**Soil Fertility and Fertilizers**
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**Lecture 56**
**Agricultural Productivity and Environmental Quality**

Welcome friends to this new week of lectures for the NPTEL online certification course of Soil Fertility and Fertilizers. This is our last week of lectures. We are at week 12.

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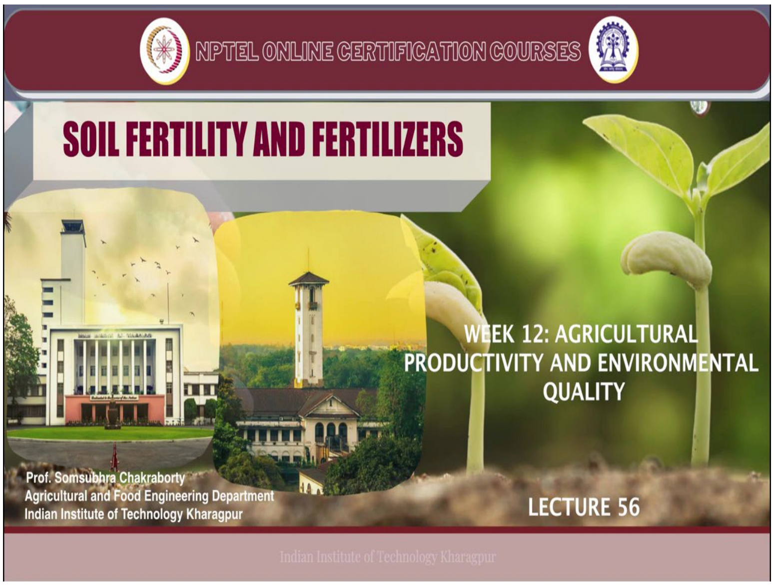


And in this week, we are going to discuss about the different environmental aspects which are related to the agricultural productivity and nutrient management. So, the topic of this week of lectures is agricultural productivity and environmental quality. Now, in this first lecture, we are going to discuss a very important concept which has got enough attention in recent days, this is called carbon sequestration. So, this lecture number 56 will be focused on carbon sequestration and different aspects of carbon management.

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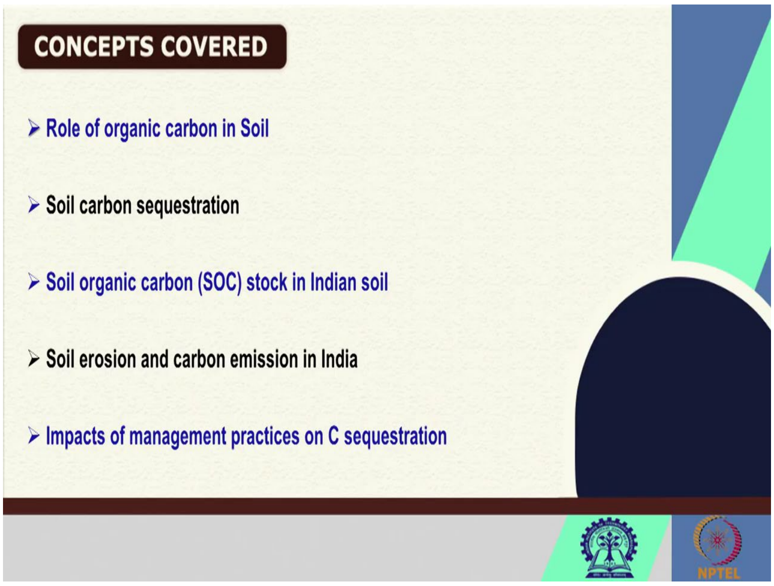


So, let us discuss the carbon sequestration. These are the concepts which we are going to discuss in this lecture. First of all, we are going to talk about the role of organic carbon in soil. And then, we are going to also talk about soil carbon sequestration and then soil organic carbon stock in Indian soil and then soil erosion and carbon emission in India. And then we are going to discuss the impacts of management practices on carbon sequestration. So, these are the 5 major concepts which we are going to cover in this lecture number 56.

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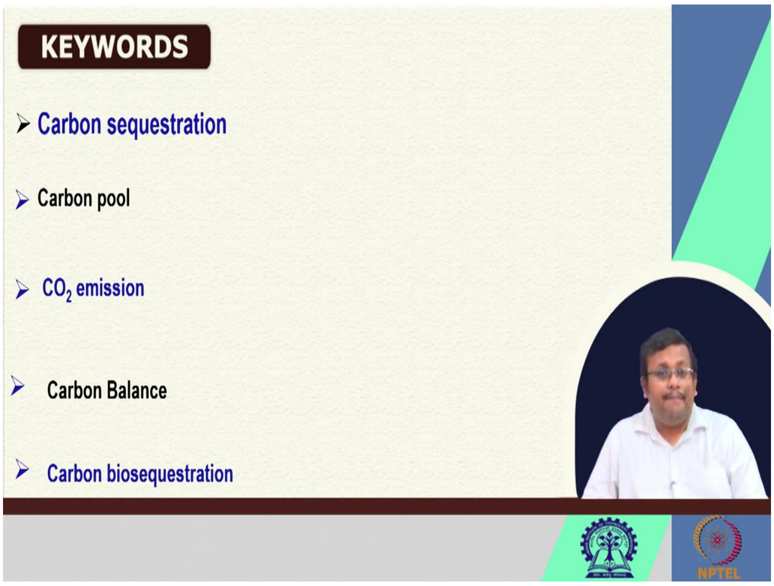


And, the 5 different keywords which are related to this lecture are carbon sequestration, carbon pool, carbon dioxide emission, carbon balance and carbon biosequestration.

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Now, let us discuss what is sustainable development goals of United Nations. So, we know that United Nations has developed 17 global goals for sustainable development. Just like here you can see no poverty, goal number one is no poverty. There is zero hunger, then good health and well-being, quality education, gender equality, clean water and sanitation and affordable and clean energy, then decent work and economic growth, then industry innovation and infrastructure, then reduced inequalities, sustainable cities and communities, responsible consumption production.

And then you can see climate action goal number 13. And apart from that also life below water, life on land, peace and justice, strong institution and partnership for the goals. Now, you can see the goal number 13 that is called climate action. So, climate has gotten tremendous importance in the sustainable development goals set, which are developed by this United Nations.

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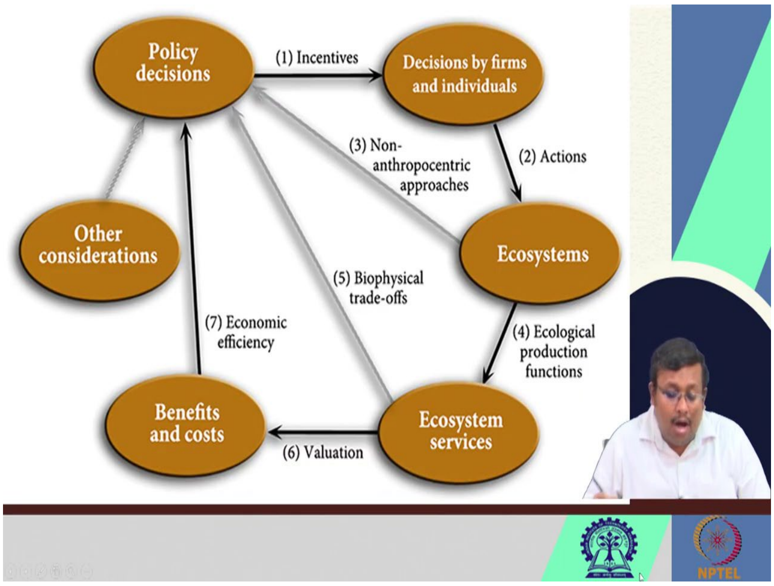


Now, of course, if we see that these policies are here having the policies which are being developed at the United Nations have their tremendous impact on maintaining the sustainable ecosystem. Now, we know that policy decision can give the incentives to that which will be required for making the decision by firms and individuals and then we can see their decisions will convert into actions, which will govern these ecosystems or which will impact these ecosystems. Also, these non-anthropogenic approaches also will be taken care of in the policy decisions.

Of course, from this ecosystem, we can see the ecological production function which goes to ecosystem services which again goes to the benefits and cost using the valuation. Now, the policy decision not only depends on the non-anthropogenic approaches, but also biophysical trade-offs, which generates from the ecosystem services. And also the benefits and costs that means the economic efficiency also impact the policy decision and are there are other considerations also.

So, ultimately, one thing we can say that these global policies of climate action is dependent on different factors, different consideration, economic efficiency as well as the ecosystem services. Ecosystem service and ecosystem or ecological production function plays an important role in the policy decision that is why you can see that the thirteenth goal that is climate action is there in this all Sustainable Development Goals.

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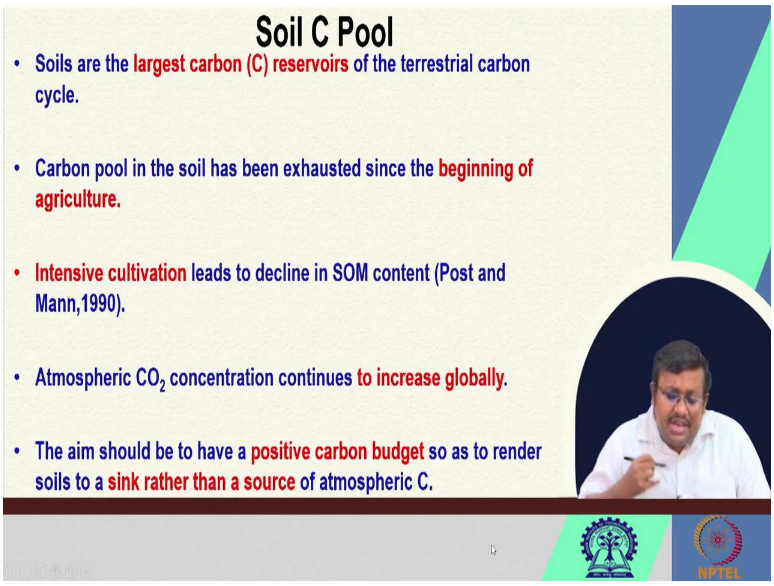


Now, if we see soil carbon pool, now, soils at the largest carbon reserves of the terrestrial carbon cycle. Now, carbon pool in the soil has been exhausted since the beginning of the agriculture. The day human civilization started agricultural practices then there from then there is a decline of the carbon pool of soil.

Now, intensive cultivation leads to decline in soil organic matter content and atmospheric carbon dioxide concentration continues to increase globally due to different factors, due to anthropogenic factors, due to industrialization they were several factors. So, atmospheric carbon dioxide concentration continues to increase globally.

So, the aim should be to have a positive carbon budget, so, as to render soils to a sink rather than a source of atmospheric carbon. Instead of considering soil as a source of atmospheric carbon can we convert this carbon which is present in the atmosphere reversibly into soil components. So, this should be the optimum goal for maintenance of a positive carbon budget.

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Now, you can see that is carbon moves from soil to atmosphere and from atmosphere plants also take those carbon dioxides to develop the photosynthetic products and then again those organic matter will decompose and come into the soil organic matter. So, there is in a continuous cycling of carbon between the soil and the atmosphere and also inside the plan body.

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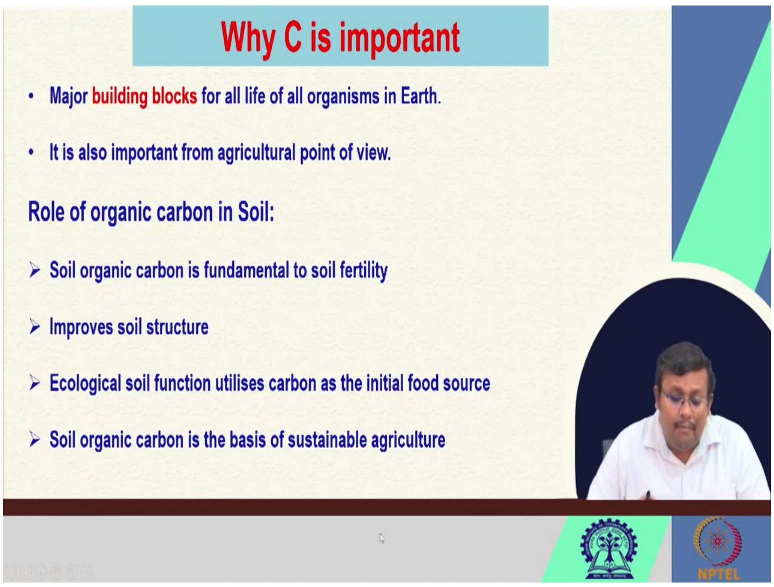


Now, so, why carbon is important? We know that carbon is the major building blocks for all the carbon compounds. These carbon compounds are the building blocks, major building blocks for all life of all organisms in earth, whatever we talk about like carbohydrate, protein, fat, these are the major building blocks for all life for all organisms on Earth. And carbon is also important from agricultural point of view.

Now, if we consider the agricultural rolls of organic carbon, then soil organic carbon is fundamental to soil fertility, because it is the storehouse of all the plant nutrients and also the addition of organic matter improves the soil structure by its binding action. Then, also, it plays ecological roles, which utilizes carbon as the initial food source. So, carbon also acts as a initial food source and soil organic carbon is the basis for sustainable agriculture. So, without organic carbon, it is not possible to maintain sustainability agriculture rather, maintaining the proper organic matter or proper organic carbon in the soil is a goal of sustainable agriculture.

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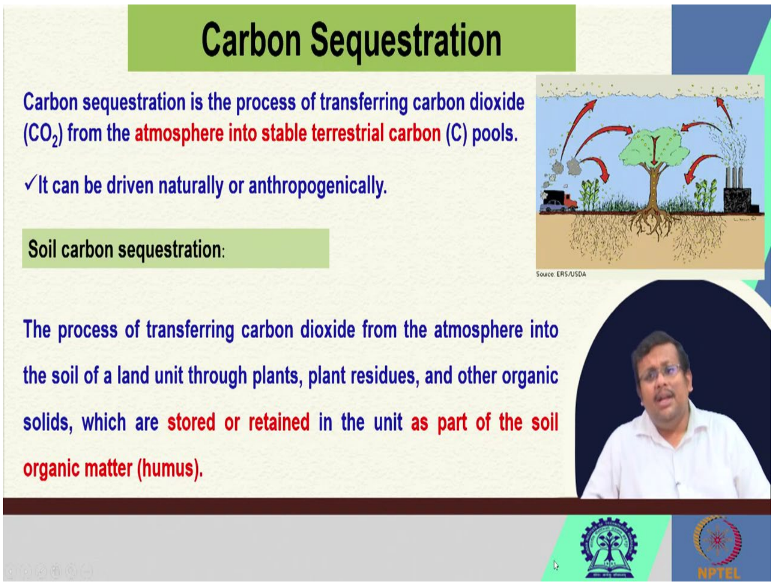


Now, let us discuss what is carbon sequestration. As we have seen in our previous slide that policy decisions take care of the environmental factors, ecosystem services and ecological considerations. So, to reverse the higher concentration of carbon dioxide in the atmosphere it is required to convert the atmospheric carbon into the soil carbon pool. Now, the conversion of or carbon from the atmosphere to the soil organic carbon is called the carbon sequestration. Now, carbon sequestration is the process of transferring carbon dioxide from the atmosphere into stable terrestrial carbon pools.

Now, it can be driven naturally or anthropogenically, anthropogenically by different management practices and also there are different natural sequestration processor also there which we are going to discuss in our coming slide. Now, in case of soil carbon sequestration, the definition of the soil carbon sequestration says that it is the process of transferring carbon dioxide from the atmosphere into the soil of a land unit through plants, plant residues and other organic solids which are stored or retained in the unit as part of the soil organic matter or humus. So, this is basically conversion of carbon from carbon dioxide to the humus which is which resides in the soil.

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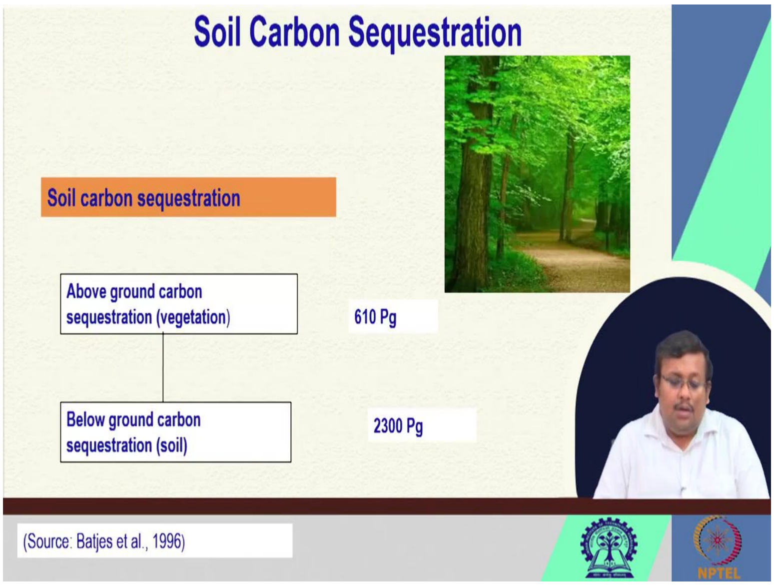


Now, if we see the distribution of the carbon sequestration, we can see that above ground carbon sequestration by vegetation accounts for 610 pentagrams whereas, the below ground carbon sequestration in the soil accounts for 2300 pentagram, so, it is very obvious that soil is the major source of carbon sequestration.

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Now, I told you about the natural sequestration. Now, natural sequestration also have several types. First of all, peat bogs, so, peat bogs are an important carbon source. By creating new bogs or preserving or enhancing the existing ones, carbon can be sequestered. Then reforestation is another way of natural sequestration. So, reforestation is the planting of trees on marginal crop and pasture lands to incorporate carbon from atmospheric carbon dioxide into the biomass. So, this is another way of natural sequestration.

And third is wetland restoration. So, wetland soil is an important carbon sink. 14.5 percent of the world soil carbon is found in wetlands while only 6 percent of the world's land is composed of wets lands. So, creating more wetlands would sequester more carbon in the soil. So, these are different processes of natural sequestration.

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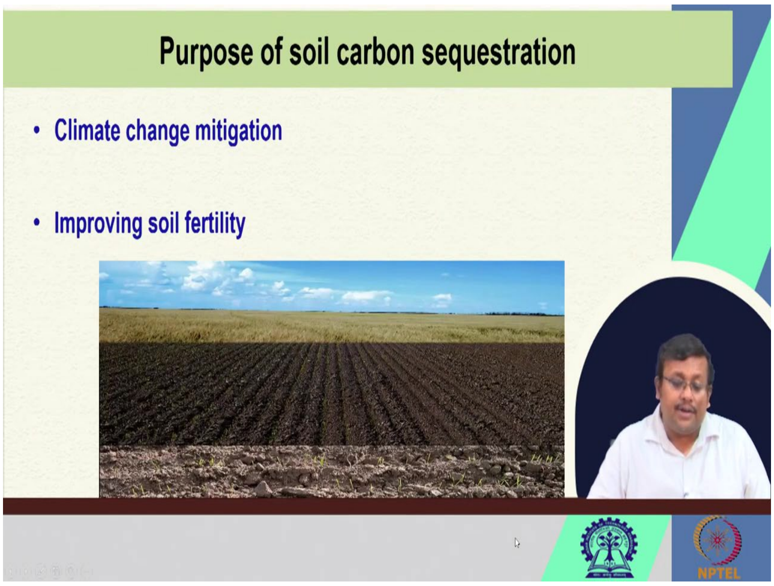


Now, why we need carbon sequestration? If this question comes to our mind, the answer is first of all, climate change mitigation is the first reason. The second reason is improving soil fertility. Of course, as carbon dioxide is an important greenhouse gas. So, if we convert the higher carbon dioxide concentration in the atmosphere and then if we can reduce that higher carbon dioxide concentration in the atmosphere by converting the carbon dioxide into some organic matter, through carbon sequestration, that will impact the climate change positively.

Secondly, improving soil fertility not only converting the carbon into soil carbon pool, but also to improve the soil fertility also, this carbon sequestration plays an important role. So, carbon sequestration is a very important process for not only the climate change mitigation, but also to improve soil fertility, which will ultimately impact the growth of the plant.

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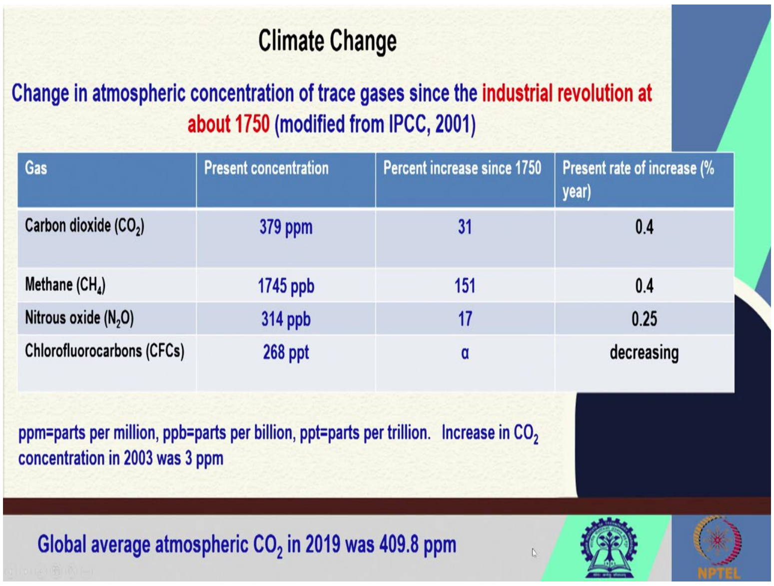


Now, if you see the change in atmospheric concentration of trace gases, since the Industrial Revolution, which occurred set around 1750. So, we can see that carbon dioxide right now, the present concentration is 379 ppm, methane is, so, percent increase since 1750. We can see it is 31 percent increase and currently present rate of increase is 0.4 percent per year. In case a methane, you can see 151 percent increase since 1750. Currently 1745 ppb concentration is there and the percent rate of increase is 0.4 percent per year.

In case of nitrous oxide, you can see the percent increase in 1750, 17 percent. Right now, it is 314 ppb and it is increasing at a rate of 0.25 percent per year. Only the chlorofluorocarbon is right now, the concentration of fluorocarbon is 268 ppt or parts per trillion and it is showing a decreasing concentration. So, we can see that the global average atmospheric carbon dioxide in 2019 was 409.8 ppm. So, you see that, how due to industrialization, there are a different greenhouse gases have increased as an alarming rate since the 1750.

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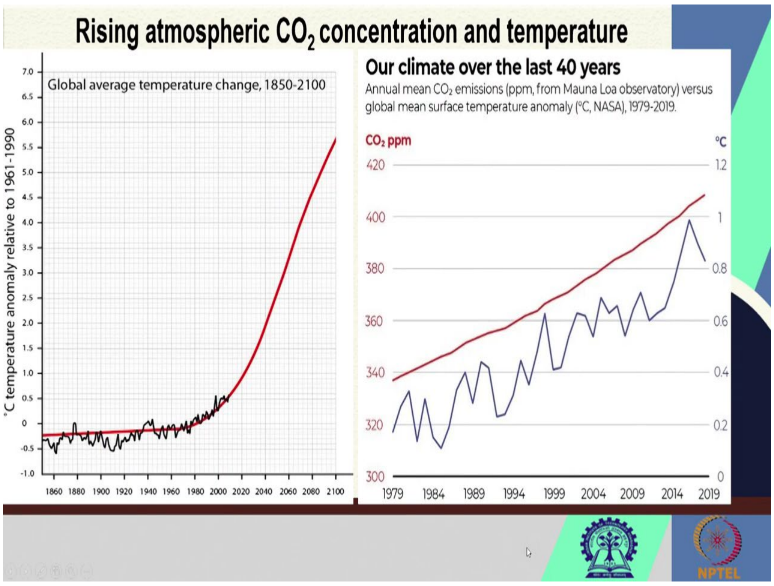


Now, if we see the rising atmospheric carbon dioxide concentration and temperature in this first graph, we can see that temporal increase in temperature anomaly relative to 1961 to 1990. So, you can see from there has been a continuous global average temperature change from 1850 to 2100.

And you can see there is always continuous increase in global average temperature and also you can see there has been a continuous increase in carbon dioxide concentration for last 40 years. So, the annual mean carbon dioxide emission versus global mean surface temperature anomaly you can see that both of them are increasing for last 40 years. So, that shows the impact of different anthropogenic as well as industrial process for rising the atmospheric carbon dioxide concentration and as well as temperature.

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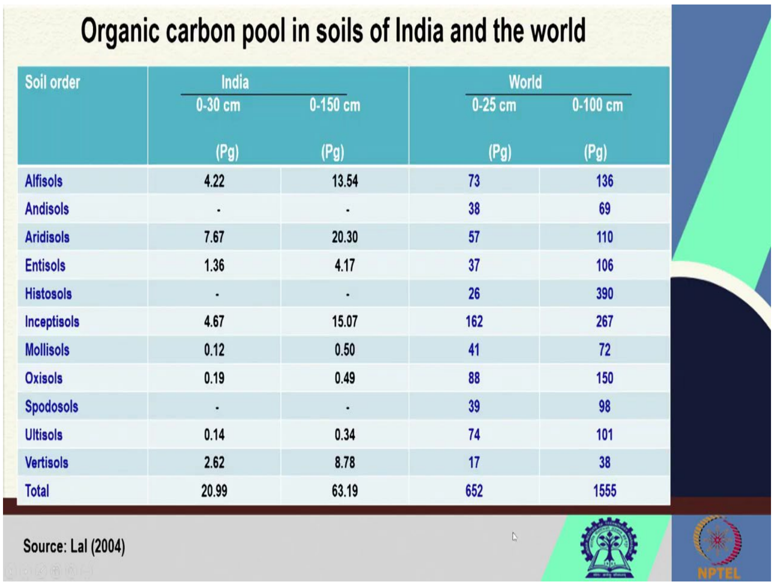
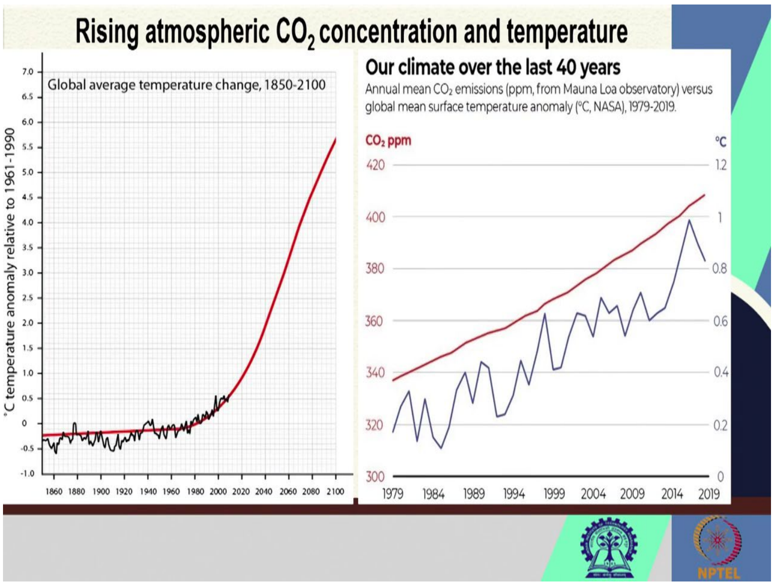


## Organic carbon pool in soils of India and the world

| Soil order | India | | World | |
|---|---|---|---|---|
| | 0-30 cm (Pg) | 0-150 cm (Pg) | 0-25 cm (Pg) | 0-100 cm (Pg) |
| Alfisols | 4.22 | 13.54 | 73 | 136 |
| Andisols | - | - | 38 | 69 |
| Aridisols | 7.67 | 20.30 | 57 | 110 |
| Entisols | 1.36 | 4.17 | 37 | 106 |
| Histosols | - | - | 26 | 390 |
| Inceptisols | 4.67 | 15.07 | 162 | 267 |
| Mollisols | 0.12 | 0.50 | 41 | 72 |
| Oxisols | 0.19 | 0.49 | 88 | 150 |
| Spodosols | - | - | 39 | 98 |
| Ultisols | 0.14 | 0.34 | 74 | 101 |
| Vertisols | 2.62 | 8.78 | 17 | 38 |
| Total | 20.99 | 63.19 | 652 | 1555 |

Source: Lal (2004)




Because when there is a high concentration carbon dioxide concentration that impacts the temperature and of course, with the higher carbon dioxide concentration you can expect the increase in mean temperature, atmospheric temperature as you can see that mean surface temperature is also increasing for last 40 years due to increase in carbon dioxide concentration.

Now, if we see the organic carbon pools in soils of India in the world, you can see that in India Alfisols contains around 4.22 pentagram for 0 to 30 centimeter. And Aridisol, andisol you can see and at the same time you can see the world concentration also for the world soil. So, you can clearly see that the Indian soils are inherently poor in organic carbon. So, for example, if you consider the Alfisols of the world it contains 73 pentagram in 0 to 25 centimeter. However, in case of India it is only 4.22 pentagram.

In case of in case 0 to 150 centimeter you can see 13.54 pentagram however, in the world it is 136. So, organic carbon pools in soils in the world we can have a comparison and Indian soils are inherently poor in organic carbon due to several reasons we will discuss them.

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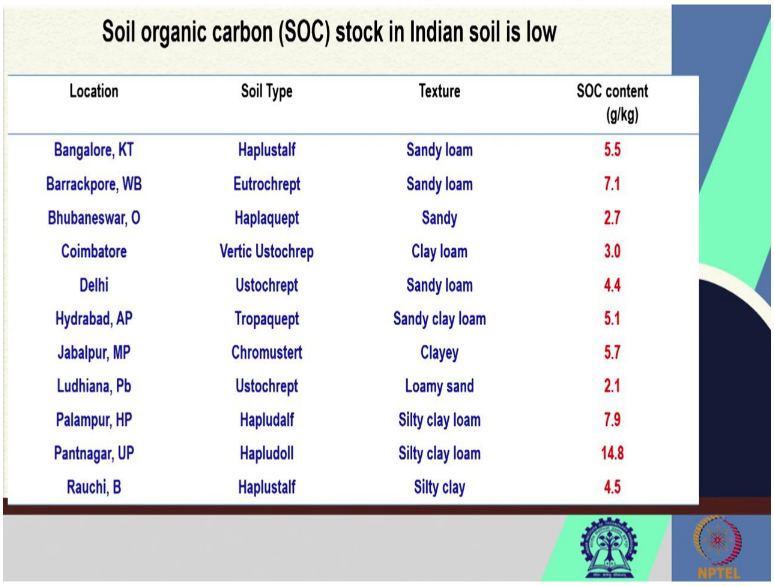


Now you can also see soil organic carbon stock in Indian soil is of course low as you can see here the SOC content in gram per kg in different soils of India we can see. So, inherently soil organic carbon stock in Indian soil is low.

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Now, the question is why our Indian soil is having low soil organic carbon? There are several reasons. First reason is soils have been cultivated for centuries and often with low off-firm inputs. Then tropical climate is another important reason for low soil organic carbon because tropical climate the organic carbon decomposition is quite fast in Indian soil and also soil mining practices of excessive tillage, little or no use of organic manures, then little or no crop residues returned to the soil, several soil degradation. So, all these are important reason for lower soil organic carbon.

Our organic manner application is very low. And as a result there the buildup of organic carbon in Indian soil is very slow. So, there is also little or no crop residue returned to the soil and as a result the organic matter buildup is also declining. And of course, the another important is soil degradation. So, soil degradation is another way of reducing the soil organic carbon pool.

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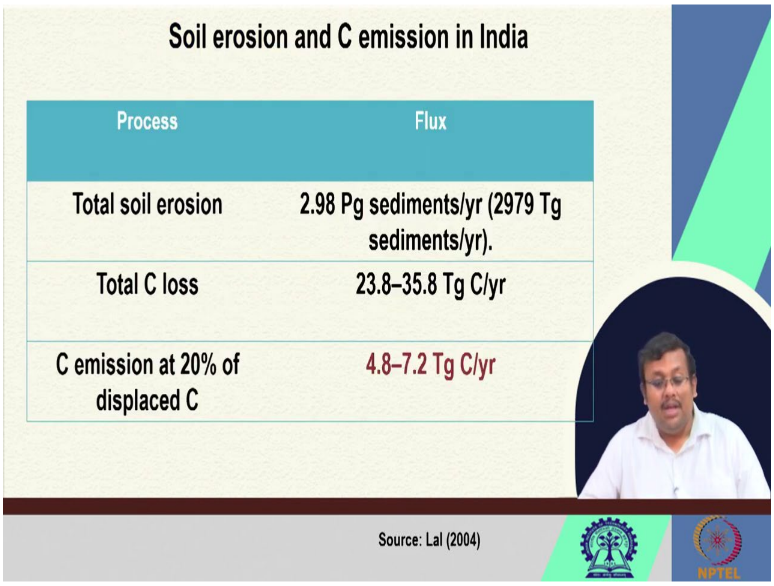


Now, if you see the soil erosion and carbon emission in India total soil erosion you can see 2.98 pentagram sediments per year and total carbon loss is 23.8 to 35.8 terra gram carbon per year and carbon emission at 20 percent of the displace carbon is 4.8 to 7.2 terra gram carbon per year. So, these are some of the statistics of soil erosion and carbon emission in India.

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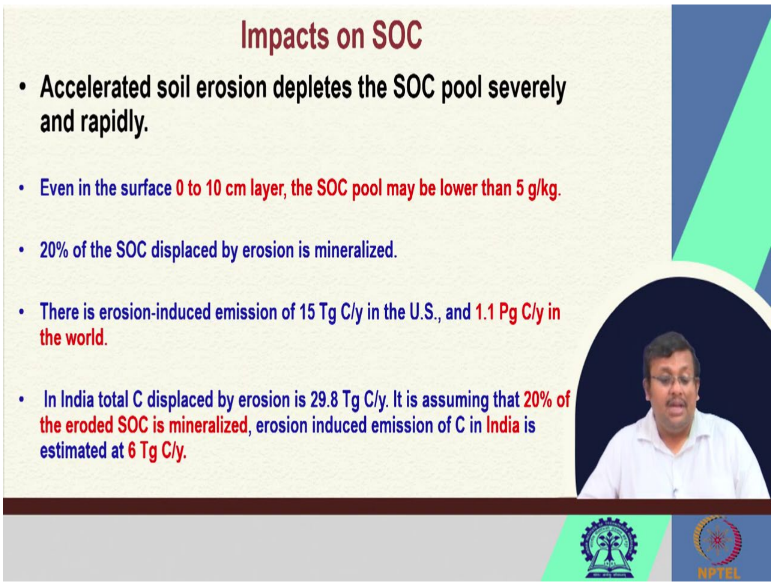


Now, what are the impacts of soil organic carbon? So, accelerated soil erosion depletes. What are the impacts of this degradation on soil organic carbon? So, we know that accelerated soil erosion depletes the soil organic pool severely and rapidly even in the surface 0 to 10 centimeter layer, the soil organic carbon pool may be lower than 5 gram per kg and 20 percent of the soil organic carbon displaced by erosion is mineralized. And there is an erosion induced emission of 15 Terra gram carbon per year in the US and 1.1 pentagram of carbon per year in the world.

In India, total carbon displaced by erosion is 29.8 Terra gram of carbon per year. It is assuming that 20 percent of the eroded soil organic carbon is mineralized and erosion induced the emission of carbon in India is estimated as 6 Terra gram carbon per year.

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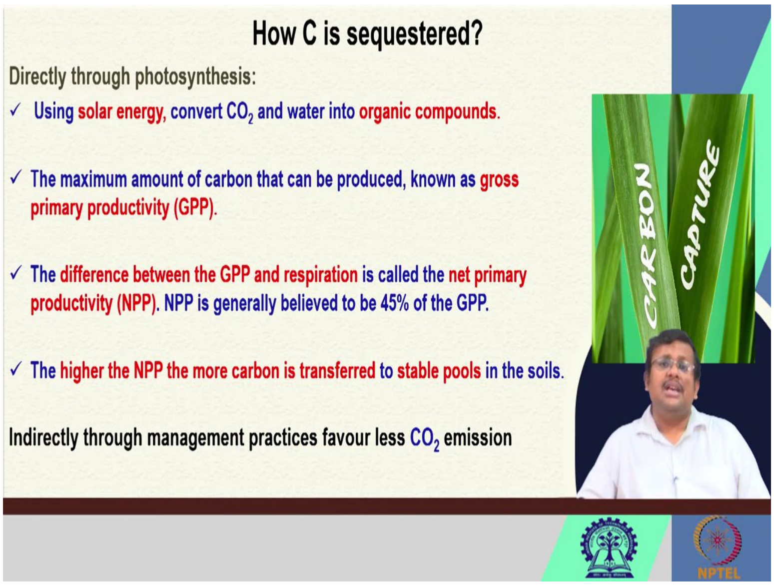


So, the next question is how carbon is sequestered? So, there are several ways. First of all directly through photosynthesis. So, using solar energy, a plant can convert carbon dioxide and water into organic compound. So, this is one way of carbon sequestration, the maximum amount of carbon that can be produced is known as gross primary productivity. So, the difference between the GPP or gross primary productivity and respiration is called the net primary productivity or the NPP. NPP is generally believed to be 45 percent of the GPP.

Now, the higher NPP the more carbon is transferred to stable pools in the soil, indirectly through also management practices, we can favor less carbon dioxide emission. So, there are two major ways, one is directly through photosynthesis. Another is indirectly through different management practices.

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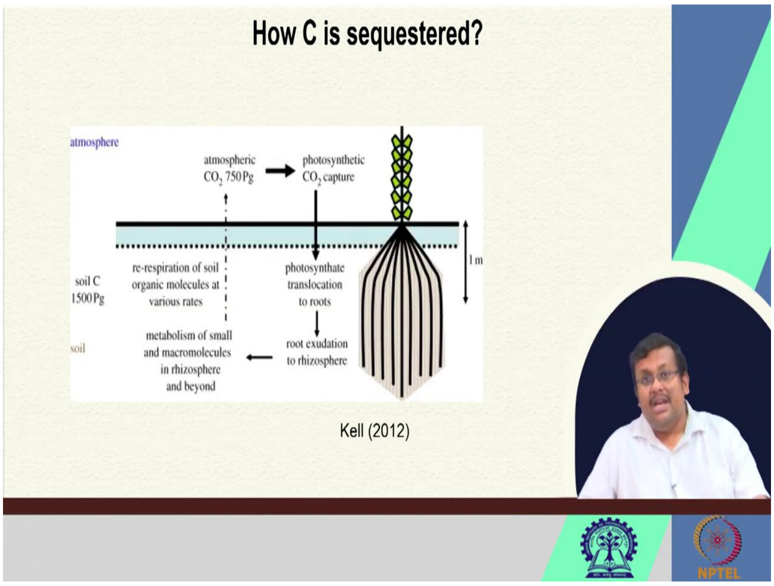


Now, if we see the diagrammatic view, you can see the atmospheric carbon dioxide which is around 750 pentagram, it can convert into photosynthetic products. So, there will be a carbon dioxide capture and ultimately this photosynthetic translocation will occur to roots and then root exudation or to rhizosphere and then metabolism of small and macro molecules in the rhizosphere and beyond. And then re-respiration of the soil organic molecules at various sites. So, this is an one other way of moving of carbon from atmosphere to soil and then again their emission from soil to atmosphere.

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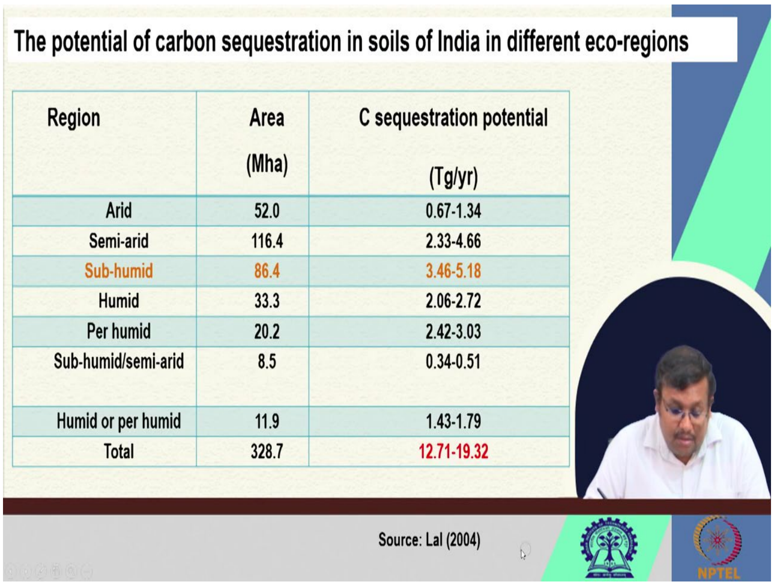
The potential of carbon sequestration in soils of India in different eco-regions

| Region | Area (Mha) | C sequestration potential (Tg/yr) |
|---|---|---|
| Arid | 52.0 | 0.67-1.34 |
| Semi-arid | 116.4 | 2.33-4.66 |
| Sub-humid | 86.4 | 3.46-5.18 |
| Humid | 33.3 | 2.06-2.72 |
| Per humid | 20.2 | 2.42-3.03 |
| Sub-humid/semi-arid | 8.5 | 0.34-0.51 |
| Humid or per humid | 11.9 | 1.43-1.79 |
| Total | 328.7 | 12.71-19.32 |

Source: Lal (2004)

Now, the potential of carbon sequestration in soils of India in different agro eco-regions we can see here, in case of sub humid region, which consists of 86.4 million hectare. We can see the it has the highest carbon sequestration potential with 3.46 to 5.18 Terra gram per year. So, the total carbon sequestration potential accounts for 12.71 to 19.32 Terra gram per year.

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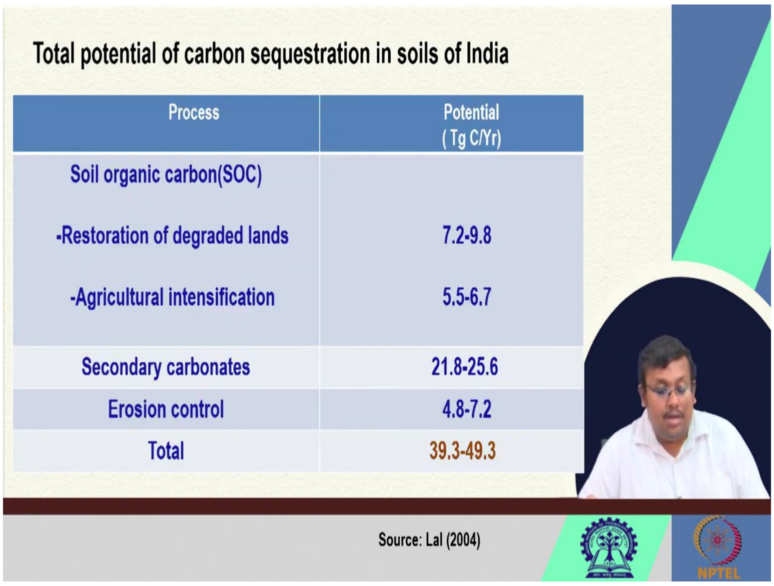


So, the total potential of carbon sequestration in soils of India we can see that restoration of the degraded lands can accounts for 7.2 to 9.8. Then agricultural intensification can accounts for 5.5 to 6.7. Secondary carbonates can accounts for 21.8 to 25.6. Erosion control can account for 4.8 to 7.2 and a total it will be around 39.3 to 49.3.

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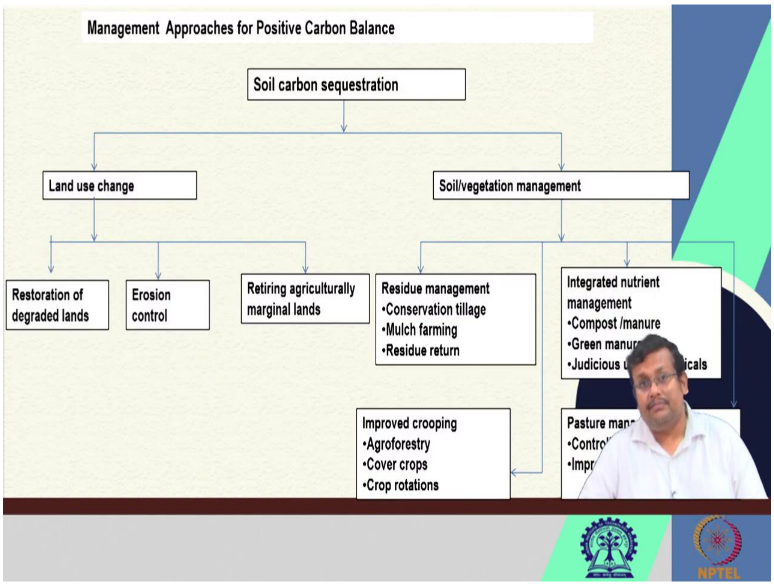


Now, what are the management approaches for positive carbon balance? You can see the soil carbon sequestration can, we can see that we can manage the soil carbon sequestration two way by changing the land use and also by soil and vegetation management. So, how to change the land use. So, we can restore the degraded land. We can control the erosion and also we can help in retaining agriculturally marginal lands. So, these three are the land use change which you can use for soil carbon sequestration. And in the soil and vegetation management we can do residue management like conservation tillage, mulch farming and residue return.

In case of also, we can do improve cropping like agroforestry cover crops, crop rotations and then integrated nutrient management like incorporating compost manure, green manure, judicious use of chemicals and then we can also do pasture management by control grazing and improve species. So, these are some of the ways of management for soil carbon sequestration.

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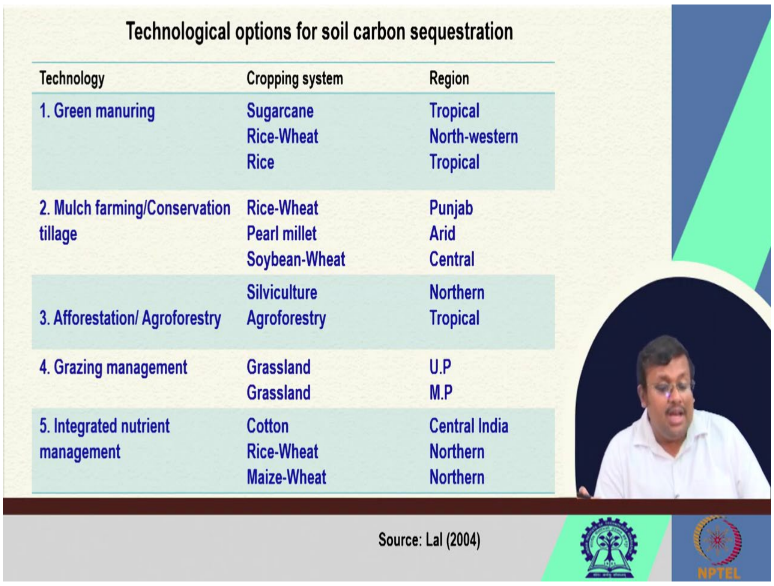


Now, if you see the technological options for soil carbon sequestration, you can see green maneuvering can be done for sugarcane rice, wheat and rice in tropical, north-western and tropical region. Similarly, you can see mulch farming and conservation tillage is useful for rice, wheat, barley, millet and soybean wheat in Punjab and arid central region and all other afforestation, agroforestry grazing management and integrated nutrient management and their respective cropping system and region are also mentioned here.

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Now, if we see the impacts of management practices on carbon sequestration, of course, the carbon sequestration can help in augmenting the soil fertility.

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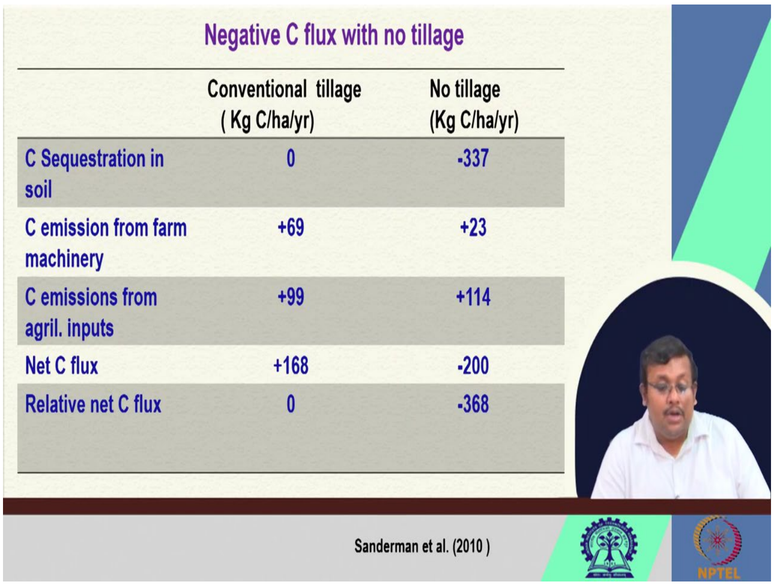


We can see that negative carbon flux with no tillage, no tillage is a way of conservation tillage or conservation agriculture. You can see in case of conventional agriculture, the carbon sequestration in soil is 0 kg carbon per hectare per year. At the same time, we can see there will be 337 kg of carbon will be fixed in the soil using no tillage. Similarly, there will be positive carbon emission from farm machinery, more positive carbon emission from farm machinery in case of conventional tillage, then no tillage.

Carbon emission from agriculture inputs will be a little bit higher in case of no tillage as compared to conventional tillage. However, if we consider the net carbon flux and relative net carbon flux, the no tillage will give you the negative result that means it will help in negative carbon flux and will help in carbon sequestration.

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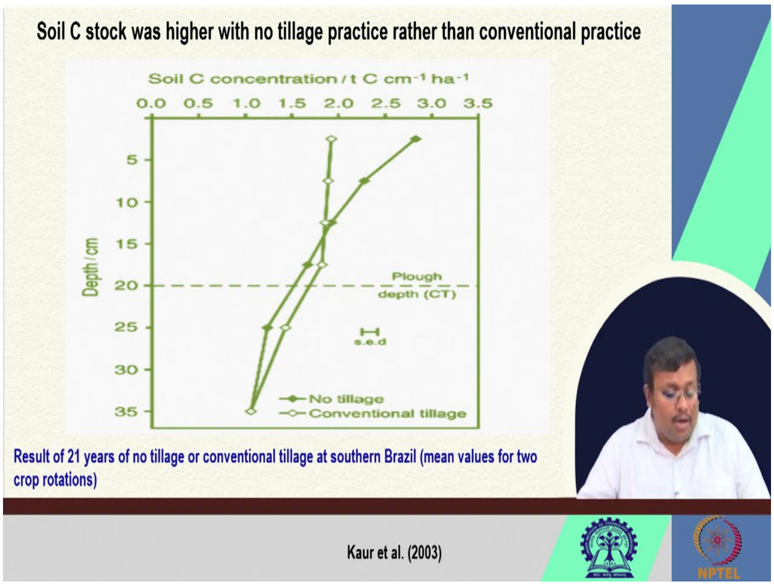


We can also see in case of a long term agricultural practice with no tillage and conventional tillage. If we compare them, we can see that a carbon soil carbon stock was higher with no tillage practice rather than conventional practice. So, you can see this is the no tillage practice. So, after 21 years of no tillage practice, they showed higher carbon concentration than the conventional tillage practice.

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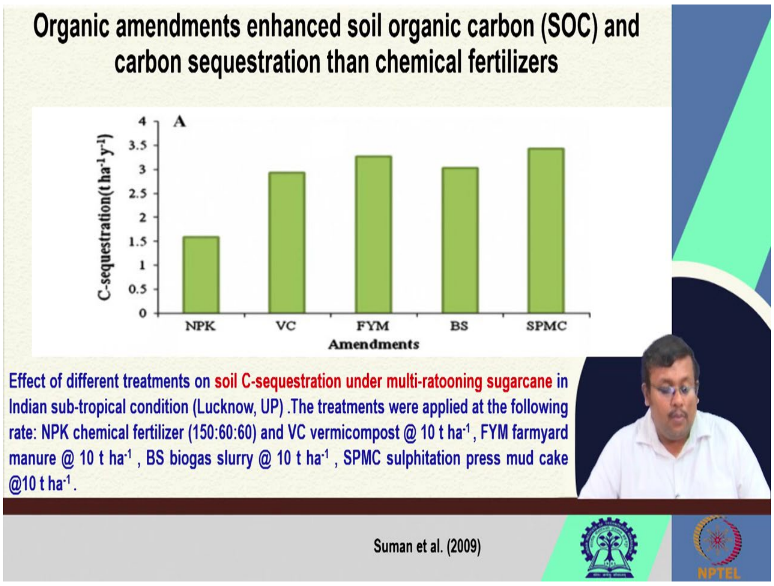

We can also see the effect of organic amendments to enhance soil organic carbon and carbon sequestration. Then chemical fertilizer we can compare. These are showing the carbon sequestration by NPK fertilizer, vermicompost, FYM, BS, SPMC. So, these SPMC stands for sulphitation press mud cake. So, these are different types of organic amendments. So, when we apply these organic amendments, these BS stands for biogas slurry, FYM is farmyard manure and then VC is the vermicompost. So, all these different types of organic products application has increased the carbon sequestration then the NPK chemical fertilizer based application in case of sugarcane.

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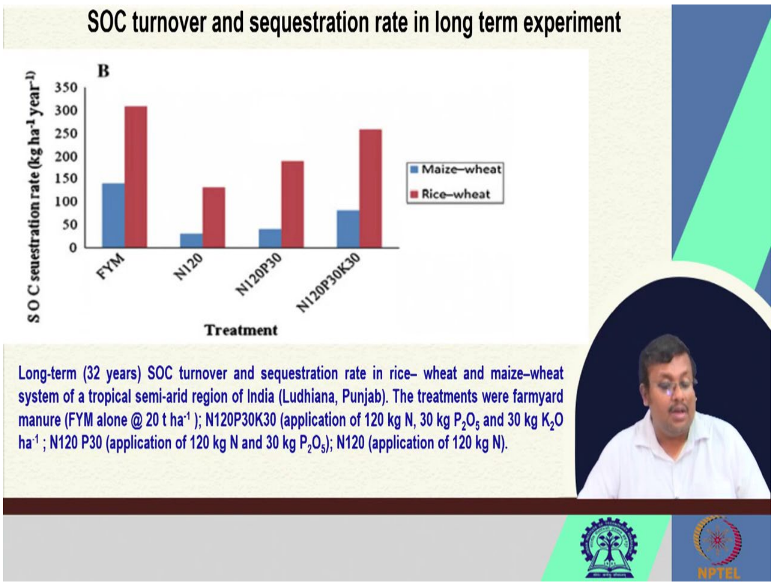


Also you can soil organic carbon turnover and sequestration rate in long term experiment. We can see that in case of long term experiment of 32 years, the soil organic carbon turnover and sequestration rate in rice-rice, so, these red bars are showing the rice-rice system, sorry, rice-wheat system, and these blue bars are showing the maize-wheat system of a tropical, semi arid region of Punjab and we can see that wheat there are different types of treatment they have used like farmyard, FYM stands for the farmyard manure and then N 120 stands for the application of 120 kg of N.

Then N nitrogen 120 kg N, 30 kg P 2 O 5, then nitrogen 120 kg P 2 O 5, 30 kg K 2 O then 30 kg. So, for all these we can see the higher soil organic carbon sequestration that can be obtained in FYM. Also we can see annual crop residue carbon input in different rain fed crop production system of India. We can see in case of soyabean saflower system we can have highest crop residue carbon input in mega gram per hectare or tonne per hectare.

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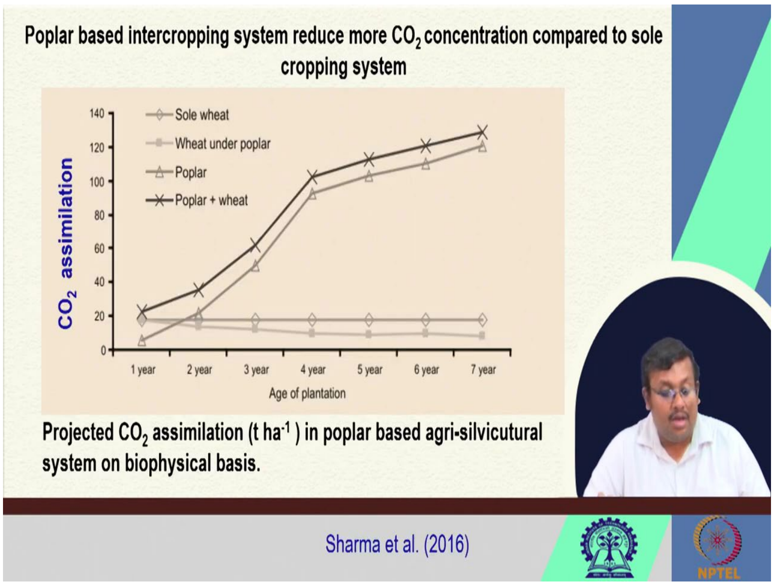


Also if you see the popular based intercropping system, this can reduce more carbon dioxide concentration compared to sole cropping system. So, if we see the sole wheat and wheat under poplar and poplar, so, we can see that carbon dioxide assimilation will be carbon dioxide assimilation in case a poplar plus wheat is showing the higher trend. So, projected carbon dioxide assimilation in poplar based agri-silvicultural system. This basically shows the projected carbon dioxide assimilation poplar based agri-silviculture system on biophysical basis.

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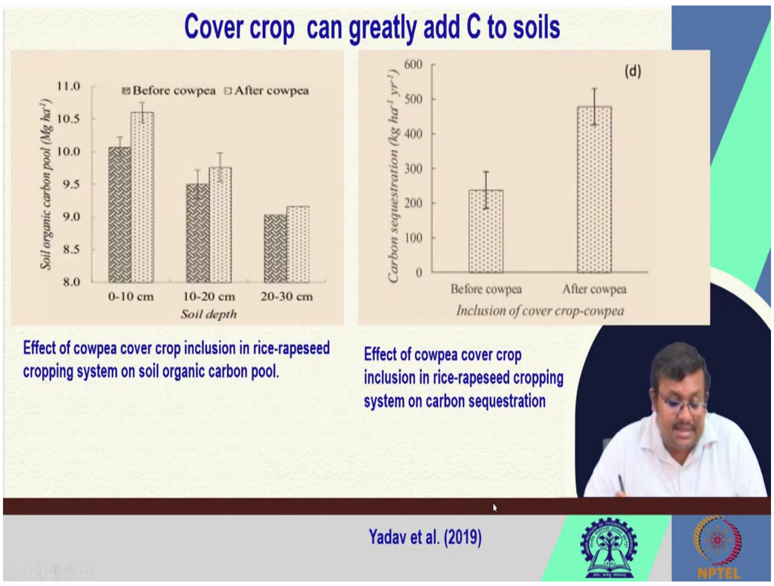


Also we can see the cover crops can also greatly add carbon to soil. So, here you can see with cowpea, this is before cowpea and after cowpea and before cowpea, after cowpea at different depths and you can see soil organic carbon pools, for rapeseed, rice rapeseed cropping system. So, you can see after you incorporate the cowpea cover crop that will increase the soil organic carbon pools.

Also these were rice rapeseed system and you can see that effect of cowpea cover crop inclusion rice rapeseed cropping system on carbon sequestration. So, this is the soil organic carbon pools and this is a carbon sequestration. You can see before cowpea and after cowpea, the carbon sequestration has changed drastically.

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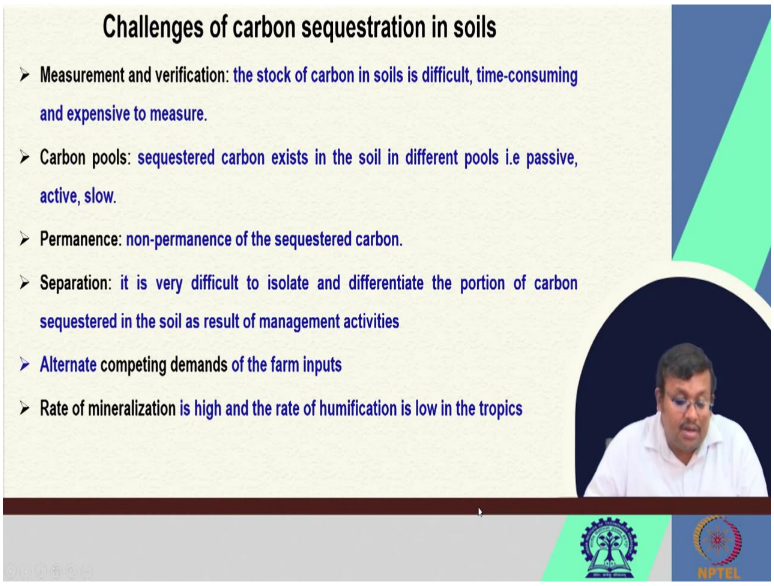


So, what are the challenges of carbon sequestration in soils? First of all, measurement and verification. So, the stock of carbon in soil is difficult, time consuming and expensive to measure. Secondly, sequestered carbon exist in the soil in different pools, which are passive, active or slow in nature.

Then there is non-permanence of the sequester carbon. They are not stayed for a long time. Separation is another issue. So, it is very difficult to isolate and differentiate the portion of carbon sequestered in the soil as a result of management activities. And then there are alternate competing demands of the farm inputs are there.

So, and finally, the rate of mineralization is higher and rate of humidification is low in the tropics. So, the rate of mineralization is higher that means, decomposition rate will be higher and humification rate is low in the tropics. So, that is another important issue. Alternate competing demands of the farm inputs is another important issue, which is diverting these farm inputs to other purposes and thereby rendering the soil devoid of organic carbon. So, these are some of the practical challenges of carbon sequestration in Indian soils.

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What are the benefits of carbon sequestration? Of course, it has shown to improve the soil quality through enhance fertility, soil structure and aggregate stability. It has increased the soil water holding capacity, it increased the capacity to reduce the toxic elements from the soil. It has sown to reduce the soil erosion and also it is known to increase the crop production. So, all these together will address to achieve the global food security. So, these are some of the benefits of carbon sequestration.

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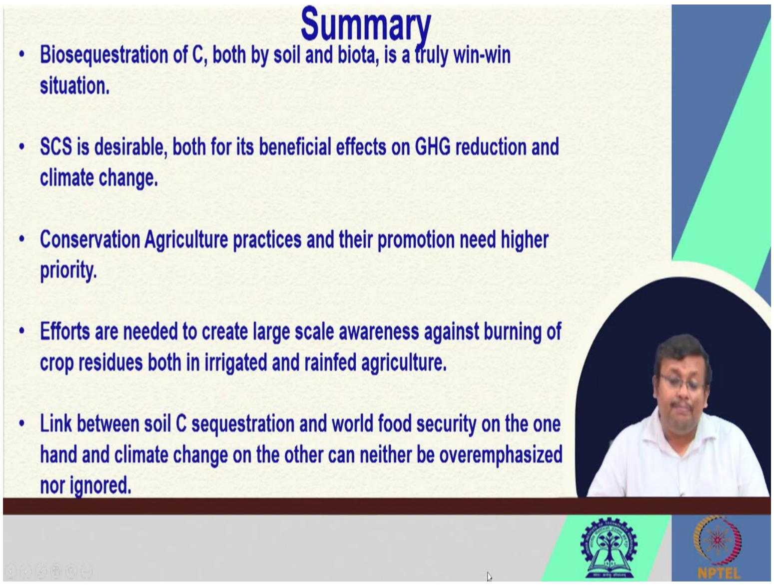

So, summary we can see that biosequestration of carbon both by soil as well as biota is a truly win-win situation. And soil carbon sequestration is desirable both for its beneficial effects on greenhouse gas emission and greenhouse gas reduction and climate change and conservation agriculture practices and their promotion need higher priority.

Efforts are needed to create large scale awareness against burning of crop residues, both in irrigated and in rain fed agriculture and link between soil carbon sequestration in world food security on the one hand and climate change on the other hand, neither be over emphasized or nor ignored. So, these are some of the salient points from this whole discussion on carbon sequestration.

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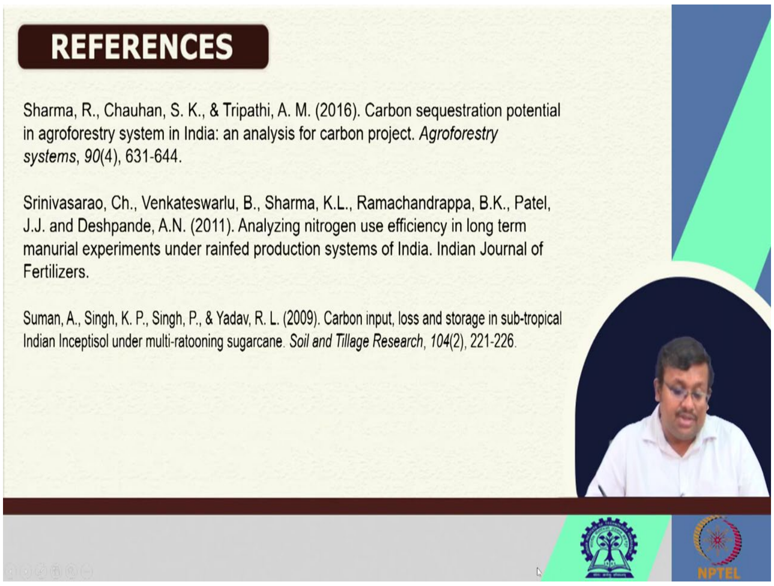

So, guys, these are the references which are used for this lecture. And please go to this lecture to gather more knowledge on carbon sequestration.

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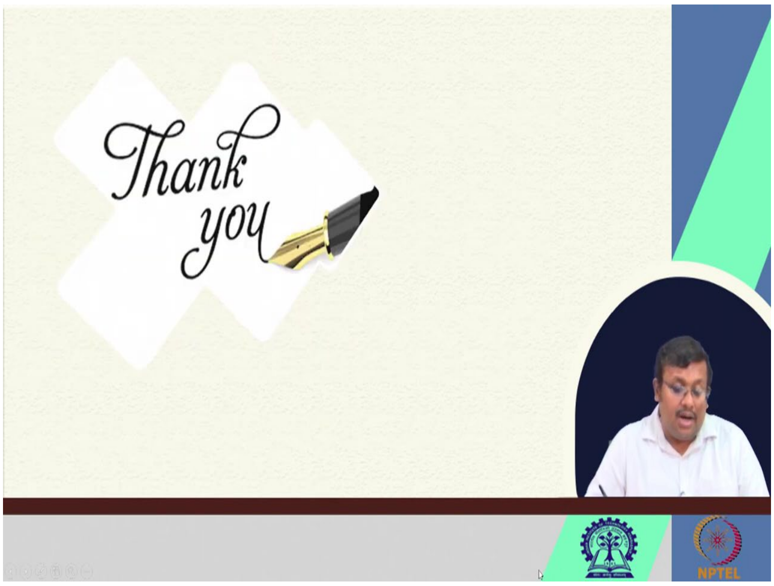


So, thank you. Let us meet in our next lecture to discuss other issues, other environmental issues which are related to nutrient management and agricultural production. Thank you.