ENVIRONMENTAL GEOSCIENCES

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Lecture-49

Chemical Properties of Soil

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We are discussing the module nine. Module nine covers process of soil formation, impact of soil erosion, physical and chemical properties of soils. We have already covered lecture one to four. Today we will discuss the lecture five that is chemical properties of soil.

In this lecture the important concepts will be covered like introduction to chemical properties of soil, types of chemical properties of soil, soil pH, soil electrical conductivity, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and soil alkalinity and salinity. So now we will start from the introduction to chemical properties of soil. Chemical properties actually refer to the characteristics of a substance that determine how it interacts with other substances at the molecular or atomic level, which leads to the chemical changes or reactions. These properties describe how a material reacts with acids, bases, water, oxygen and other chemicals. The chemical properties of soil refer to the composition and interactions of the chemical elements and compounds within the soil, which influence its fertility, nutrient ability, pH balance and overall suitability for the plant growth.

These properties determine how soil retains, releases and cycles nutrients essential for plants and microorganisms. The chemical properties of soil play a major role in soil fertility, plant growth and environmental sustainability. Maintaining the right pH, organic matter, nutrients, and salinity levels is essential for healthy crops and sustainable agriculture. Now, the types of chemical properties of soil. Chemical properties of soils are generally mentioned by soil pH, soil electrical conductivity, nitrogen content, phosphorus content, potassium content, calcium content, magnesium content, and sulfur content.

First we will discuss the soil pH. It is a measure of soil acidity or alkalinity. It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability and soil microorganisms activity which influences key soil processes. Soil pH can be managed by measures such as applying the proper amount of nitrogen fertilizer, liming and cropping practices that improve the soil organic matter and ultimately the overall soil health.

Soil pH is determined by the concentration of hydrogen ions. It is a measure of the soil solutions acidity and alkalinity on a scale of from zero to fourteen. Acidic solutions have pH value less than seven while basic or client solutions have pH value greater than seven. pH is measured on negative logarithmic scale of the hydrogen ion concentration. You can see the scale also. Below seven is the acidic, above seven is the alkali and seven is the neutral.

Now let us solve an example related to the pH. A mining area has a water body contaminated with acidic runoff. Hydrogen ion concentration in the water sample is measured as 3.2×10^{-4} molar. Calculate the pH of the water sample.

$$pH = -\log[H^+] = -\log(3.2\times10^{-4}) = 3.5$$

Hence the water sample is acidic in nature. Now inherent factors affecting soil pH. Inherent factors affecting soil pH such as climate, mineral content and soil texture cannot be changed. Natural soil pH reflects the combined effects of soil forming factors, parent material, time, relief or topography, climate and organisms. The pH of a newly formed soils is determined by minerals in the soil's parent material. Temperature and rainfall control leaching intensity and soil mineral weathering.

In warm, humid environments, soil pH decreases over time in a process called soil acidification due to leaching from high amounts of rainfall. In dry climate, however, soil weathering and leaching are less intense and pH can be neutral or alkaline. Soils with high clay and organic matter content are able to resist a drop or rise in pH than sandy soils. Although clay content cannot be modified, organic matter content can be changed by management. Sandy soils commonly have low organic matter content, resulting in a low buffering capacity, high rates of water percolation and infiltration, making them more vulnerable to acidification.

Second important component is the soil electrical conductivity. Soil electrical conductivity measures the ability of soil water to carry electrical current. Electrical conductivity is an electrolytic process that takes place principally through water-filled pores. Cations like calcium, magnesium, potassium, sodium and ammonium and anions like sulphate, chloride, nitrate, bicarbonate from salts dissolved in soil water carry electrical charges and conduct the electrical current. The concentration of ions actually determines the electrical conductivity of soils.

In agriculture, EC that is electrical conductivity has been used principally as a measure of soil salinity. However, in non-saline soils, electrical conductivity can be an estimate of the other soil properties such as soil moisture and soil depth. Electrical conductivity is expressed in desi-Siemens per meter. Electrical conductivity is affected by the sample's temperature and by the mobility, valences, and relative concentrations of each ion in the solution. Ion pairs that are less charged contribute proportionately less to electrical conduction than when fully dissociated.

Electrical conductivity has been customarily reported in micromoles per centimeter or millimoles per centimeter. In the international system of units, that is SI, the reciprocal of home is the Siemens. This system reports electrical conductivity as Siemens per centimeter or as desi-Siemens per centimeter. One desi-Siemens per meter is equivalent to one millimho per centimeter. The electrical conductivity increases at a rate of approximately one point nine percent per degree centigrade increase in temperature.

Therefore, electrical conductivity needs to be expressed at a reference temperature for purposes of comparison and accurate salinity expression; twenty five degree centigrade is most commonly used in this regard. Soil electrical conductivity measures the ability of a soil water to carry an electrical current which is directly related to the number of dissolved salts and ions that is nutrients in the soil. Third important component is the nitrogen. Nitrogen is the most abundant element in the atmosphere and it generally is the most limiting nutrient for the crops. Nitrogen cycles in soil through various processes and in various forms.

Some of the processes convert nitrogen into forms that can be used by plants and some of the processes such as leaching and volatilization can lead to nitrogen losses. Nitrogen is added to soil naturally through nitrogen fixation by soil bacteria and legumes and through rainfall. Additional nitrogen typically is applied to the soil by use of fertilizer, manure and other organic material. The nitrate-nitrogen level is an excellent indicator of soil organic matter mineralization and excessive or inadequate application of nitrogen fertilizer for optimum crop production. Excessive applications of nitrogen fertilizer can result in leaching of nitrates below the root zone and into the groundwater at a shallower depth or into drainage tiles.

A dynamic equilibrium exists among the various forms and processes of nitrogen in the soil. Nitrogen addition and losses and nitrogen transformations within the soil are important for agriculture as well as environment since the gaseous losses of nitrogen increase the atmospheric pollution. Nitrogen plays an important role in increasing the agriculture production and being a constituent of protein, it increases the food value. A majority of soils in the world are mineral soils and organic soils occupy only a small area. Nitrogen deficiency in mineral soils and crops is widespread and nitrogen is the most extensively limiting plant nutrient in crop production.

About fifty percent of human population relies on fertilizer nitrogen for food production and the world uses around one thirty million tons of fertilizer nitrogen. Here you can see the nitrogen cycle diagram in which we are seeing that in one way nitrate is leaching and at the top you see denitrification, ultimately it is going to the atmospheric nitrogen. Then through the plants also you can see the ammonium is exchangeable and because of the immobilization again the organic nitrogen is there and it mineralizes and again forms the ammonium. So in this way somewhere plant is just uptaking and in somewhere we are seeing it is going to the atmosphere as atmospheric nitrogen. So a diverse pool of nitrogen compounds such as organic compounds like urea, amines, proteins, amides and mineral forms of nitrogen in soil as well as gases that are chemically active in the troposphere determine the nitrogen availability to the crops and pollution and greenhouse effect.

The total nitrogen content of soil varies between 0.02 percent to 0.44 percent. Now the forms of soil nitrogen. As discussed, nitrogen in soil exists in two major forms. In the first form is the organic nitrogen and second form is the inorganic nitrogen. A bulk of total nitrogen is present in the organic form and only about 2 percent is present in the inorganic form except where large quantities of inorganic nitrogen fertilizers have been added.

Up to 8 percent of total nitrogen of the surface soils and up to 40 percent in the subsoil may be present in the clay fixed form. The organic nitrogen, particularly in the hydrolyzable form, is slowly mineralized and is transformed to mineral nitrogen through aminization, ammonification and nitrification processes and becomes available to the crops. In contrast, non-hydrolyzable nitrogen is resistant to mineralization. The stability of some fractions of the organic nitrogen is due to the formation of complex organic molecules which resist the mineralization. Nitrogen present in the organic manures, bio-fertilizers, green manures, crop residues and several organic wastes besides the nitrogen fixed with the intervention of bio-fertilizers is mostly in the form of organic nitrogen.

Proteins, polypeptides and amino acids are the most common organic constituents of plant and animal materials. In organic nitrogen, the inorganic forms are very important from crop nutrition point of view because plant roots take up nitrogen from the soil mostly as nitrate and nitrate nitrogen and to some extent as ammonium nitrogen. The nitrous form is unstable and is usually present in soil in lesser content. Heavy application of nitrogen fertilizers, anaerobic conditions of the soil, extreme pH values, salinity and low temperature favor its accumulation in soil. Next component is the phosphorus in soil.

Phosphorus, an essential nutrient for all living organisms, is a vital component of the substances that are building blocks of genes and chromosomes. In plant, it plays a role in all biochemical processes that involve energy transfer. It is a constituent of adenosine triphosphate that is ATP which is often termed as energy currency of the plant cell. Uridine triphosphate UTP, cytidine triphosphate CTP and guanosine triphosphate GTP are analogous compounds to ATP which are required for the synthesis of sucrose, synthesis of phospholipids, and formation of cellulose, respectively. An adequate supply of phosphorus encourages root growth and enhances the maturity.

In seeds and fruits, phosphorus is stored as phytin, whereas in vegetable tissues, it is found as inorganic phosphate in the vacuoles. The total phosphorus content in agriculture crops generally ranges from 0.1 percent to 0.5 percent. Deficiency of phosphorus leads to severe growth retardation, lowering of shoot-root ratio, and poor seed-fruit setting. Visual deficiency symptoms appear as unusual dark green pigmentation on older leaves. The total phosphorus content is generally highest in soils developed on granite gneiss, followed by shale with basic intrusion, limestone with intrusions of micaceous schist and quartzite and major fraction of total phosphorus is present in clay. The total phosphorus is rather poorly correlated with available phosphorus in soils and therefore rarely used as an index of soil fertility. In the diagram also you can see the dark green pigmentation on older leaves because of the deficiency of phosphorus. Now next component is the potassium. It is an essential nutrient element it is an essential nutrient element required by all living organisms including plants and animals. It is found in large concentration in the plant cell sap. Potassium is not incorporated into the structure of organic compounds but remains in ionic form in solution in the cell and is mobile in plants. Potassium is required for the activation of over eighty enzymes. And it is estimated by flame photometer. Potassium plays very vital roles in water relations, that is osmotic regulation, control of ionic balances, etc., energy relations, translocation of assimilates, photosynthesis, protein-starch synthesis, metabolic processes, and grain seed formation. Improving quality of flowers, fruits, vegetables and other fields crop in terms of size, shape, color, taste, shelf life and fiber quality etc. Preventing lodging in crops, imparting resistance against environmental stresses such as drought, cold and frost, improving resistance to pests and diseases.

The deficiency of potassium leads to slow and stunted growth, weak stalks, low yield and poor quality of plant leaves. Next important component is the calcium. Calcium is the fifth most abundant element in the earth crust. Calcium being small and strongly electrovalent is the most abundant cation occupying the exchange sites of the soil collides both inorganic and organic.

Thus most soils with the possible exception of highly weathered, leached acid soils contain enough Ca for crop growth. Activity of Ca is related to its capacity for coordination by which it provides stable but reversible intermolecular linkages predominantly in the cell walls and at the plasma membrane. These calcium ion mediated linkages respond to local changes in the environmental conditions and are part of the control mechanisms for growth and developmental processes. Calcium is a non-toxic mineral nutrient even in high concentration and is very effective in detoxifying high concentration of other mineral elements in plants. The metalloenzyme amylase has calcium as the major cation in the middle lamella of the cell walls of which calcium pectate is the principal constituent.

Thus, calcium provides mechanical strength to tissues, enhancing cell division and plant growth, protein synthesis, carbohydrate movement, and balancing the cell acidity. In the tabular way, you can see here the details about the calcium, that is atomic weight near about 40.08, atomic number twenty, specific gravity 1.52, proportion of earth crust 3.20, forms absorbs Ca^{2+}, hydrated ionic radius 0.412, hydration energy 1577. and typical concentration in plant dry matter in percentage 0.2 to 1. Soil seldom become calcium deficient as long as soil pH is maintained towards neutral range. Deficiency of Ca is characterized by a reduction in meristematic tissue. Deficiency first appears in the growing tips and youngest leaves and subsequently in an advanced stage, necrosis of leaf margin occurs.

One symptom of calcium deficiency in apple is discoloration of the fruit meat. The condition is commonly called as bitter pit. Bitter pit is the physiological breakdown of the cells under the skin causing slight depressions generally concentrated at the calyx end of the fruit. The tissue in this depressed area is darkened, dry and spongy with a bitter taste. You can see the diagram of the bitter pit conditions in apple because of the calcium deficiency.

Next component is the magnesium. Magnesium is an essential constituent of chlorophyll in plants. Magnesium is the most common activator of enzymes concerned with energy metabolism. The functions of magnesium ion in plants are related to its mobility within the cells, its capacity to interact with strongly nucleophilic ligands that is phosphoryl group through ionic binding and to act as a bridging element and or forming complexes of different stability. Most bonds involving magnesium ions are ionic, some are partially covalent as in the chlorophyll molecule.

Magnesium forms ternary complexes with enzymes in which bridging cations are required for establishing a precise geometry between enzyme and the substrate. A high proportion of total magnesium ion is involved in the regulation of cellular pH and the cation-anion balance. Calcium may sometimes inhibit the activating effect of magnesium by displacing it from the functional groups. Magnesium deficiency is common in plants growing on coarse-textured acidic soils. Magnesium deficiency first appears on lower leaves as a yellowish bronze or reddish color while leaf veins remain green.

In strongly acid soils, that is pH less than four point five, there is a reduced absorption of magnesium by plants. Forages grown in acid soils have low magnesium content and cattle feedings on such forages may suffer from hypomagnesemia called Grass Tetary disease. Next important component is sulfur. Sulfur occurs as sulphides in igneous and sedimentary rocks. Sulfur is also present in organic compounds in soil, in industrial waste, seawater and as gaseous emissions in atmosphere.

Sulphur deficiency normally occurs on old, deeply weathered land surfaces of strongly leached soils and soils away from sea and industrial areas. Sulphur absorbed as sulphate ions is reduced in plants and incorporated in organic compounds. Sulphur is required for the synthesis of vitamins. Sulphur is essential for the production of three amino acids found in plants and animals. Proteins are the compounds in which most of the sulfur of the plant tissue is incorporated.

For every fifteen parts of nitrogen in protein, there is one part of sulfur which implies that nitrogen and sulfur ratio is nearly constant within a very narrow range of fifteen is to one. Sulfur requirements of crops are very similar to their phosphorus needs. Sulfur deficiency leads to inhibition of protein synthesis. In field crops, it is difficult to distinguish between the deficiency of sulfur. Yellowing of leaves in wheat is a common sulfur deficiency.

In case of leguminous crops, nodulation is often poor due to the sulfur deficiency. In tomatoes, plants are smaller with stunted growth and lighter in color. In general, mottled yellow-green leaves with yellowish veins in younger leaves is the characteristic symptom of sulfur deficiency. Next is the soil alkalinity and salinity. Alkaline soils have sufficient sodium saturation and alkalinity to adversely affect the plant growth and crop productivity.

Carbonates of sodium are the dominant salts. The concentration of neutral salts is much lower. Sparingly soluble gypsum, which may be present in many saline soils, is nearly absent in alkali soils. In some parts of India, they are called Usar and in others, it is called Kallar. Dispersed and dissolved organic matter is deposited on the surface alkali soils to give dark brown-black appearance that is black alkali soils.

In India, these soils are mainly distributed in arid and semi-arid regions of Punjab, Haryana, Uttar Pradesh, Bihar and Rajasthan states. Saline soils contain sufficient concentration of soluble salts in the root zone soil to adversely affect the plant growth and productivity. The soluble salts in these soils are predominantly the chlorides and sulfates of sodium, calcium and magnesium. The concentration of potassium is generally low. The concentration of neutral salts are much higher than those alkali salts, namely carbonates.

Excessive concentration of boron, fluoride and nitrates may also be present in these soils under arid conditions. Many saline soils may also contain small to appreciable quantities of sparingly soluble gypsum. These soils are characterized by saline efflorescence or white incrustation of salts at the surface. In India, these soils are known at some places as Reh and in other places as Thur. Now let us conclude the chapter that is the module nine.

We have discussed in the module nine the process of the soil formation. Soil forms through the weathering of rocks and decomposition of organic matter. Climate, organisms and time influence the soil characteristics and horizon development. Impact of soil erosion, we have discussed. Erosion removes the topsoil, reducing fertility and crop yield.

It leads to the sedimentation in water bodies, causing environmental degradation. Then we have discussed in module nine about the physical properties of soil, in which we have discussed the texture, that is sand cell clay affects the water retention and aeration. Structure and porosity influence the permeability and root penetration. Then chemical properties of soil. Soil pH affects the nutrient ability and microbial activity.

Organic matter and mineral content determine the soil fertility and productivity. And last that is the conservation and management techniques like contour ploughing and afforestation prevent the erosion, sustainable farming and organic amendments improve the soil health. These are the references from which I have prepared the model nine that is from the fundamental of soil science, environmental chemistry, then test book of soil science, the nature and properties of soils, soil science, then principles of soil physics, fundamental of Soil Science and Soils and Introduction to Soils and Plant Growth. Thank you very much to all.