Remote Sensing: Principles and Applications
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Lecture No -27
Spectral Properties of Few Common Earth Features in the Visible,
NIR and SWIR Bands - Part 1

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. Till now we have discussed in detail about remote sensing image acquisition systems. The basic principles of data collection, what data is being collected and how to convert the data into surface reflectance? All those concepts essentially with respect to data our focus is on the solar reflective portion of the electromagnetic spectrum that is wavelength less than 3 micrometers.

Also the image acquisition systems that we have seen till now, the whisk broom scanner, the Push broom sensor all those concepts are essentially the ways in which images in this particular solar reflective portion and also the thermal infrared portion, how data will be collected in these two portions till wavelength up to 14 micrometers. So, now we are going to continue with the topic of analyzing the data in the solar reflective portion of the electromagnetic spectrum.

Rather than analyzing I will say that how this particular reflectance is being recorded. That is we now know that satellite sensors collect radiance and we have also seen the steps to convert this radiance to surface reflectance. Acquiring the surface reflectance of various features is of the primary interest to remote sensing users especially when we are dealing with wavelengths less than 3 micrometers.

Starting from this lecture and maybe in the next few lectures we are going to see what causes certain objects to look like in a certain way. That is we now know what the reflectance will be, what we are going to see now is, why the reflectance is like that and how commonly occurring earth surface features will behave in different wavelengths starting from visible to SWIR range of electromagnetic spectrum.

So, the topic of the lecture we are going to see, starting from today is analyzing or understanding the spectral reflectance curves of few commonly occurring earth surface features in the visible NIR and SWIR domain. While discussing the interaction of EMR with earth surface features I introduced you the concept of spectral reflectance curve. So, a spectral reflectance curve is nothing but recording the wavelength and the spectral reflectance observed in the corresponding wavelength. So, an example is given in this particular slide.

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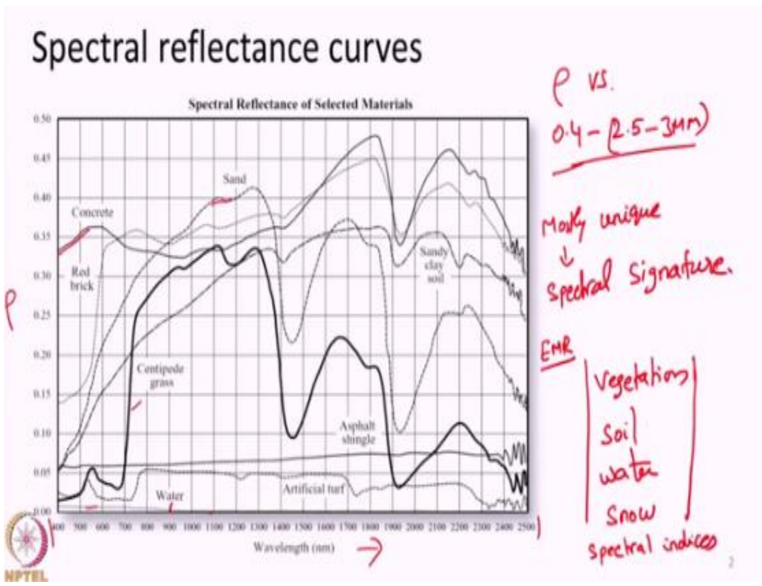

Here you can see that in x-axis we have wavelength in y-axis we have reflectance. So, if we plot various wavelengths especially within the range of say 0.42 to 0.5 or even 3 micrometers, we call this particular plot as spectral reflectance curve. So, we have also seen that this spectral reflectance curve is mostly unique for various earth surface features and that is why sometimes we call this spectral reflectance curve also as spectral signature.

So, here you can see for different features, for grass, which is a form of vegetation and for water body, these tiny dotted line along the bottom and then for sand it looks something like this, for concrete it looks something like this. So, essentially what we observe is different features behave differently when EMR is irradiated over it or when EMR interacts with different features it will behave differently.

And hence we get a unique spectral reflectance pattern or unique spectral reference curve for different features. In the series of lectures we are going to analyze why such spectral reference curves are observed. We are going to go a little bit in detail and reason out why the spectral reference curve has a particular pattern for a particular feature. So, we are going to discuss about the spectral reflectance curves of vegetation, soil, water and snow.

So, we are going to describe in detail about the spectral reflectance curve of these four features which are mostly abundant on the earth surface. And also we are going to discuss about what factors influence the spectral reference curve of these four class of features. In addition to this at the end of this particular lecture or this particular topic we are also going to get introduced to the concept of spectral indices.

So, this is what we are going to cover in the series of lectures starting from today maybe for next 3 to 4 lectures. So, first we are going to start with the spectral reflectance curves of vegetation. So, one of the earliest and primary application of remote sensing was vegetation monitoring and vegetation has been studied in detail about how it will look in the solar reflective portion of EMR and what factors will affect it.

And if you look at vegetation in a global scale, vegetation as a whole can influence earth's surface or earth system to a larger extent. Vegetation plays a major role in controlling the earth's system itself. It can change the water cycle, it can change the carbon cycle. Only from vegetation we derive our food that is, essentially the crops. So, vegetation covers the entire spectrum or entire gamut of starting from trees, plants, crops, grasses and so on.

Even though vegetation has many different complex forms starting from tiny algae to huge trees it can take variety of shapes and everything, the spectral reference curve of vegetation has a one particular unique pattern. So, this is general for healthy green vegetation or in particular we are going to discuss about the spectral reference curve of healthy green leaf.

We will start with understanding the spectral reference of one leaf and then slowly we will build our understanding of how it will look when we move up in the sky. That is first we start with a single leaf then we move away from single leaf to looking at one plant or one full canopy and so on. So, at first we will start by looking at the spectral reference curve of one single healthy leaf.

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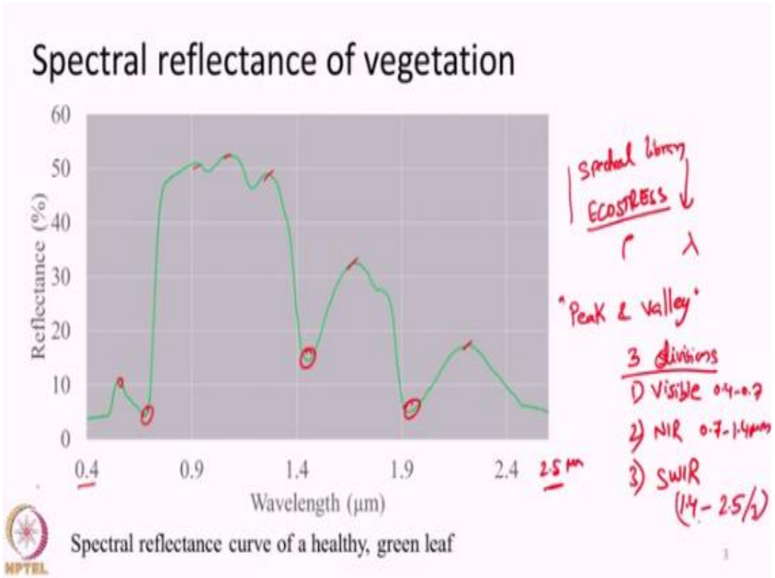

That is given in this particular slide. So, here in the x axis we have wavelengths ranging from 0.4 to roughly 2.5 micrometers and reflectance is plotted along the y axis. So, this is a observed data in laboratory measurements. I have taken it from a spectral library called ECOSTRESS library. So, you can search it in internet and you can easily access this spectral library.

So, this spectral library contains reflectances for hundreds of features on earth surface. How the reflectance will vary with different wavelengths. You will get it in form of a table, you can just plot them and analyze in detail how different features look. So, I will use this spectral library to a good extent in the series of lectures. You can easily refer it in the internet.

So, coming back to the spectral reference curve of vegetation, it is typically called to have a peak and valley configuration. If you look at this, it has a lot of small peaks here, all these portions here and here and so on. And also a lot of valleys here, here and so on. So, that is why this particular reflectance pattern got a name of peak and valley configuration.

We can divide this particular curve into three portions according to the wavelength range. That is we will first analyze what happens in visible band. Then we will analyze what happens in the NIR band and finally we will analyze what happens in the SWIR band. Roughly 0.4 to 0.7 micrometers, 0.7 to 1.4 micrometers and from 1.4 to say 2.5 or 3 micrometers. We will divide this curve into three different portions and then we will analyze in detail.

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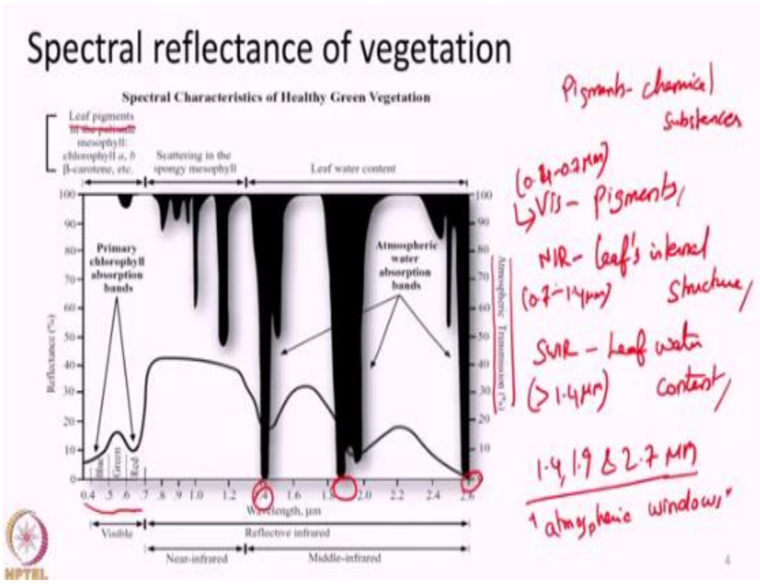

Before doing that it will be beneficial for us to understand some information about the structure of a leaf.

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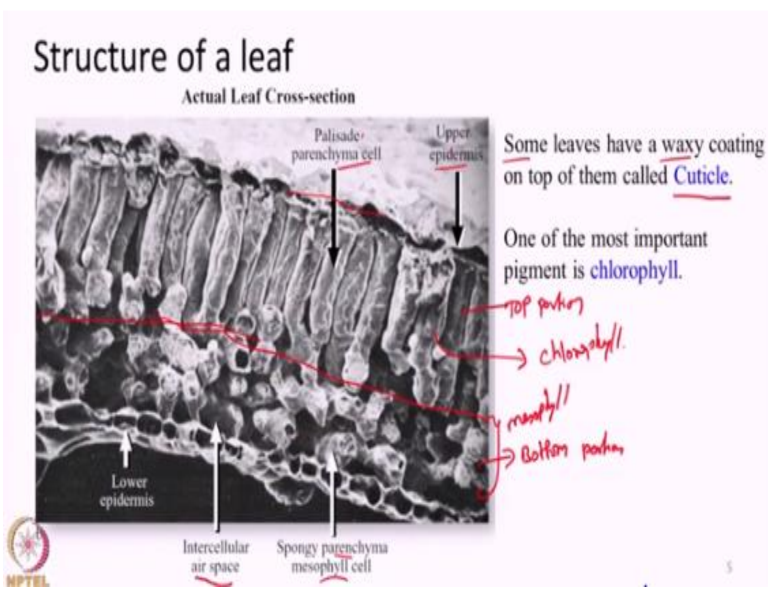

So, if you look at the structure of a leaf, the electron microscopic image of one single leaf, it shows that it has different portions. That is a leaf has one top portion what we call as epidermis. Similar to our skin even the plant leaf has a top layer we call as epidermis. And some varieties of leaves have a waxy coating on top of it called cuticle. So, this is a waxy coating present on top of the leaf which prevents the leave from over draining of water. So, this will be a thick coating over desert plants and shrubs. It may be a thin coating over plants and trees present in heavy rainfall region. If you look here you can observe two different types of cells. One elongated lengthy cells on top half of the leaf and at the bottom it is having irregular shape of cells. The cells that are present on the top portion we call as the palisade parenchyma cells. The cells present on the bottom portion we call as the spongy parenchyma mesophyll cell.

In the top portion we have one of the most important pigments in the vegetation that is the chlorophyll. And we all know that chlorophyll is one of the most essential pigments or chemical substance to be present in the leaf that enables the leaves to do photosynthesis which produces food on its own that gives leaves its characteristic green color and so on.

So, the chlorophyll the most important pigment in the leaf is present in the palisade parenchyma cells. That is the elongated cells mostly on the top portion of the leaf. If you look at the bottom portion, the spongy parenchyma portion, we can observe lot of air gaps or air space that is present in between the cells. So, this particular air space sometimes will be filled with water.

That is when plants take water from the root system, the water will come and occupy this particular air space. And when plants dry out, this space will be removed of water and it will again become airspaces. So, this is a very basic structure or basic introduction to the structure of leaf. Now we go back to the spectral reflectance curve and possibly analyze or understand what controls the spectral reflectance curve for different portions.

So, here this one more spectral reflectance curves of healthy green vegetation. So, within the visible range that is in the wavelength of 0.4 to 0.7 micrometers the primary factor that influence the spectral reflectance curve is the leaf pigments or absorption due to leaf pigments. So, pigments are nothing but chemical substances which are present in the leaf. Chlorophyll is one of the most commonly occurring pigments that are present in the leaf.

Similarly there can be other type of pigments like carotene and so on. So, within the visible range it is the presence or absence of leaf pigments which influences the spectral reflectance curve to a large extent. Once we enter into the NIR portion that is starting from 0.7 to 1.4 micrometers, the leaf internal structure or the scattering happening within the leaf controls the spectral reflectance portion.

So, in the visible, it is the pigments, in the NIR range, it is the leaves internal structure and in the SWIR range, that is after 1.4 micrometers, it is the leaf water content that controls the spectral reflectance curve. So, these three factors, one is the pigments, then the leaves internal structure and then the leaves water content influences the spectral reflectance curve of healthy green vegetation.

Also in this particular slide the atmospheric absorption is superimposed on the spectral reference curve, it is denoted as atmospheric transmissivity on this particular part of the y axis on the secondary axis. We can see that for most of the portions up to NIR the atmosphere is kind of fairly transparent with almost 50% transmissivity. And almost in most of the bands the transmissivity is up to 80%.

But there are really strong absorption bands of atmosphere around this 1.4 around this 1.9 and around this, 2.7 micrometers. So, when we study the spectral reflectance curve of vegetation in laboratory measurement we will get the entire curve. But when we do it in the atmosphere or when we do it from satellites, because of influence of atmosphere we may not be able to do remote sensing of the entire solar reflected portion. We may have to leave certain bands. So, that the atmospheric influence is reduced or essentially we have to do remote sensing of vegetation in the atmospheric windows, avoiding the bands in which atmosphere is highly absorbed in.

Now we have got a very broad general introduction about the leaves internal structure and also what factors controls the reflectance or spectral reflectance curve of vegetation in different portion of EMR especially in the solar reflected domain. So, now we will go little bit in detail and study each portion individually. First we will start with the visible portion of the spectrum.

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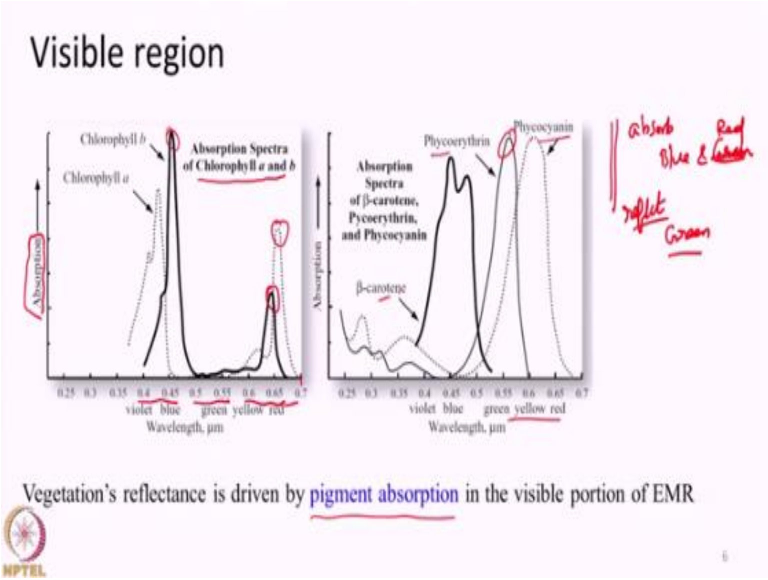

As I have already told you the most important factor that controls the vegetation's reflectance is the pigment absorption in the visible portion of EMR. And pigments essentially mean chemical substances present within the cell or present within the leaf. And one of the most important pigment or the most abundant pigment is chlorophyll. So, this particular curve on the left hand side gives the absorption curve of chlorophyll.

So, this is not the reflectance curve this is the absorption curve. How chlorophyll absorbs in different wavelengths starting from ultraviolet and all the way up to red band. If we closely observe this, the absorption is pretty high in blue wavelength roughly around like 0.4 to 0.45 micrometers. And similarly the absorption is fairly high in the red wavelength that is from 0.6 to 0.7 micrometers. And absorption is very low in the green band of the spectrum 0.5 to 0.6.

So, essentially a leaf containing lot of chlorophyll pigments will be absorbing blue wavelength and red wavelength to a significant extent and will be reflecting green wavelength again to a large extent. That is chlorophyll pigments absorb blue and red wavelength and reflect green wavelength. And this is especially for chlorophyll. So, two kinds of chlorophyll pigments are there chlorophyll a and chlorophyll b. Both of them have typical characteristics. But if you look at this, the chlorophyll b pigment has a really strong absorption in the blue band in comparison to chlorophyll a. On the other hand chlorophyll a has a really strong absorption in the red band in comparison with chlorophyll b pigment.

So, based on the presence of different types of chlorophyll the reflectance can vary. But essentially the overall feature, that is absorption in blue and red wavelength and reflection in green wavelength will be remaining the same. Apart from chlorophyll there can be other pigments that can be present in the leaf say beta-carotene, pycoerythrin, pycocyanin and so on. So, as the pigment changes or as the leaf changes through different stages of its growth cycle and the pigments contained within the leaf will change. And hence the leaves characteristic color also will change. So, essentially we have seen for healthy green leaf chlorophyll will be the most abundant pigment present within the leaf. So, the absorption features or the reflection feature of chlorophyll will be dominating and it will be absorbing lot of red and blue wavelength and will be reflecting green wavelength.

That is what gives healthy leaves its characteristic green color which means chlorophyll is abundant in healthy green leaf. But if the leaf progresses through different stages of its growth cycle, we call it as senescence or phenological cycle. If the leaf matures what will happen is different pigments will come in and chlorophyll will drop. Other pigments may start to increase in the quantity. When that happens the leaves color may change depending on the pigments that are becoming abundant now. So, here let us say beta keratin is being present in the leaf. So, you can see that beta carotene absorbs a lot in the blue wavelength again. But its absorption becomes extremely low in green and red portion combined together. So, when beta-carotene becomes the dominant pigment within the leaf, it will absorb blue and it will reflect green and red portions and a leaf may have a yellowish appearance.

Similarly if pycoerythrin is the primary pigment present in the leaf, it absorbs primarily in the green band with very low absorption in blue and red bands. So, again it may produce a completely different color to the leaf. So, the absorption by different pigments is what drives the spectral reflectance curve of vegetation in the visible part of the spectrum. And also this particular absorption of certain characteristic wavelengths gives the leaves its characteristic color. Absorption of blue and red leaving green out will give the leaf the green color. This is done by chlorophyll. Absorption of blue only allowing green and red to pass may give the leaf an yellowish color. That is because of the beta keratin and so on. So, the presence or absence of certain pigments will drive or will dominate the spectral reference property of vegetation. So, as the vegetation goes through different cycles of its growth phase or if the vegetation undergoes certain amount of stress the pigments present within the leaf will change and hence the colour of the leaf will start to vary. We will observe it visibly with our eyes as our eyes are tuned to observing visible portion of EMR.

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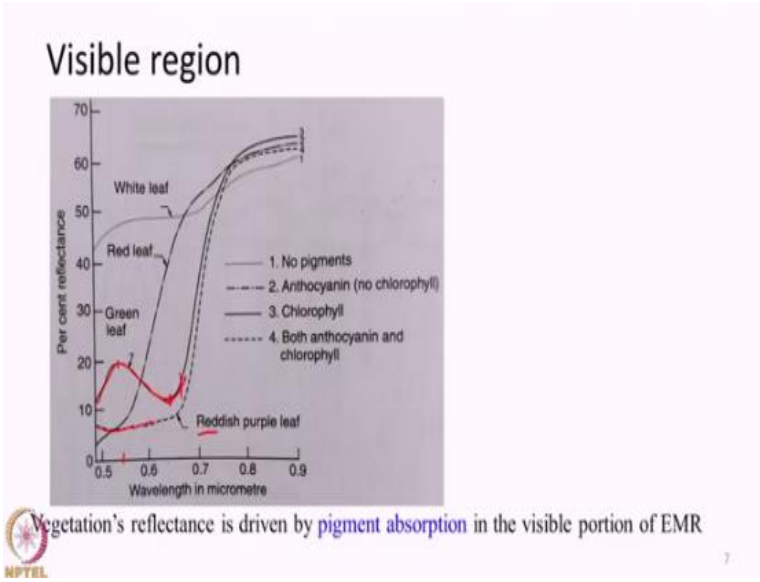

So, this particular figure gives another example of how leaf with different colors look or how the spectral reflectance curve of leaves in different colors look. Say for a healthy green leaf you can see reflectance is pretty high in the green portion that is around 0.55 micrometers. And it is low in the blue and also it is low in the red portion you can observe it from here up to 0.7. But if you look at other leaves that is say this reddish purple leaf, you can see that the reflectance is pretty low in almost all portion of EMR giving a combined mix of a dark color.

That is why the leaf may appear reddish purple or for a red leaf the reflectance in red portion is very high with very low reflectance in green portion. So, this is because of presence of different pigments present within the leaf essentially. That will dominate or that will control the reflectance pattern of leaf especially in the visible range. Next we will move on to discuss about the spectral reflectance property of leaf in the NIR portion of electromagnetic spectrum. So, if you look at the basic spectral reflectance curve, we can observe that the reflectance is quite low in the visible part that is around 10 to 12% maximum in the visible portion. If you transfer to NIR portion after this 0.7 micrometers you can see the reflectance increases drastically it reaches 50%. And again it slowly begins to decrease as we increase in the wavelength. But if you look at this particular curve, in general the reflectance starting from NIR all the way up to SWIR portion is relatively higher when compared to the reflectance in the visible band. And in the NIR portion the reflectance is highest. The reason is that the plants typically need light for its function we all know that. It has to do photosynthesis it needs its internal energy which is derived from sunlight. And sunlight is a mixture of various wavelengths we also know that.

With the primary wavelength or the wavelength with in which maximum energy coming is green portion typically. So, what happens is leaves derives most of its energy requirement from the visible portion of EMR that is between 0.4 to 0.7 micrometers. Leaves do lot of absorption and uses that particular energy for its functioning and photosynthesis. That is why leaves reflect very little amount in the visible portion. The reflectance is pretty low, less than 15% in almost the entire visible range.

And this is still lower in the blue and red band in comparison to green. But leaves will not absorb EMR with the same efficiency in the NIR portion of the spectrum, because a significant amount of solar energy will come in the near portion of the spectrum also. And if leaves absorb all these things with the same efficiency with which it absorbs visible wavelength then it will overheat the leaves and leaves may die causing an irreparable damage.

So, that is why in order to prevent the leaf from dying or from preventing the leaf from irreparable damage leaves generally has a tendency of high reflectance and high transmittance in the NIR portion of electromagnetic spectrum. So, essentially in the NIR portion it is the leaves internal structure that controls the reflectance. That is leaves do not want to store NIR and leaves do not want to absorb because it is not going to use it.

Most of the uses for leaves or most of the energy requirement for leaves comes in from the visible portion of the spectrum itself. That is why it absorbs a lot of visible portion of EMR reflecting very little. But it does not want to store and use NIR with a full efficiency. So, the leaves internal structure that contains the palisade parenchyma cells which contains chlorophyll and the lower half of the portion contains all gaps plus spongy parenchyma cells influences the reflectance to a great extent. So, when NIR energy enters through a leaf, first thing leaf has a high transmissivity and it allows NIR to pass through it. It is not going to absorb it, when it passes through it will cross the top portion of the leaf, then it will enter the lower portion where it encounters air gaps or water. So, there will be a change in the medium. We have already discussed about how EMR will interact with different features in the initial lectures when we discuss about properties of EMR.

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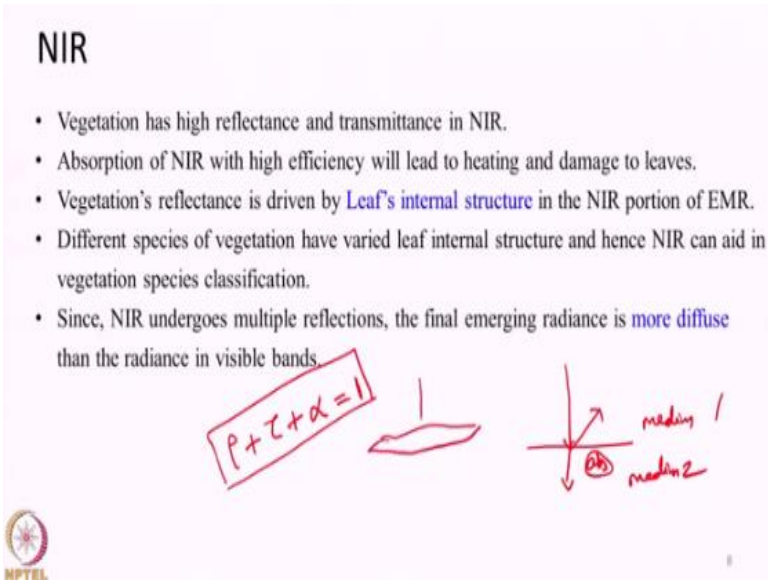

I told you that when EMR travels from one medium to another medium, at the surface that divides medium 1 and medium 2 it will undergo reflection, that we have already discussed. So, some part may be transmitted inside, some part may be absorbed and some part may be reflected. And this is what we studied as reflectance plus transmittance plus absorptance is equal to 1. This is we have already studied.

But what we have to remember is when there is a change in medium a portion of EMR is reflected back and some portion is transmitted inside the medium. If you take leaf absorption is quite low it has lot of reflection and transmittance. So, when we see in the case of a single leaf, EMR is going to incident on it, so what will happen? The leaf will allow or leaf will transmit a large portion of EMR and whenever this NIR energy encounters a discontinuity or a change in medium say from a plant cell to air gap or if it is filled with water whatever it may be, it will undergo multiple reflection. It may be reflected here, it can again be reflected here and it can undergo a lot of multiple reflections.

So, the leaves internal structure, how the cells are oriented within the leaf, how the air gaps are oriented within the leaf will cause the energy in the NIR portion to undergo multiple reflection within the leaf. And also combining this with high transmittance the leaf after undergoing multiple reflectance will be either reflected totally in the upward direction like some part of it may be reflected again in the top part or some may be reflected or transmitted down to the bottom part.

So, essentially what I want to convey is leaf has high transmittance and high reflectance especially in the NIR portion. So, when energy enters into the leaf, it will transmit through and when it encounters a change in medium that is from leaf cell to air gap or whatever if when it encounters a different medium it will undergo reflection. And because of the random orientation of leaf pigments and leaf air spaces, NIR will undergo multiple reflections. And finally some fraction of NIR will come out of the top part of the leaf itself giving a total reflectance. Some portion of energy will be allowed to transmit completely through the leaf and will be coming out of the bottom part of the leaf. So, essentially what you have to remember is a large portion of NIR is either reflected or transmitted from the leaf.

So, in this particular lecture we have started discussing about the spectral reflectance property of vegetation especially of a leaf. We have covered the reflectance property in the visible portion and we have started discussing about the NIR portion. And we will continue this and further topics in the next lecture.

Thank you very much.