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Lecture-11
Chemistry of Soil Organic Matter

Welcome friends to this third week of lectures of this NPTEL course of environmental soil chemistry and in this week we will be talking about chemistry of soil organic matter. In the previous week we have talked about the chemistry of the structures of important soil inorganic components and in this week we will be talking about soil organic matter.

Now you know that soil organic matter is one of the most important fraction in the soil which governs different soil chemical, physical and biological properties. So, in this module we will be talking about this will be basically covering this concepts will first discussing about the soil organic matter and humus their definitions. Then we will be talking about effects of soil forming factors on soil organic matter.

Then we will be talking about carbon cycling and carbon sequestration, then will be talking about composition and fractionation of soil organic matter. And then we will be talking about structure and properties of soil organic matter and finally we will be talking about interaction of soil organic matter with clay and metal complexes.

So let us start with a definition of soil organic matter, soil organic matter definition has been given by many scientists. So, I am just giving here one example of d one definition given by the scientist Schnitzer and 2 scientist Schnitzer and Khan in the year 1978. So, this is that soil organic matter is a mixture of plant and animal residues in different stages of the composition.

Substances synthesized microbiologically and or chemically from the breakdown products and the bodies of life and dead microorganisms and their decomposing remains. So, one thing is very important to you know to understand that soil organic matter is a very heterogeneous mixture. It is not only consist of plant and animal residues in different stages of decomposition, it also consist of synthesize microbiologically and chemically from breakdown products.

And bodies of live and dead animals and also their decomposing remains so, it is basically very heterogeneous mixture. And humus, humus basically includes humic substances plus resynthesis products of microorganism which is stable and part of the soil. So, humus is basically a component of soil organic matter, soil organic matter composed of different fractions humus is one of the major fractions of soil organic matter.

So if we see the definitions of soil organic matter and other fractions we you know this table will be helpful. So, by defining the organic residues, organic residues are basically undecayed plant and animal tissues and their partial decomposition products. Soil biomass, what is soil biomass?, soil biomass is basically organic matter present as live microbial tissues. So, whatever microorganisms and macroorganisms which are present in the soil are known as the soil biomass.

Humus is a basically total of the organic compound in a soil exclusive of undecayed plant and animal tissues their partial decomposition products and the soil biomass. So, if we remove the undecayed plant and animal tissues partially decomposed products as well as living organisms or soil biomass from the organic matter whatever will be remaining means call the humus. Humic substances are basically a series of a relatively high molecular weight brown to black color substance formed by secondary synthesis reactions.

The term is use to as a genetic name to describe the color materials or it is fractions obtain on the basis of solubility characteristics. And these materials are distinctive to the soil or sediment environment and environment in that they are dissimilar to the biopolymers or microorganisms and their higher plants including the lignin. Non humic substances, so one is humic substance another is non humic substance.

Non humic substance are compound belonging to known classes of biochemistry such as aminoacids, carbohydrates, fats, waxes, resins and organic acids. Humus probably you know probably contents most if not all the of the biochemical compounds synthesized by living organism. So basically non humic substances by non humic substance definition we know the classes of compounds with known chemical structure that is aminoacids, carbohydrates, fats, waxes, resins and organic acids.

Humin, humin will discuss in later in details. However, humin is the alkali soluble fraction of soil organic matter or humus. Humic acid is the dark colored organic material that can be extracted from soil by various reagents and is insoluble in dilute acids. And fulvic acid the colored material that remains in the solution after removal of the humic acid by acidification. And hymatomelanic acid or hymatomelanic acid is basically alcohol soluble portion of humic acid. So these are different definitions of soil organic matter and their fractions.

So if we just go ahead and see the composition of soil in volumetric basis we will see that the soil basically composed of 45% of inorganic materials only 5% of organic matter and the rest 50% is basically pore space and these pore space are basically occupied by air and water. And in case of well balanced you know well balanced soil composition. This pore space will be occupied by 25% air and 25% water.

However in some extreme cases the soil will be basically 2 phase system. For example in case of rice soil we will see all the pore spaces will be filled with water because there is a standing water and in case of soils of the arid region will see there is no water all the pore spaces filled by air, so essentially all the pore space will be filled by either air or water. Now one thing is very important that you see only there is 5% of organic matter.

And this is the maximum limit. So, soil organic matter varies in soil type when it is expressed in percentage. Generally in case of mineral soils I am talking about the mineral soils this concentration of organic matter varies from 0.5 to 5% and organic soils like histosols have sometime may have 100% of soil organic matter. Because they are very high in organic matter.

And soil organic matter has very high reactivity even in low concentrations because of their huge amount of charge development, huge amount of cation exchange capacity in the soil organic matter will be discussing that in details. So, if you see the soil organic matter composition itself, the soil organic matter can be divided into several parts. So, it is only 5% of the total soil volume however if you see the total if you consider the volume of the soil organic matter as 100% we will see there will be 7 to 21% radially decomposable radially decomposable material in the soil organic matter. And then there will be stable that is humus 70 to 90% of humus ok and rest of them will be the soil organisms.

And in the soil organisms, so basically soil organic matter has 1 to 6% of the total soil mass and or 1 to 5% of the total soil mass volume. So, soil microbial biomass varies from 3 to 9% of the soil organic matter mass. So, basically if we consider the total soil microbial biomass also you will see the fauna soil fauna basically consist of 10% of of the mass and yeast, algae, protozoa, nematodes consist of 10%, fungi consist of 50% of the mass and bacteria actinomycetes consist of 30% of the mass.

So, this is how this is the composition of the soil organic matter, so, again soil organic matter composed of humus, readily decomposable part of organic, readily decomposable organic residues as well as soil microbial biomass. In the soil microbial biomass the majority is the fungi followed by bacteria and actinomycetes is basically weight basis and also fauna 10% and yeast, algae, protozoa, nematodes at 10%.

Remember this is only mass basis if we see the numbers number wise you know uhhh bacteria is the highest followed by actinomyces and then fungi. However, biomass wise the biomass of fungi is highest 50%. So, what are the functions of soil organic matter, well soil organic matter functions are you know you know they have multiple functions in the soil.

All most of them are very beneficial for the soil. So, for a first time you know first example is soil organic matter improves soil structure water holding capacity, aeration, aggregation of the soil, it improves the soil structure by it has got the bonding power. So by binding different clay particles and different sand particles, different silt particles it can improve the soil structure.

And as a result of that because of improvement of aggregation they have water high you know they they have better aeration and aggregation of the soil. Also due to the millions and millions of micro pores which are present in the soil organic matter they have high water holding capacity also.

They also serve as a source of various macro and micro nutrient because of their huge negative charge develop. And these negative charge basically develops due to the pH dependent charge or variable dependent charge or variable dependent charge and as they result of it if you have they have huge amount of negative charge on the surface which can attract all the macro and micro nutrients.

They have high or it is a large quantities of the carbon which serves as the energy source, they have high you know specific surface area 800 to 900 square meter per gram. And high cation exchange capacity 150 to 300 centimole per kg of soil. So, therefore it sorbs plant nutrients heavy metals cations and organic materials not only that it can also adsorb pesticides also.

So you can see it has got variable functions and these functions are always better for you know most of them are you know most of them are very good for maintaining the soil physical, chemical and biological activities. So, if you see the distribution of soil organic matter in the soil we will see that at the surface soil the concentration or the content of soil organic matter is always higher.

And as you go down in the sub soil it is generally I am talking about the mineral soil. So, as you go down in the subsoil obviously there is a continuous decrease of organic matter content. And as you can see in the picture in this diagram obviously these in huge amount of negative charge develop due to this different carboxylic groups.

And phenolic groups will be discussing in details. And they will basically deprotonate to develop these negative charge and as a result they will attract this positive charge cations which access a major source of cations for the plants plant or major source of cationic nutrients for the plants.

So, these are some functions of the soil organic matter. Now what are the general properties of soil organic matter. These table shows that general properties of the soil organic matter for example color and we have also measured we have also seen that remarks as well as their effect in the soil. So, if we see the color of the organic matter the typical dark color of many soil is caused by the organic matter.

So, it basically may facilitate warming because darkness also changes the albido of the soil. Water retention, water retention organic matter can holds up to 20 times of more water than that of clay. So, also as a result of that it can helps preventing drying and shrinking and may significantly improve the moisture retaining properties of the sandy soil you know in case of sandy soil the moisture retaining properties is very less.

So, as a result plant cannot grow well, so if we add organic matter into that sandy soil there will be increase in organic you know water holding capacity as a result plant will grow in those soils. Combination with clay minerals it basically as a result of that combination with clay mineral they can cement soil particles into structural units called aggregates which will basically improve the soil structure.

And the benefit is the it will permits the exchange of gases stabilize the structure and increase the permeability for better movement of air and water for maintaining the organisms which are present in those soil. Chelation also forms stable complexes with copper, manganese, zinc and other polyvalent cations. And it may enhance the availability of the micronutrients to the plant because they become more available as a result of the chelation.

Solubility in water insoluble in organic matter in you know insolubility the organic matter is basically insoluble because of their association with the clay and also salts of divalent and trivalent cations you know with organic matter are insoluble, what is the benefit of that. Because of this insolubility there is very little organic matter loss by leaching, so that is benefit if it is highly soluble then it will be easily moved away by leaching solution.

It has buffering capacity organic matter exhibit buffering in slightly acid, neutral and alkaline ranges. So, it is also by buffering capacity it helps to maintain a uniform reaction in the soil, cation exchange capacity it is have very high cation exchange capacity also you know 20 to 70% of the CEC of many soils is due to the organic matter it is quite you know several fold higher than that of clay minerals.

So, that is why the nutrient supplying capacity or fertility of the soil is dependant on the organic matter content. Mineralization like decomposition of organic matter is carbon dioxide, ammonium, nitrate, phospur and sulfate which are you know basically sources of nutrient elements for the plant growth. And also combination organic chemicals like effects affects, biodiverse, bioactivity, persistence and biodegradability of the pesticides which further that you know modifies the application rate of pesticides and effective control.

So these are some of the important properties and their practical implication as per as the soil physical, chemical and biological properties are concern. So, if we go ahead and see the effects of soil forming factors on soil organic matter will see that the factors as per as the genie's formula the all the factors like climate, vegetation, parent material, time and topography all they affect the soil organic matter also. Just like they effect the soil formation, they also effect the soil organic matter.

So soil organic matter accumulates rapidly initially and then decline slowly and then reaches a equilibrium. And equilibrium is attained due to microbial attack of resistant organic acids. So, basically when they will produce the equilibrium that means at that stage humus is produced. Because humus is a microbial synthesis product it is more or less resistant to further microbial degradation. And they basically occurs due to the microbial attack resistant organic acids, stability of you know stability.

And the stability of the humus due to it is interaction with the polyvalent clays and cations and low amount of essential nutrients. So, you can see that at the final stages of soil organic matter degradation you will see the formation of humus. So, let us see the factors one by one, let us see the importance of climate. If you see the climate inform importance of in the importance of climate for soil organic matter formation climate effect the type of plants species amount of plant material produced and also the degree of microbial activity.

Also in the semiarid, grassland associated soil usually have higher soil organic matter in case of desert, semi desert and tropical soils have low soil organic matter because of high temperature. And however in case of tropical soil sometime they have high humus because due to complexation of humic substances with inorganic constituents like quartz and amorphous materials presence in tropical soils. So these are the reason that sometime tropical cells have high amount of humus.

So, as per as the vegetation is concern grasslands usually have high soil organic matter than forest soils. As you can see here grassland, this is the grassland which is showing high soil organic matter then that of forest soils. And this is due to greater amount of the plants inhibition of nitrification that preserves nitrogen nitrogen and carbon. And higher humus synthesis and high base status of grasslands which promotes ammonium fixation by lignin.

So, these are the reason that when there is a grassland there is high accumulation of soil organic matter. So, vegetation is a important factor that governs the concentration of soil organic matter in a soil. So, what is the importance of parent material?. So the imp parent material affects the resulting soils texture and hence the soil organic matter content.

So clay soils have high soil organic matter than sandy soils, so you can see that there is a correlation between the soil texture and sandy soils. And clays like montmorillonite adsorbs organic matter organic molecules very well because as you know that the structure of montmorillonite they have high amount you know specific surface area which is amenable to adsorption of cations as well as different organic molecules.

As a result of that they can adsorb different you know high high amount of organic molecules. Also they can protect the nitrogenous materials from microbial attack. So, this is the importance of parent material for the development of soil organic matter or concentration of soil organic matter. If we talk about the topography, topography affects the climate, runoff, evaporation and transpiration and hence the soil organic matter content.

And north facing so why it is important because you see that north facing slopes are wetter and cooler than that of south facing slopes. So, as a result the you know as a result that north facing slopes have more soil organic matter because of low temperature. If there is a low temperature obviously there will be less degradation of organic matter. So, in general moist and poorly drained soils have high soil organic matter due to reduce microbial activity than well drained soils. So, you can see that the topography also impacts the concentration of soil organic matter in the soil.

So, we have seen the definitions of different soil definitions of soil organic matter and their different fractions. And we have seen that how different you know soil forming factors affect soil organic matter content. Now to know the dynamics of soil organic matter it is very important to learn about the global carbon cycle. Now why it is important to learn about the global carbon cycle.

So, you know that atmospheric carbon has approximately 280 ppm of carbon dioxide in the preindustrial era which has increase to 370 ppm by 2000. So, there is going to be a drastic increase in carbon dioxide which is an important greenhouse gas. To stabilize the future atmospheric you know carbon concentration at 550 ppm threshold that is 2 times of the preindustrial level will require an annual reduction in worldwide carbon dioxide emission from the projected level of 21 to 7 billion tons, that is measured as carbon by the year 2100 at 2100.

So, one thing is clear that due to the industrialization there is been a huge improve you know increase in carbon dioxide concentration which is an important greenhouse gas. And to restrict the atmospheric carbon dioxide to 550 ppm which is 2 times higher than that of preindustrial level we have to do a herculean job of reusing the emission of you know reducing the emission by 21 to 7 billion tons by the year 2100 and it will be annual reduction.

So, over the past 150 years the amount of carbon in the atmosphere from greenhouse gases such as carbon dioxide, methane and nitrous oxide has increase 30%. So, the increase level of gases particularly carbon dioxide has strongly linked to the global warming, when there is an increase of these gases like carbon dioxide, methane, nitrous oxide there will be high global warming.

So, as you can see here starting from 1959 to 2019 the global carbon dioxide emission continues to rise, so there is been no decline in global carbon dioxide emission. And as a result they are producing more and more greenhouse gas effect. So, the increase level of greenhouse gas level are likely due to the high level of fossil fuel because in the due to industrialization fossil fuel burning is there, oil like oil coal combustion and then deforestation wild fires and cultivation of land as a result of that carbon dioxide concentration is ever increasing.

So, what is carbon sequestration, so, the to minimize the carbon dioxide level in the atmosphere we have to go to the carbon sequestration, what is carbon sequestration. So, you know that atmospheric carbon is steadily increasing due to global warming phenomena. And so the carbon sequestration is an you know carbon sequestration is basically is the long term storage of carbon in ocean, soil and vegetations and geologic formations.

And this carbon sequestration helps in reducing the atmospheric carbon level. So, this is our ultimate goal we have to reduce the atmospheric carbon dioxide concentration. To reduce the atmospheric carbon dioxide concentration we have to ensure the long term storage of carbon in ocean, soils and vegetations and geologic formations, so, this is known as the carbon sequestration.

So, if you see the global carbon cycle, the global carbon cycle is basically composed of both inputs which are known as the pools and outputs which are known as the fluxes of carbon into the environment. So, there are 5 major pools of carbon or inputs, what is ocean which is basically accounting from 38000 pentagram, pentagram is basically 10 to the power 15 grams, geologic which accounts for 5000 pentagrams, soil organic carbon which basically accounts from 1500 to 2400 pentagrams, atmosphere which is 750 pentagram.

And biotic pool which is accounting for 560 pentagrams and due to global warming atmospheric pool is increasing at the expenses of all other pools. And obviously all you know as land use changes they also impact the carbon cycle as land use changes. For example from forest to cultivation cultivate land obviously there changes in carbon you know changes in the forest to this cultivation cultivate land will also change the you know atmospheric pool.

So, let us see as I have discuss in the previous slide that atmospheric pool carbon dioxide is getting increase at the expenses of carbon from 3 other pools. Like geological pool from you know from the geological pool we are seeing that there is a continuous fossil fuel emissions, increase in fossil fuel emissions so that is contributing into the atmospheric pool from the biotic pool deforestation and wild fire.

So, obviously when there is a change in land fire sorry change in land use there will be deforestation. For example forest to arable land there will be deforestation, as a result of this deforestation obviously the there will be increase in carbon dioxide concentration in the atmospheric pool and also due to atmos you know wild fire also that will also produce the huge amount of carbon dioxide.

Soil pool basically due to cultivation and anthropogenic disturbances the carbon which is present in the soil will be converted to carbon dioxide which will ultimately come to the atmospheric pool. So, you see that atmospheric pool is the final you know sink where all the carbon dioxide from different pools are basically going.

So, if we see that this is a global carbon cycle the things will be getting more clear. So, you can see here there will be 6 pentagrams of carbon you know are going from different industrial sources to the atmosphere from plants are also taking 120 pentagrams of carbon from the atmosphere for the photosynthetic activities and also releasing 45 pentagrams. And then from the soil cultivation you know 75 pentagrams is going to the atmosphere.

And then net distraction of vegetation 0.9 pentagrams and from there also there will be movement to the rivers of 0.4 pentagrams of dissolve oxygen organic carbon and 0.4 pentagrams of dissolve inorganic carbon. In the ocean there has been 38000 you know pentagrams which is reserve in the ocean carbon. And from the ocean the flux is 90 pentagrams whereas in you know there is a you know inflow or there is an input in the ocean that 92 pentagrams.

So, you can see that in the atmospheric pool it is 750 pentagram there is a continuous increase of 3.2 pentagram in per year basis. So, this is the global carbon cycle and it shows that how this carbon is moving from one source to another source and as a result there is been a continuous increase in the atmospheric pool and this is is very alarming situation.

So, so soil pool is basically soil organic carbon or soil organic pool basically constitutes about the 75% of the total organic pool of the land. And soil inorganic carbon or SIC is another important pool in the subsurface horizon of aerid and semiarid soils. Because they have produce huge amount of carbonates around 695 to 748 pentagrams of carbonates are present in the subsurface horizons of the semiarid and arid land.

So, soil organic pool is mainly compressed of primary and secondary carbonates and secondary carbonates as you know aids in the carbon sequestration. Because basically they are not moving out as carbon dioxide, so the pedogenic carbonates are formed when carbonic acid chemically reacts with the calcium and magnesium in the solution in the upper portion of the profile and they leached in the lower soil horizon via irrigation.

And the rate of soil inorganic carbon sequestration by this mechanism maybe from 0.25 to 1 megagram that is 10 to the power 6 carbon that is megagram carbon per hectare per year. So, huge amount of you know carbon is getting sequestrate by this mechanism of forming the carbonates. So, the soil pool reserves as you know as global soil pool is you know is one of the major deserve of global carbon of total reserves.

So, basically soil that is why soil pool accounts for a major portion of total soil global carbon reservoir. So guys we have seen the basics of soil organic matter in their definitions in this lecture. We have discuss about the functions of soil organic matter and then we have seen the different pools of soil organic you know different pools of carbon in the environment.

We have seen the ocean pool, we have seen the soil pool, we have seen the atmospheric pool, we have seen the other pools and how these movement of carbon from one pool to another pool affects the global carbon cycle we have seen. Let us wrap up our lecture here and then next lecture will be seeing a you know more details about the soil organic matter and their structures, thank you.