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Lecture-12
Chemistry of Soil Organic Matter (Contd.)

Welcome friends to this second lecture of module 3 and we are basically discussing the chemistry of soil organic matter. And in the first lecture of module 3 we have so far discussed what is soil organic matter and what are the composition what is the composition of soil organic matter, what are the different components of soil organic matter, what is humus. And then we have talked about what are the functions of soil organic matter.

And we have talked about different soil farming factors and their impact on soil organic matter formation. And and finally we have discussed about the global carbon cycle and different pools of organic carbon or different pools of carbon and how they can interchange from one pool to another pool and then we have talked about the carbon sequestration.

So friends just to reiterate that soil organic matter is not the you know the soil humus cannot be termed as a whole of soil organic matter. Obviously soil organic matter with although we use the soil organic matter and humus vary you know interchangeably. But these 2 terms are somehow different however a major part of soil organic matter contains soil humus.

However, the other parts are rapidly decaying organic matter, intermediate decaying organic matter and as well as the partial decaying organic matter and different microbial biomass which are present in the soil. You remember the microbe among the microbial biomass, biomass wise fungi as the major you know share followed by bacteria actinomycetes. So in the last lecture, we have stopped while discussing different pools of global carbon cycle and we have started talking about the soil pool.

So as you know that soil organic carbon or SOC pool basically constitutes about the 75% of the total carbon pool on land. And soil inorganic carbon that is SIC is another important pool in subsurface horizons of arid and semiarid soils and will basically contain 695 to 748 pentagrams of carbonate. And this soil inorganic pool is basically mainly comprised of primary and you know secondary carbonates you know and also secondary carbonates are basically aids in carbon sequestration.

Because you know we are basically sequestrating carbon to remain in the field and in the form of carbonates in the subsurface horizons and as a result there is carbon sequestration. Now the pedogenic carbonates you know are basically formed formed when the carbonic acid chemically reacts with calcium and other you know and magnesium in the soil solution.

In the upper portion of the profile and then leach in the lower soil horizon via irrigation water. And the rate of this soil inorganic carbon sequestering by this mechanism maybe 0.25 to 1 mega gram carbon per

hectare per year, so it is huge. So the soil pool serves as a global carbon reservoir.

So, let us move ahead and see what are the different processes which are involved in the soil pool of carbon. So, soil organic pool basically declines as you can see that there is a continuous decline in soil organic carbon pool because of several processes. So, these are the several processes, first of all it is mineralization of soil organic carbon and then soil erosion losses as well as the leaching.

So, these are the 3 major processes through which soil organic carbon pools declines. So basically as you can see here this in this picture if you consider the carbon added to residues and root biomass basically in the plants. So from there and also there is a humidification after there after their death of these plant and ultimately that will go to the soil organic carbon pool.

And from the soil organic pool there is methanogenesis or formation of carbon dioxide. So 2 you know it can produce either methane or it can produce either carbon dioxide. Or the soil organic carbon pool maybe you know maybe decline due to the erosion process as I have mentioned here the soil erosion loss, when there is a soil erosion obviously simultaneously there is also loss of soil organic carbon.

And when there is a soil you know when these organic carbon eroded from the soil surface they either go somewhere and deposit. And from this deposition also there is generation of carbon dioxide and methane depending on the aerobic or anaerobic conditions. And in also these eroded material can redistribute over the landscape and which also can produce either carbon dioxide or methane.

So, as you can see from the carbon which is present in the residues and the root biomass can move into the soil organic carbon pool due to the humification process. and from the humification you know from this soil organic carbon pool it can move you know it can be declined through the erosion the eroded materials can be deposited and further you know reduced or decline because of carbon dioxide or methane emission or they can various distributed over the land surface.

Also the soil organic carbon from the soil organic carbon pool there is a possibility of leaching as I have mentioned here. So, from this leaching you know they can go to the aquatic system or the ground water and then from there also there could be generation of carbon dioxide. So, these are some of the ways through which that you know soil organic carbon pool declines and also the humification process it is nothing but the mineralization process of soil organic carbon.

So as you can see all these 3 processes are mentioned in this process in this in this diagram which shows the process affecting soil carbon dynamics. Now remember that land use change from natural to agricultural system increases aeration and mineralization hence decreases the soil organic carbon. Obviously when we convert a land which was pristine to a cultivated land obviously the soil will be much more expose to the air as

well as you know open sunlight which will further increase the degradation of organic carbon.

As a result there will be continuous decline of organic carbon pool in the soil and so obviously the soil which is no till will produce will contain more organic carbon than that of the soil which has which has been cultivated for a considerable amount of time. So, remember that this loss is more in tropical soil then in temperate soil because of the difference in the temperature.

Obviously when there is an increased temperature the microorganisms which are involved in the degradation of organic carbon are more active and as a result in the temperate region you will see more deposition of organic carbon than that of temperate you know than that of tropical region. In the tropical region soil the organic matter content is comparatively low than that of temperate region soils.

So how to manage this soil pool as you see that for the carbon sequestration it is very important that you should manage this carbon pool otherwise you cannot maintain the judicious amount of carbon in the soil. Otherwise, it will be going to the atmosphere producing the you know in the form of greenhouse gases. So, to manage the SU pool in the soil or in other words to increase the carbon sequestration you know limited cultivation or no tillage helps in reducing the soil organic carbon losses by reducing mineralization and erosion.

So as you can see it is a no tilled soil it is a picture of a no tilled soil in this no tillled soil obviously due to the less exposure of soil to the air as well as sunlight there is less degradation of organic carbon. As well as due to the presence of plant residues they are less you know I mean you know they are they are less eroded. So, as a result these erosion and mineralization both the process are limited in this kind of no tilled condition.

And cover crops, the cover crops like legumes and crop rotation can enhance the soil organic carbon sequestration. And carbon sequestration is can be also improved by restoring the degraded soil which are basically degraded by erosion, desertification, salinity and mining operation. So, these are some of the major process through which the soil get degraded and to restore these degraded soil carbon seques you know you know when we restore this degraded soil by different means the carbon sequestration also gets improved.

So let us see what are the what is the composition of soil organic matter well, soil organic matter is mainly composed of 4 major element. As you can see here carbon, then oxygen, then hydrogen and nitrogen. Now in the carbon, carbon contains 52 to 58% of you know 52 to 58% of organic matter is composed of carbon, different carbonaceous products we will see very soon.

And also oxygen basically accounts for 34 to 39% of the total or the soil organic matter. Hydrogen accounts for 3.3 to 4.8% of soil organic matter, whereas nitrogen accounts for 3.7 to 4.1% of the total soil organic matter. Now remember that the lignins and proteins are the major organic

matters groups which present in in the soil organic matter along with other groups obviously in decreasing quantities.

Such as the other groups maybe hemicellulose as you can see maybe hemicellulose maybe cellulose and ether and alcohol soluble compounds. So, what I what we see that among all the elements carbon is present in the highest concentration which is quite obvious followed by oxygen and then hydrogen and nitrogen. And among the organic groups lignins are proteins are the major organic groups which are present in the soil organic matter followed by cellulose, hemicellulose, ether and alcohol soluble compounds.

Now remember that you know as far as the soil organic matter is concerned we can broadly divide the soil organic matter into humic substances and non humic substances. Basically the non humic substances are the consist of the compounds which are having the known you know structure. However in case of humic substances their structure is somewhat complex we will see that in a way in in the incoming slides ok.

So, let us move and see what are the you know what are the non humic substances, well the non humic substances has several characteristics. First of all the first important characteristic is they have recognizable physical and chemical properties. So, whatever compound we can recognize in the soil organic matter that will basically come under the non humic substances.

And also these non humic substances can be easily attacked by different microbes, remember that humus which is the humic material present in the soil organic matter is resistant to microbial attack which we have already discussed in last class. However, these non humic substances are very, very you know they are susceptible for microbial attacks. Now what are those non humic compounds.

The non humic compounds are carbohydrates, proteins, peptides, amino acids, fats and low molecular weight acids. So, as you can see that all these different compounds which I have mentioned here have their recognizable physical and chemical properties and these compounds can be easily attacked by different microbial microbial population. So, these compounds all these compounds are present in the soil organic matter and they are known as the non humic substances ok.

So, let us talk about the humic substances, so, humic substances is basically a general category of naturally occurring biogenic and heterogeneous substances. There is no specific physical or chemical property as in well defined organic compounds. So, just opposite to what we have seen in case of non humic substances, in case of humic substances their chemical composition is complex and they are not well defined.

And this is basically these humic substances again it is a general category of different natural occurring occurring and biogenic and heterogeneous subjects. Now what are the color, the physical characteristics of these humic fraction they vary and also their color vary from black to you know yellow to black in color. And they have also high molecular weight and basically rerefractory.

So, some they basically subdivided into 3 major fraction this is very important, so this is basically a structure of a humic substance. Now you can see that they can be divided into 3 major you know fraction, one is called humic acid, another is called fulvic acid and the third one is called humin. These are very important please remember these 3 categories humic acid, fulvic acid and humin and they differ from each other based on certain characteristics which we will discuss.

So, before we go and see the properties of different humic substances like humic acid, fulvic acid and humin. Let us first discuss what is what are the different formation theories for humic substances. Now scientists have differed in their opinion on how the humic substances generally form in the soil because they are very complex in nature and they are basically formed due to the you know due to the microbial degradation.

And they are basically resistance. So, they are have been you know a tremendous controversy a tremendous I mean you know differences in the opinion and the pathways through which they thought the scientists thought that the humic substances basically form. So, as you can see that humic substances generally formed by 4 different pathways. So, these are the 4 major accepted pathways through which humic substances can be formed. One is pathway 1, pathway 2, pathway 3 and pathway 4.

So, in this figure in this in this diagram it will be clear that this is basically pathway 1, this is pathway 2, this is pathway 3 and this is pathway 4, now soil organic or humic substances formation. Now this pathway 2 and pathway 3 are also known as the polyphenol theory. However there is some you know minor difference between these 2 pathways. However they are basically known as the polyphenol theories and pathway 4 that is this pathway is also known as the lignin theory.

Now let us consider let us first you know let us discuss all these pathways one by one if you consider pathway 1 given by the scientist Stevenson in 1982. They basically assume this is the pathway 1 and they basically assume that the humic substances are formed from different sugars. And basically although they have they have conceptualize this pathway, they are not this is not usually considered very significant pathway among all these 4 pathways. However, it is the one of the major pathways given by the scientist Stevenson.

So as you can see the you know first the plant residues, the plant residues basically transformed by different microorganisms to sugars and from these sugars the humic substances form this is the first pathway or pathway 1 for formation of humic substances.

So, if we go and see pathway 3, let us first discuss pathway 3 and then we will see what is the difference of this pathway with the pathway 2. Now in the pathway 3 also known as the polyphenol theory. Here we consider that lignin is an important component of humic substance formation. So, this is the pathway 3 and you can see here that lignin undergoes different microbial attack enzymatically and release phenolic, aldehydes and acids.

So, basically plant residues converted to you know they are basically attacked by different microorganisms and then they form these lignin decomposed decomposition products. And these lignin decomposition products ultimately form this quinones and this quinones will be ultimately you know producing these humic substances. So, lignin undergoes microbial attack when the lignin undergoes further microbial attack although lignin is highly stable against the microbial attack.

But sometime it is also attacked by microorganisms and enzymatically you know and release phenolic aldehydes and acids and these are altered to quinone. So whatever phenolic aldehydes and acids they produce due to the decomposition of lignin they basically form and they basically alter to quinones. And the quinones basically polymerizing the presence and absence of amino acids as you can see due to the decomposition of organic compounds or plant residues amino compounds are formed also because they are proteinaceous material.

And when these amino compounds basically degrade these amino acids will basically add into this pathway 3 to form this humic substances. So, again this quinones and polymerize in the these quinones basically polymerize in the presence and absence of amino acids to form humic like molec macromolecules. So, again this pathway 3 is starting with this plant residue basically degraded by the different microorganisms producing amino compounds as well as lignins.

Lignins are further degraded by these microorganisms produced lignin decomposition products. These lignin decomposition products produce quinones and this quinones basically you know reacts with different types of amino acids, amino compounds to produce the humic substances. So, this is how this is known as the you know this is one of the most important pathway of humic acid or humic material formation, this is pathway 3 also known as polyphenol theory.

So, this picture shows in more detail how these different compound basically form. So, here the lignin is an important you know component of humic acid you know humic substances formation. As you can see we are starting with a lignin and then it is attacked by the microorganisms when the lignin is attacked by microorganism they will produce phenolic aldehydes and acids.

So, this phenolic aldehydes and acids will have 2 different fates either they will be further utilized by microorganisms and you know or they will oxidize to carbon dioxide or this phenolic aldehydes and acids will produce the polyphenols. These polyphenol polyphenols with the help of phenoloxidase enzymes they will produce the quinones. And these Quinones will either go to produce in the presence of amino acids amino compound they will produce the fulvic acids, amino acids and fulvic acid can be also converted into amino acids. So, this is the pathway 3 which we have discussed so far ok.

So, now what is the difference between pathway 3 and pathway 2, now pathway 2 is also similar to pathway 3. However, here the polyphenols are synthesized from non lignin sources like cellulose ok. So, we have we have seen that according to the pathway 3 the polyphenols are synthesized

from the degradation of lignin compounds. However, according to pathway 2 the polyphenols are synthesized from the non lignin like sources like cellulose.

So, it will be more clear when we see the next slide, so, poly polyphenol pathway 2 and 3 are predominate basically in forest soils. So, if we if we just see in details about the pathway 2 and so, this is basically pathway 3 which we have discussed so far. Now major difference between pathway through pathway 3 and pathway 2 is you can see here these polyphenols.

These polyphenols according to the pathway 3 they are basically formed from the degradation of microbial degradation of lignin. However, these polyphenols according to pathway 2 are formed due to the degradation of cellulose and other non humic substances.

When the cellulose and other non humic substances are attacked by different microorganisms they will converted to polyphenols. And these polyphenols will further go down the same way. we have seen in case of pathway 3 and then they will produce the different humic compounds like fulvic acids, humic acids. So, this is how the pathway 2 and pathway 3 are different.

However, one thing is clear that irrespective of pathway 2 and pathway 3 polyphenols are one of the major precursor of formation of quinones as well as the different humic compounds. So, as a result of that these 2 pathways are known as polyphenol theory. So, this is a phenol and when this phenol polymerize they will produce the polyphenols ok.

So, let us discuss the last pathway that is pathway 4, now the pathway four also follows the lignin theory and you know they basically assume that humic substances are nothing but the modified lignins that remain after microbial attack. So, as we can see here these also this pathway 4 also starts from this plant residues. And this plant residue basically produce the modified lignins and these modified lignins ultimately produce different types of humic substances.

So, this is the difference between the pathway 4 and other pathways and these lignins basically undergo further modification results in further humic acid and then fulvic acid. And then basically there you know this type of pathway is more prevalent in poorly drained soil. However, the pathway 3 and pathway 2 are more predominant in the forest soils.

So, so we have we have to see that what are the environmental pathway of humic substances, well water is a major medium that affects the humic substances transport in the in the environment. And basically they can produce either oxic and anoxic environment which affects ultimately the humic substances. And also humic substances stay for hundreds of years in the soils and aquifers.

So, if you see this if you see this diagram it looks very clear than that from the terrestrial plants the you know these humic substance can move to water. They can move to streams and rivers from the streams and rivers we can see these lotic sediments. And from these streams and rivers these

humic substances can move to different estuaries where further addition can be seen from algae and sea grasses.

From the estuaries they can further move to oceans and where further addition from the algae can be seen ultimately they can be deposited as the marine sediments. And from this you know soil to water and also from streams you know can be can be seen interconnected with this peat which is basically getting organic humic substances from mosses and other plants.

And these peat can move either to streams or in the groundwater and this from the streams and leave streams and rivers they can further move to the lakes from the lake we you know they can the hemi substance can further move to groundwater. And from these lakes we can see the lacustrine sediments they can be deposited in the lacustrine sediments. And further in the lakes we got the deposition by the algae and macropytes.

So, you can see that this shows the dynamics of humic substances or their movement of the humic substance from one type of a water body to another type of water body. And they are getting either deposited there or they are getting further contribution from different other you know algae and sea grasses or macropytes. And ultimately they are getting deposited there special in case of lake the we are getting lacustrine sediments.

In case of ocean we are getting marine sediments, in case of streams and rivers are getting lotic sediments. So, this is how the soil you know these humic substances can move in the environment different you know in the environment through water and that is why water is a major medium that affects the humic substance transport. So, friends in this lecture we have discussed about in details about different strategies for maintaining the soil organic carbon pool.

Then we have discussed about the major components of soil organic matter the humic substances and non humic substances. Then we have discuss the 4 major pathways of human humous formation or humous formation theories I would say. And then we have discussed about the environmental pathways of humic substances.

I hope that you have learned something new and let us meet in our next lecture where we will discuss the details and of the the differences between the different humic substances. And how we can separate them from each other, thank you very much, let us meet in our next lecture.