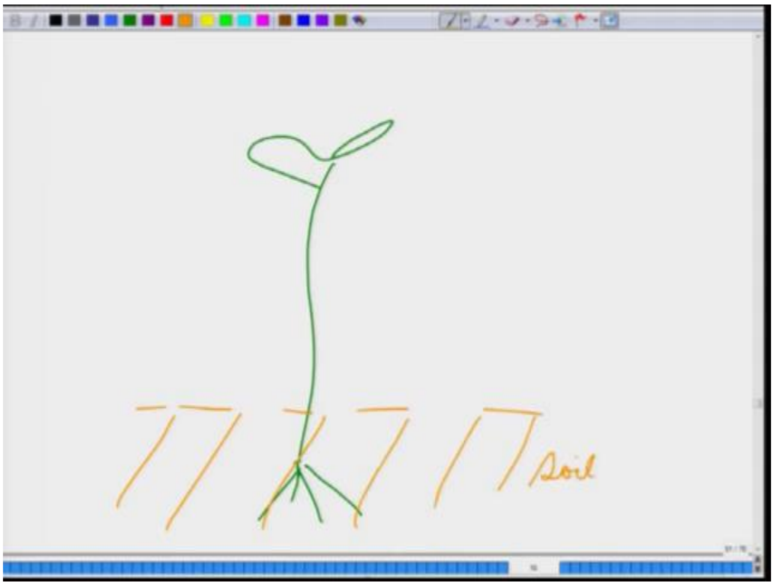

But then if you talk about a plant, so here we have a plant, it has its roots and these this portion is within the soil. Now, let us consider a situation in which this plant got some nutrients; let us say that, it got phosphorus from the soil.

So, we are having phosphorus that is moving from the soil into the plant, and now you have the phosphorus here. Now after the while this plant gets eaten up by some animal, but then in that case where does the phosphorus go? So, the phosphorus gets into the body of the animals, but then what happens to the soil here.

Now the soil has less amount of phosphorus. How does this in the soil get the phosphorus back? Because this soil always needs a supply of phosphorus, so that it is able to support the plants, otherwise this soil will slowly become barren; it will become infertile, it would not be able to support the plants.

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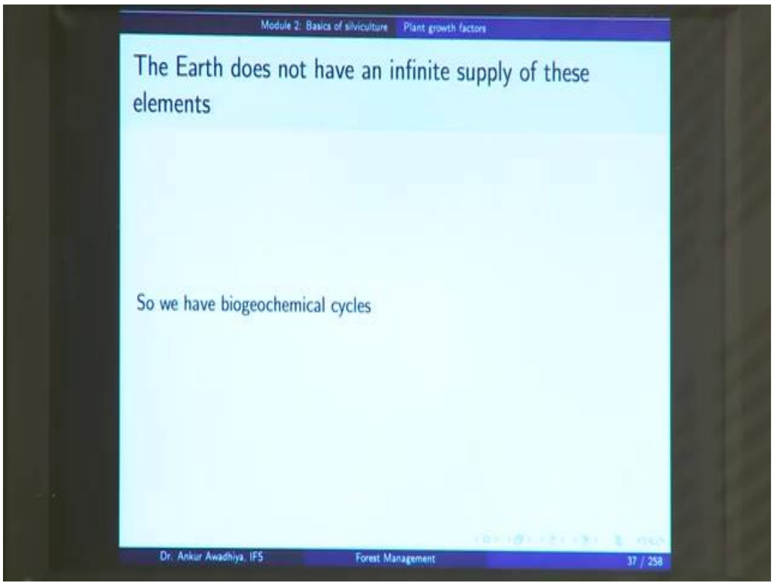

Now on the - on our planet earth, the soil has been able to support life for a very long period of time. So, where do we get all these nutrients from? So, the answer is that, the earth does not have an infinite supply of these elements, but we do have the biogeochemical cycles. Now what is a biogeochemical cycle?

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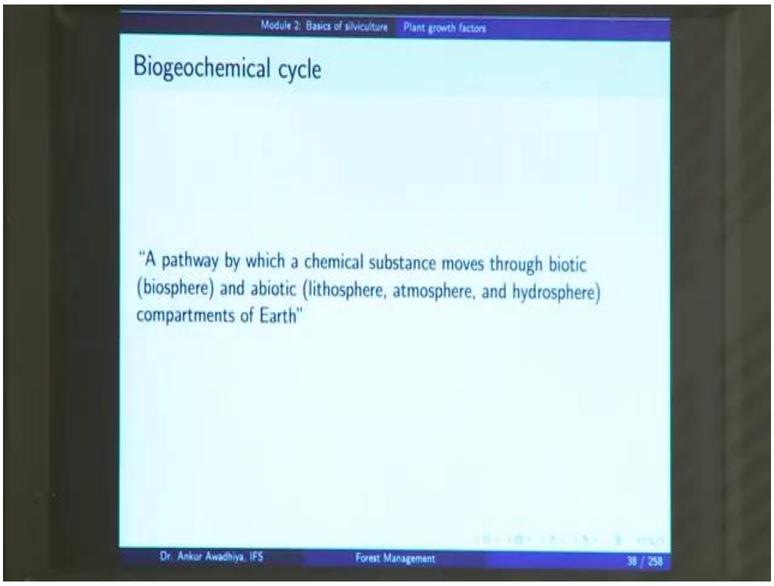

Now, a biogeochemical cycle is defined as a pathway by which a chemical substance such as nutrients moves through biotic that is the living portion or the biosphere, and the abiotic or the nonliving portion, which comprises of lithosphere, atmosphere and hydrosphere compartments of the earth. So, your nutrient is moving through the bio portion - the living portion, and the geo portion which is the earthy portion.

Now earth comprises of the atmosphere or the air; the lithosphere or the solid portion, which comprises of the soil and the rocks; and the hydrosphere, which comprises of the water bodies. And, at the combination of all three of these, we also have the biosphere, which is the living component.

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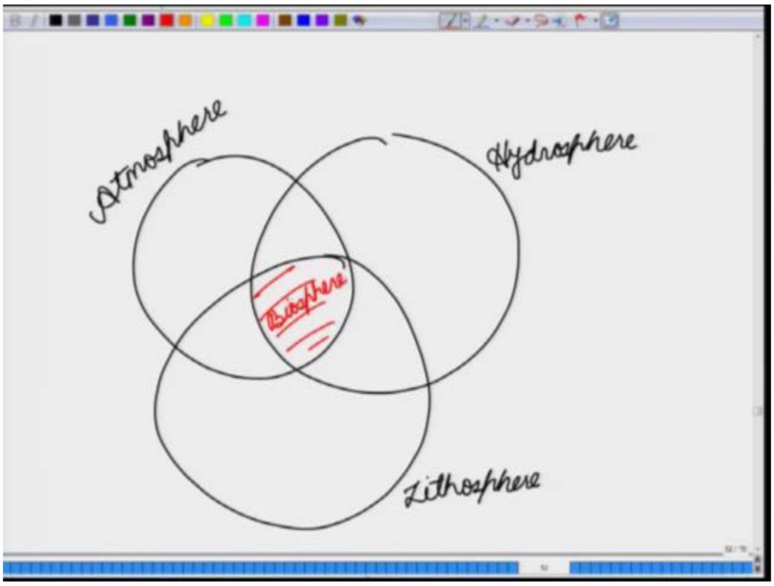

Now, what we are saying here is that, you have the atmosphere, you have the hydrosphere, and you have the lithosphere. And at the confluence of all of these, you have the biosphere. Now, in the case of a biogeochemical cycle, the nutrients are moving through all of these; they are moving through the biotic components and the abiotic components and all of these compartments of the earth.

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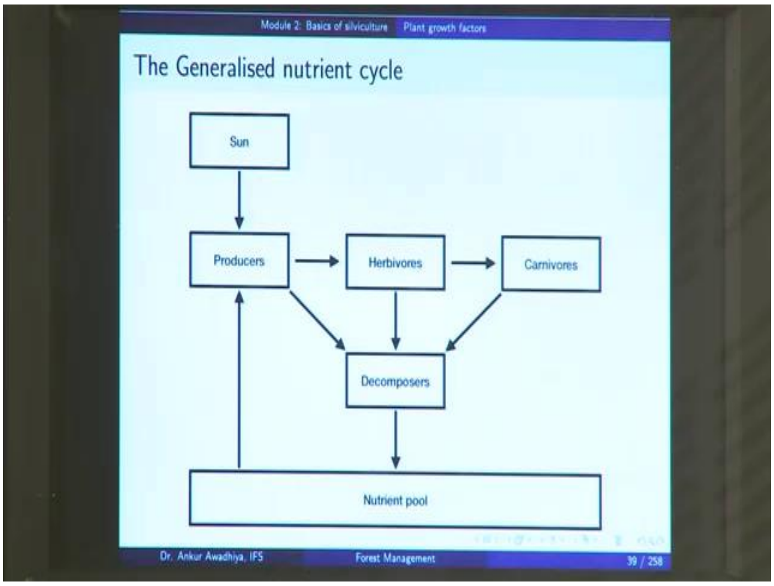

So, what does a biogeochemical cycle look like? how does a nutrient cycle look like? Now, this is a generalized nutrient cycle. Now, what it shows is that the sun that is the primary source of all the energy is driving the whole of the cycle. Now, the sun gives light which is used by the producers.

Now producers are those organisms that are able to produce their own food; they are also known as autotrophs. Autotrophs- ‘Auto’ is ‘self.’ and ‘troph’ is ‘nutrition’. So, autotrophy is self-nutrition; you are making food by yourself. So, the and, these autotrophs are also known as producers.

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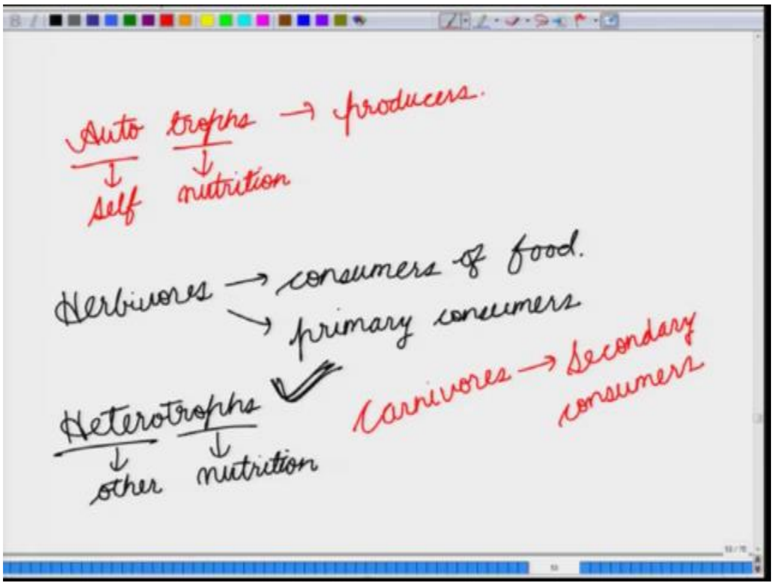

Now, the sun is giving light to these autotrophs, which are in turn producing food for the other organisms. Now, these producers are making use of the nutrient pool, and this nutrient pool can be there in the lithosphere, the hydrosphere or the atmosphere. Because there are certain nutrients, such as carbon dioxide, which are taken from the air, so it is coming from the atmosphere. There are certain nutrients that come from water, in the form of dissolved salts, and there are certain nutrients that come from soil and rocks, or the lithosphere. So, this nutrient pool may be there in the atmosphere, hydrosphere or lithosphere, or many of these. So, there can be a nutrient that is also present in hydrosphere and also present in say - lithosphere.

So, you can have combinations; but then there is a nutrient pool on the earth, and the producers are using chemicals from the nutrient pool, and they are using energy from the sun, to produce food. Now, these producers, once they have produced this food, this food is then eaten by herbivores. So, herbivores in this case, are consumers of food. So, herbivores are consumers of food; they are not able to produce their own food, so they consume it from other organisms, which are the producers.

So, the producers make food; the consumers consume that food. And, the herbivores are also referred to as the primary consumers, because they are the first one to consume this food. So, if you look at the movement of energy and nutrients, the producers produce food, so they fixed the energy, and they fix, and they also deposited the nutrients in their biomass, which is now the food for the organisms. And then from here, the energy and the nutrients are moving to herbivores, when these herbivores are consuming these producers.

Now herbivores are also known as heterotrophs. So, ‘hetro’ is ‘other’ and ‘trophy’ is ‘nutrition’. So, they are getting nutrition from others, so these are heterotrophs. So, producers are the only autotrophs, rest all of these are heterotrophs. So, the energy and nutrients have now moved to herbivores. Now, at the same time, there could be some plants that are also dying off, probably because of an old age. Or, there are some portions of the plants such as dead leaves or dead twigs that are coming down, that are falling down, and these dead plants and their parts are also eaten up by their decomposers.

Now, decomposers are those organisms that are taking up these dead portions, and then they are feeding on these dead portions. So, they are also getting their energy; they are also getting their nutrients from these dead portions; and they are releasing these nutrients back to the nutrient pool. So, they are taking, this these nutrients which were there in the bodies of these plants, which are now dead, and they are acting on those, they get the energy, they get the nutrients, and then when they die these are getting released back into the nutrient pool.

Now, in the case of herbivores as well, these herbivores can be eaten up by carnivores or they can die. So, when these herbivores die, and get decomposed. Now, when these herbivores are getting eaten up by the carnivores, then this energy that was there in the producers that move to the herbivores, then this energy is moving to the carnivores. The nutrients that these producers fixed from the nutrient pool, it moved to the bodies of herbivores, and then it moves to the bodies of the carnivores.

Now, carnivores in turn are also heterotrophs; they also cannot make their own food, they are dependent on other organisms; in this case, the herbivores for their food. So, they are also heterotrophs. And they are known as; so, when we look at the carnivores, these are the secondary consumers. Because they are not the first one to consume, the first one to consume were the herbivores, and these are consuming the herbivores, they are the secondary consumers. Now, these carnivores could be further eaten up by some other carnivores, which will then be called the tertiary consumers. They would be eaten up by the quaternary consumers, and then this chain can go along for some time.

But then, when these carnivores; so, let us consider all these carnivores, whether they are the - this the secondary consumers or the tertiary consumers or the quaternary consumers, and so on. Let us group them together, and let us call that these are the carnivores.

Now when these carnivores when they die off, then you then their bodies and their dead parts are also decomposed by their decomposers, and then the nutrients get released back into the nutrient pool. Now, the decomposers again are heterotrophs; they are dependent on producers, herbivores and carnivores for their nutrition.

So, in this case what is happening is that, the sun gave up energy which was used by the producers to make their own food; they also use this energy to survive, to grow, to reproduce. And then this energy is, in turn getting converted into heat, and is then released back into the atmosphere, and is lost. Some energy which was fixed in their bodies was eaten up by the herbivores, which then use this energy to grow, to survive, to reproduce, and they are also releasing energy back into the system, in the form of heat when they are doing the respiration.

Similarly, the carnivores and the detritivores are also converting all this fixed energy into heat. So, energy is getting lost. So, if you do not have the sun, the -this whole system will collapse; because the energy has to be taken from an outside source. But if we talk about the nutrients, then nutrients move in a cyclical fashion; because nutrients are taken up by the producers, and then it can go like this or it can go like this or it can go like this.

So, even if you, so, these nutrients do not have to come from outside the earth; this nutrient pool in the earth is able to self-sustain, because these nutrients are moving in a cyclical fashion. So, these are the biogeochemical cycles, and we will look at them in more detail in a later lecture.

So, in this lecture, we began with the definition of growth, and we said that growth is increase in numbers, or increase in size, or increase in the amount. And, we are interested in growth, because we want to have plants that are growing at a fast rate; that are sequestering carbon dioxide placing it into their biomass, which we can later use in the form of timber or in the form of non-timber forest produce. So, we want to have plants that show a very good growth, that show a very fast growth.

Now, this growth is dependent on a number of factors, and there we looked at the net primary production, and the gross primary production. Now, at all times, we have two processes that are going on together - we have the process of photosynthesis, and we have the process of respiration. In the process of photosynthesis, energy has been taken from the sun and is fixed in the form of biomass. In the case of respiration, this biomass is being burnt and the energy is getting released that is being used by the plants or by other organisms.

So, gross primary production is the amount of energy that is fixed from the sunlight by a plant. Net primary production is the amount of - photosynthesis - the amount of energy that was fixed through photosynthesis minus the amount of energy that was lost through respiration by this plant. And if we divide production by time, we get productivity. Then, we also looked at the efficiency.

So, we have the efficiency of gross production, and the efficiency of net production, which is your amount of energy that is being fixed either in gross production or in net production divided by the amount of energy that was coming from the sunlight. So, if you are getting 100 units of light from or 100 units of energy from the sun, how many of these are you able to convert into the biomass, will give you the efficiency of the system.

Then we looked at how, what are the factors on which this efficiency depends on. So, we saw that the net primary productivity depends on the APAR into light use efficiency, where APAR is the Absorbed Photosynthetically Active Radiation. So, if we, so using this formula that, then the net primary productivity is APAR into light use efficiency, we can put in values and do a modeling to get an idea of the amount of net primary productivity in different regions of the earth.

Then, we also saw that this net primary productivity depends, or is dependent on a number of variables, such as the solar constant or the amount of energy that is given out by the sun and is reaching the earth; it depends on things like latitude, on cloudiness of the area, amount of dust and water in the atmosphere, the amount of nutrients that we have in an area and so on.

So, there are some factors amongst these that we can control and there are some others that we cannot control. So, for instance, we cannot control the solar constant, but we can control whether the plants are getting enough amount of water and other nutrients, and that will determine the net primary productivity.

Then, we looked at what is a nutrient? We defined a nutrient, and then, we looked at the different categories of nutrients. We looked at macronutrients that are required in larger amounts, and are divided into primary and secondary nutrients; and, we also looked at micronutrients or trace elements that are required in smaller amounts.

Then, we defined essential elements as those elements that are required by the organism for its growth and survival, which cannot be replaced by any other element, and which directly takes part in some metabolism of the plant. And then, we looked at certain essential elements and their roles in the bodies of the plants.

Next, we looked at different macronutrients and micronutrients. And, because the earth does not have an infinite supply of these nutrients, so we looked at the biogeochemical cycles through which these nutrients move through the biotic and the abiotic compartments of the earth. Biotic compartment is the biosphere, and abiotic compartments are the lithosphere, the atmosphere and the hydrosphere.

Then, we looked at a generalized biogeochemical cycle, in which the plants use nutrients from the nutrient pool, energy from the sun - fix this energy and the nutrients into their biomass, they get eaten up by the herbivores, which get eaten up by the carnivores.

Now all these three – plants, the herbivores and the carnivores - in turn, when they die or when they give out waste products, so, these all bio masses are eaten up by the decomposers. And, at all these stages energy is released back into the system, in the form of heat, so, it does not become use, so, it ceases to be able to remain useful; but the nutrients are released back into the system or released back into the nutrient pool, by the decomposers.

So, sun is continuously required as a source of energy, but the nutrients get recycled again and again, because of which a life has been made possible on the earth. So, that is all for today.

Thank you for your attention [FL].