By Team Studiffy

Index

Lecture 1- Composition of Earth Crust

Introduction

Earth's Spheres:

- Three spheres, corresponding to the three states of matter (solid, liquid and gas) constitute the earth. The solid zone is lithosphere, land which is covered by water forming seas and oceans is the hydrosphere, the gaseous envelope over the earth's surface is the atmosphere.
- The lithosphere consists of continents, oceans basins, plains, plateau and mountains, valleys, sand dunes and also it include interior of earth which consists of rocks and minerals. It is covered by gaseous and watery envelops. It accounts to 93.06 % of the earth.
- The earth ball consists of three concentric rings: crust, mantle and core (Fig-1).
- The crust is 5-56 km thick and consists of rocks with density of 2.6-3.0. It varies from 5 to 11 km in the oceans and 35 to 56 km in the continents. The soil scientists are interested in this skin.

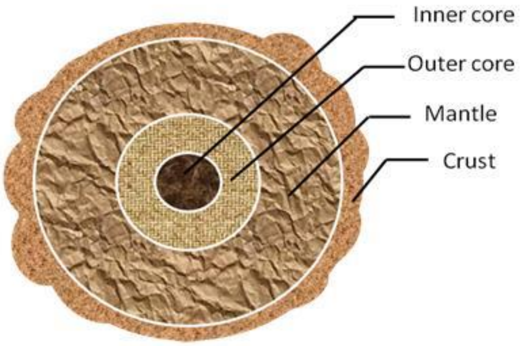

Fig.1. Internal structure of earth.

Composition of earth's crust:

- The hard, naturally formed substance of the earth is referred to as rocks. Rocks are built from minerals.
- Minerals in turn are constructed from natural elements and compounds. Out of total elements known eight element covering major portion 98.6 % (by weight) of the earth's crust (up to 16 km).The two elements occurring in greatest abundance are non-metallic (oxygen and silicon) and comprised of 3/4th (74.32%) of the total composition of the earth crust (Table.1).

Table 1.Eight Major Elements of the Earth's Crust

Elements		Approx. Abundance (by weight)	Example of mineral
Non-metallic	Oxygen	46.60	Quartz
	Silicon	27.72	Mica
Metallic	Aluminum	8.13	Mica
	Iron	5.00	Pryoxines
	Calcium	3.63	Mica
	Sodium	2.83	Feldspar
	Potassium	2.59	Mica
	Magnesium	2.09	Pryoxines
Others		1.41	

Rocks

The rocks are generally composed of two or more minerals. Petrology (Greek, *petra* means *rock, logos* means *science*) deals with science of rocks. It consists of
i) ***Petrography*** which deals with description of rocks
ii) ***Petrogenesis*** which is the study of the origin of rocks. Geologists have classified rocks into three major groups: Igneseous, Sedimentary and Metamorphic.

Igneous Rocks (Latin *ignis*, means *fire*):

- The whole surface of the earth passed through a molten stage and the first solid mineral was derived from this molten material known as magma.
- Igneous rocks are formed by cooling and crystallization of molten material-magma-on or beneath the surface of the earth.
- Igneous rocks formed from molten magma that cooling within the earth's crust are called intrusive rocks. The volcanic rocks that cool on the surface of earth are termed extrusive. They are source of parent material for other rocks and ultimately for soils.
- The examples are Granite, Syenite, Diorite, Gabbro, Dolerite and Basalt.

Sedimentary Rocks

- Sediment is the material that settles on the bottom of something else, usually a liquid. Thus sedimentary rocks are formed from sediments, derived from the breaking down of pre-existing rocks. These are composed of materials that have been worn down by wind, water, or ice and deposited somewhere. Stratification is the most common feature of these rocks and as such these are also termed as stratified rocks.
- Sedimentary rocks are classified into three subgroups: Clastic sedimentary, Chemical particulates, and organic sedimentary. Clastic sedimentary are simply rock fragments e.g.

sandstone and shale. The second subgroup is sedimentary rocks that are formed from chemical compounds settling out of water solutions e.g. Limestone and Dolomite. The last subgroup, organic sedimentary rock, is formed of living or once-living substances settling out of water. Coal is a well-known example of an organic sedimentary rock.

Metamorphic Rocks

- The word metamorphic means "change in form" and thus metamorphic rocks are those which have undergone some chemical or physical change from its original form.
- The change due to water is called Hydrometamorphism, due to heat is Thermometamorphism and due to pressure is called Dynamometamorphism.
- The examples are Gneiss- Formed from granite; Schist- Formed from basalt or shale; Quartzite Formed from sandstone; Slate- Formed from shale; Marble- Formed from lime stone

Relative abundance of rocks:

- Composition of earth's crust as a whole

Igneous rocks – 95%, Sedimentary rocks – 5% (Shales 4%, Sandstone 0.75% and limestone 0. 25%)

- Composition of the upper five kilometers of the earth's crust:
- Sedimentary rocks: Shales – 52%, Sandstones – 15%, Limestone & Dolomite – 7% (Total 74%)
- Igneous rocks: Granite – 15%, Basalt – 3% (Total 18%)
- Others – 8%

Note: Although sedimentary rocks forms only five per cent of the total earth crust, yet they are important as they occur to the extent of 74 per cent (almost 3/4th) at or near the surface of the earth (upper 5 km). As we go deeper, we find predominance of igneous rocks.

Minerals:

- The minerals may be defined as naturally occurring, homogeneous element or inorganic compound having definite chemical composition.
- More than 90 percent of all the minerals in the earth's crust are made up of compounds containing Silicon and Oxygen.
- There are over 2500 minerals on earth. Only 30 minerals are commonly found on the earth's surface and in surface rocks.
- Most minerals are made from nonliving substances. Many have crystal shapes. These are three-dimensional and hence easy to recognize.

Minerals are classified into primary and secondary.
1. Primary minerals: The original component of an igneous rock is known as primary mineral. Those primary minerals which are recognized as the characteristic component of that rock are known as essential mineral, while those which occur only in small quantities and whose presence and absence is not so important are called accessory minerals.
2. Secondary minerals: A mineral resulting from the decomposition of a primary mineral or from the reprecipitation of the products of decomposition of the primary minerals are called secondary mineral.

Relative abundance of important rock forming minerals:

Minerals (arranged in the order of their crystallization)	Important constituents	Percent distribution
Primary minerals		
Ferro magnesium minerals		
Ortho-ino silicates		16.8
Olivine	Fe, Mg	
Pyroxenes	Ca, Na, Fe, Mg	
Amphiboles	Ca, Na, Fe, Mg, Al, OH	
Phyllo Silicates		3.6
Biotite	K, Fe, Mg, Al, OH	
Muscovite	K, Al, OH	
Non-Ferro Magnesium minerals		
Tecto Silicates		
Feldspars		61.0
Anorthite	Ca, Al	
Albite	Na, Al	
Orthoclase	K, Al	
Quartz		
Secondary minerals		
Clay minerals	Na, K, Ca	11.6
Others	Mg, Fe, Al, OH	6.0

Soil

- As early as 5000BC, the Vedas and Upanishad as well as other Indian literature mentioned soil as synonymous with land – the Mother – supporting and nourishing all life on earth.
- For a laymen it is the dirt and dust on the surface of the earth.
- To the farmer, soil is that portion of the earth's surface which he can plough and grow crops to provide him with food and fiber for his own needs and that of animals, to the poor man.
- For a mining engineer soil is debris covering the rocks
- For engineers soil is any unconsolidated material removed in excavations and used for filling or provide foundation structure
- **Definations:**

Whitney (1892) : Soil is a nutrient bin which provides all the nutrients required for plant growth.

Hilgard (1892): Soil is more or less loose and friable material in which plants , by means of their roots , find a foothold for nourishment as well as for other conditions of growth.

Dokuchaiev (1900): Father of soil science- Soil as a natural body composed of mineral and organic constituents, having a definite genesis and a distinct nature of its own.

Joffe (1936): Soil is a natural body of mineral and organic constituents differentiated into horizons of variable depth, which differs from the material below in morphology, physical makeup, chemical properties and composition and biological characteristics".

Jenny (1941): Soil is a naturally occurring body that has been evolved due to combined influence of climate and living organisms acting on parent material as conditioned by relief over a period of time .

Simonson (1957): The soil is three dimensional body having length, breadth and depth which form a continuum over the land surface and differ gradually from place to place.

Soil Science Society of America (1970):
(i) The unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of plants
(ii) Soil is the unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors viz. parent material, climate, macro and microorganisms and topography, all affecting over a period of time and producing a product, that is **"SOIL"** that differs from the material from which it is derived in physical, chemical, biological and morphological properties and characteristics.

Land and Soil:

- Land and soil are often confused by students as synonymous. Land is broadly defined as total natural environment of the areas of the earth not covered by water. In addition to soil, its attributes include all the living organisms, the air and water bodies with in or on it and rocks below.
- Soil forms a part of an ecosystem which is the base functional unit of ecology including both biotic and abiotic environment mutually influencing each other to maintain dynamics of life on earth.
- The biotic component comprises all the living organisms whereas the abiotic component consists of the solid mineral matter on earth, the water in the oceans, lakes, river etc., the gaseous mixture in the air and radiant solar energy.
- Soil as natural body: The scientist considers the soil to be a natural body having both depth and surface (L X B) area. In fact, the soil is product of nature resulting from both destructive and synthetic forces. The weathering of rocks and minerals and decomposition of the organic matter are the examples of destructive processes. Whereas, formation of various minerals, clays and development of different horizons are synthetic processes. Thus, a scientist considers the soil as a habitat for the plants. He recognizes the contribution of plants in the development of soil and also its importance in crop production. The term soil is derived from Latin word "Solum" which means the floor.

Major component of soil:

- Soil is composed of partly weathered, unweathred, transformed products of rocks, rock minerals and organic matter.
- The mineral soil consists of four major components/phases: mineral material and organic matter (solid), water (liquid) and air (gases). In an ideal surface soils these components are observed in amounts (by volume,Fig.2) as follows,

Soild Phase (Mineral matter): The solid phase is broadly composed of inorganic and organic constituents. The inorganic constituents which forms bulk of solid phase of soil includes silicates, carbonates, soluble salts and free oxides of Fe, Al and Si in addition to some amorphous silicates. Only a small fraction of the solid phase is of organic origin. The sources of organic constitutes are plant and animals. Of total volume, about half is solid space, 45 per cent mineral matter and 5 % organic matter.

Liquid phase (Soil water): Forty to fifty per cent of the bulk volume of the soil body is occupied by soil pores, which may be completely and partially filled with water. The soil acts as a reservoir for supplying water to plants for their growth. The soil water keeps salts in solution which act as plant nutrients. Thus, liquid phase is an aqueous solution of salts.

Gaseous Phase (Soil air): The air filled pores constitutes the gaseous phase of the soil system. The volume of the gaseous phase is thus dependent on that of liquid phase. The nitrogen and oxygen contents of soil air are almost same as that of atmospheric air but concentration of carbon dioxide is much higher.

The four major components of a typical soil exist mainly in an intimately mixed condition. The proportion of these components may vary from time to time and from place to place. The volume composition of sub- soil is different from the surface soil. Compared to top soils they are lower in organic matter content, lower in total pore space and contain a higher percentage of small pores. This means they have a higher percentage of mineral and water and considerable lower content of organic matter and air.

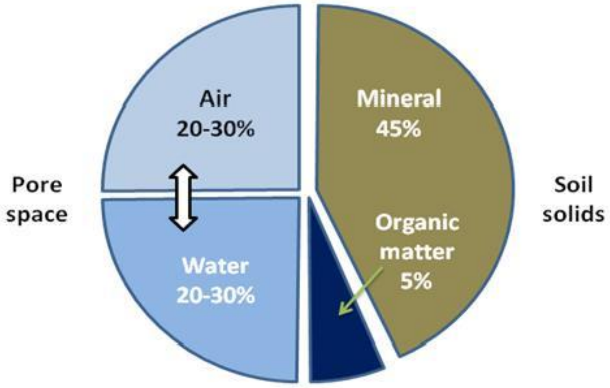

Fig.2. Composition of ideal surface soil

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Lecture 2- Soil Forming Processes

Introduction

- A soil forming process may be defined as a complex or sequence of events including both complicated reactions and simple rearrangement of matter which intimately affect the soil.
- These processes are also known as soil building processes or pedogenic processes.

The basic soil forming processes involved in soil formation (Simonson, 1959) includes the following.

- Gains or Additions of water, mostly as rainfall, organic and mineral matter to the soil.
- Losses of the above materials from the soil.
- Transformation of mineral and organic substances within the soil.
- Translocation or the movement of soil materials from one point to another within the soil. It is usually divided into two aspects.
  - Movement in solution (leaching)
  - Movement in suspension (eluviation) of clay, organic matter and hydrous oxides

A. Fundamental Soil Forming Processes

Humification:

- It is the process of transformation or decomposition of raw organic matter in to humus.
- In this process the soluble organic substances regroup themselves in to large molecules by polymerization and become poorly soluble.
- The characteristics are influenced by the nature of vegetation residue and the way it becomes decomposed and synthesized in to new organic compounds.

Eluviation (Latin, *ex* or *e*,out and *lavere*, to wash):

- Eluviation means washing out. It is the process of removal of constituents in suspension or solution (Clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$, other salts etc) by the percolating water from the upper to lower layers. The Eluviation process involves mobilization and translocation of mobile soil constituents resulting in textural differences. Translocation depends upon relative mobility of elements and depth of percolation.
- The horizon formed by the process of eluviation is termed as eluvial horizon (A_2 or E horizon).

Illuviation (Latin- *il*, in, and *lavere*, to wash):

- The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer is termed as Illuviation.
- This is the region of maximum accumlation of materials such as iron and aluminium oxides and silicate clays.
- The horizon formed by this process is termed as illuvial horizon (B-horizon, especially Bt).
- The process leads to horizon of gains and textural contrast between E and Bt horizons.

Specific Soil Forming Processes

The fundamental processes provide a framework for more specific processes like-
Podzolization (Russian, *pod* means under and *zola* means ash):

- It is the process of eluviation of oxide of iron and aluminium (sesqui oxides) and also humus under acidic condition (pH 4-5), removal of carbonates by organic acids formed by organic matter and illuviation of the silicon in surface horizon.
- Abudant organic matter, commonly found under forest, cold and humid climate are favourable for the formation of such soils.
- The eluiviated horizon assumes a bleached grey colour and is left in highly acid, siliceous condition and, the term podzol has been used for such soils.

Laterization (Latin, *later*-a brick):

- The term laterite is derived from the word later meaning brick or tile and was originally applied to a group of high clay Indian soils found in Malabar hills of Kerala, Tamil Nadu, Karnataka , Madya Pradesh and Maharashtra.
- Laterization is inverse process to that of podzolization i.e. the process that removes silica, instead of sesquioxides from the upper layers and thereby leaving sesquioxides to concentrate in the solum.
- The process operates under rain forests of tropical areas, warm and humid (tropical) climate and basic parent materials are favourable for such soils.
- It refers specifically to a particular cemented horizon in certain soils which when dried, become very hard, like a brick.
- Such soils (in tropics) when massively mixed with sesquioxides (iron and aluminium oxides) to an extent of 70 to 80 per cent of the total mass, are called laterites or latosols (Oxisols).

Salinization

- It is the process of accumulation of salts, such as sulphates and chlorides of calcium, magnesium, sodium and potassium in soils in the form of a salty (salic) horizon.
- The intensity and depth of accumulation vary with the amount of water available for leaching.
- It is quite common in arid and semi arid regions.
- It may also take place through capillary rise of saline ground water and by inundation with seawater in marine and coastal soils.
- Salt accumulation may also result from irrigation or seepage in areas of impeded drainage.

Desalinization

- It is the process of removal of excess soluble salts from horizons that contained enough soluble salts to impair the plant growth.
- Drainage is essential for desalinization.

Alkalization (Solonization) :

- The process by which soils with high exchangeable sodium and $pH > 8.5$ are formed; often sodium carbonate and sodium bicabonate are formed in extreme cases.
- The soil colloids become dispersed and tend to move downward. The dispersion results in poor physical condition of the soil.

Dealkalization (Solodization):

- The process refers to the removal of Na^+ from the exchange sites. This process involves dispersion of clay. Dispersion occurs when Na^+ ions become hydrated.
- The process is effected by intensive leaching and degradation which takes place in older soils.

Calcification

- The process operates in arid and semi-arid regions and refers to precipitation and accumulation of calcium carbonate ($CaCO_3$) in some part of the profile. The accumulation of $CaCO_3$ may result in the development of a calcic horizon.
- Calcium is readily soluble in acidic soil water and/or when CO_2 concentration is high in root zone as:

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 + Ca = Ca\ (HCO_3)_2 \text{ (soluble)}$$

$$Ca\ (HCO_3)_2 = CaCO_3 + H_2O + CO_2 \text{ (precipitates)}$$

Decalcification

- In regions where some water percolates through the soil profile , decalcification takes place leading to the formation of calcic horizon down below.
- In humid regions, calcium cabonate reacts with water containing dissolved carbon dioxide to form soluble bicarbonate which may be completely leached out of the soil profile.

$CaCO_3 + CO_2 + H_2O$ (insoluble) = $Ca(HCO_3)_2$ (soluble)

Carbonation

- It occurs when carbon dioxide interacts chemically with minerals. When carbon dioxide is dissolved in water, it forms weak carbonic acid.
- When carbonic acid comes in contact with the surface of the earth it dissolves large masses of limestone, creating caves and caverns.

Gleization:

- The term *glei* is of Russian origin means blue, grey or green clay.
- The gleization is a process of reduction, due to anaerobic condition, of iron in waterlogged soils with the formation of mottles and concretions. Such soils are called as hydromorphic soils.
- The process is not dependent on climate (high rainfall as in humid regions) but often on drainage conditions.

Pedoturbation:

- It is the process of mixing of the soil.

1. **Faunal pedoturbation:** It is the mixing of soil by animals such as ants, earthworms, moles, rodents, and man himself
2. **Floral pedoturbation :** It is the mixing of soil by plants as in tree tipping that forms pits and mounds
3. **Argillic pedoturbation:** It is the mixing of materials in the solum by the churning process caused by swell-shrink clays as observed in deep Black cotton soils.

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Lecture 3- Aerial Photography

Definition:

Aerial photography is defined as the science of obtaining photographs from the air using various platforms, mostly aircraft, for studying the surface of the earth . The pictures taken by camera fitted in an aircraft and flying over the predetermined height, depending on the scale of aerial photography and focal length of camera.

- Aerial photographs gives a bird's eye view of large areas.
- The sun provides the source of energy (electromagnetic radiations or EMR) and the photosensitive film acts as a sensor to record the images.
- Variations in the grey tones of the various images in a photograph indicate different amounts of energy reflected from the objects as recorded on the film.
- The photographs contain 50 to 65 percent overlap which is essential for stereoscopic viewing and analysis of stereo pairs.
- The aerial photographs ranging in scale from 1:8000 to 1: 60,000 are used in different types of soil surveys.
- In soil survey , we mostly use panchromatic black and white air photos taken with a black and white film. In these photographs, there are many shades of grey colour.
- Black and white air photos can indicate a lot of information about land forms, vegetation, human interference as well as soils. Natural colour and infrared film are also used for aerial photography, especially for forest areas to discreminate forest types/ species.
- Many landforms – terraces, flood plains, sand dunes, coastal plains, plateaus, paleochannels, hills, valleys and mountain can be recognized on the photographs based on their shapes, relative heights and slopes. Difference in tones or colour may also reflect soil differences.
- When we look at an aerial photograph , we can see various objects of different sizes and shapes. Some of these objects may be readily identifiable while others may not be, depending on the interpreter's perception and experience.
- Individual objects like trees, houses, roads, foot paths, field boundaries, lakes, river courses etc, are imaged clearly depending on the scale of photographs. These 'landmarks' serve as effective reference point or local control points that facilitates a soil surveyor in orientation and navigation during the field work and in demarcating boundaries of high local accuracy.
- Base maps for publication can be prepared from aerial photographs economically and in reasonable time.

Classification of aerial photography:

On the basis of scale:

- Large scale : Between 1:5,000 and 1: 20,000
- Medium scale: Between 1: 20,000 and 1:50,000
- Small scale : Smaller than 1:50,000

On the basis of tilt:

- Vertical : When the tilt is within 3 (nealy vertical)
- Oblique: Low oblique (horizon does not appear but tilt is more than 30)
- Horizontal or terrestial: Camera axis is kept horizontal

On the basis of angular coverage:

- Narrow angle : Angle of coverage less than 500
- Normal angle : Angle of coverage less than 600
- Wide angle : Angle of coverage less than 900
- Super-wide angle : Angle of coverage less than 1200

On the basis of film:

- Black and white panchromatic
- Black and white infrared
- Colour
- Colour infra-red/ false colour

Application of aerial photography:

Mapping: This is a valuable tool for soil mapping. It has been found to be fast, accurate, indispensable in inaccessible areas and cost effective in the long run.

Interpretation: Photointerpretation has revolutionalised the method of data collection in various disciplines. It is greatly reduced the field work and thereby the cost. The information is reliable and acceptance for most studies such as in the fields of geology, water resources, geomorphology, hydrogeology, forestry and ecology, soil surveys and urban and regional planning.

Map substitute: In a situation where there are no adequate large scale maps available, aerial photographs can serve as map substitutes in the form of photomaps.

Limitations:

- Elevations are not shown on the photographs.
- Scale is not precisely uniform and the differences of scale between adjoining photographs create some problems in matching and transferring of soil boundaries.
- Distance and directions can not be measured as accurately as on topographical maps.

Factors affecting aerial photography:

Atmospheric conditions : The presence of particles (smoke or dust) and molecules of gases in the atmosphere tends to reduce contrast because of scattering, therefore, the best time photography is when the sky is clear (November-February).

Scale: Scale is the ratio of distances between two images on an aerial photograph and the actual distance between the same two points/ objects on the ground, in other words the ratio of f/h (f- focal length of the camera lens and h- flying height above the mean terrain). Due to variations in flying height , the scales of different photographs may vary. Scale may also vary because of the effects of tilt and relief displacements.

Camera/Film/Filter combination: To ensure good image quality,modern distortion free cameras are used. Depending upon the requirements different lens/ focal length/ film/ filter combinations can be used.

Flight direction: Aerial photography is flown in strips to cover the designated area. It is advisable to keep the number of strips to minimum. The flight direction of strips is therefore kept along the length of the area.

Time/ Season of photography: Aerial photography should be flown when the sun's elevation is 30 degrees above the horizon or three hours before and after the local noon time.

Remote sensing:

- Remote sensing is the science of obtaining information about objects or phenomenon in the enviornment through the use of sensing devices located at a distance without any physical contact between the object and the sensing device.
- Electromagnetic energy is the means by which information is transmitted from an objects to sensor.
- Earth orbitting satellites equiped with sensors, including cameras provide imagery and digital data.
- Remote sensing technology makes use of visible (0.4-0.7um), infrared (0.7-3.0um), thermal infra red (3-5 um and 8-14 um) and microwave (0.3 – 3.0um) regions of electromagnetic spectrum to collect information about various objects on the earth's surface.
- The Indian Remote Sensing Satellite (IRS-ID & P6) launched at an altitude of 817 km with an inclination of 98.70 in the descending mode cross the equator at 10.30 AM.
- The Indian Remote Sensing Satellite (IRS & P6) takes 101.35 minutes to complete one revolution around the earth and thus completes about 14 orbits a day.
- The entire earth is covered in 341 orbits during a 24 day cycle. Earlier, the planned life of satellites was three years, but it is 5-7 years presently.

Indian Space Research Organization has launched 14 Indian Remote Sensing Satellites:
IRS -1A March ,1988 ;IRS -1B August ,1991;IRS-1E September, 1993; IRS-P2 October, 1994;IRS- 1C December, 1995;IRS P3 March ,1996;IRS – 1D September, 1997 ;IRS – P4 May ,1999;Technology Experiment Satellite (TES) Oct ,2001; RESOURCESAT-1 (IRS-P6) October, 2003;Cartosat-I May,2005;Catosat-2 January, 2007;Cartosat- 2A and Indian Mini Satellite (IMS-1) April,2008

Basic characteristics of features used in Interpretation:

Shape:

- It refers to general form, configuration or outline of the individual objects. Numerous components of environment can be identified with reasonable certainty, merely by their shapes or forms.
- This is true for both the naturl features (e.g. Geological structures) as well as man made objects (e.g.) different type of industrial plants and buildings.

Size:

- The size of an object is one of the most useful clues in the possible identification. Objects can easily be picked up from photos if the scale is large.
- An irrigation ditch and an anti tank ditch are very much alike except in size, and simple measurement may be sufficient to make the identification.

Pattern:

- Repetitive arrangements of both natural and cultural features are quite common. Patterns are clearly visible on images and also capture many small but significant patterns which might be over looked by the ground observer. Cultural features are conspicuous because they consist of straight lines or regular configurations.
- A road and railway may look much alike in a photography/imagery, but an interpreter can separate them by the slight configurations required by their function. For example, a road may have fairly steep grades, sharp curves and many intersections while a railway has gentle grades, wide curves and few intersections.

Shadow:

- It defines outline of an object and its length may help to estimate its height as well as elevational out line of an object.
- Shadows are especially useful in geomorphological studies where micro relief features may be easier to detect under conditions of low angle solar illumination than when the sun is high the sky.

Tone or color:

- Tone refers to the colour or relative brightness of objects in aerial data. Different objects emits or reflect different wavelengths and intensities of radiant energy. Such differences may be recorded as variations of pictures tone, colour or density.
- In black and white images, the tone varies from light grey to dark. The terms light, medium and dark are used to describe the variations in tone.

Texture:

- Texture is the frequency of tonal change on photographic image and is created by tonal repetitions of groups of objects which are two small to be disurned as individuals.
- Common photography textures include smooth, rippled, mottled, lineated and irregular. This is very important unit for rock identification.

Site:

- At an advanced stage in a photo interpretation procedure, the location of objects with respect to terrain features of other objects may be helpful in defining the identification and classification of certain picture contents. For example, certain tree species would be expected to occur on well drained upland sites, whereas other tree species would be expected to occur on poorly drained lowland sites.

Interpretation methods:

1. Visual interpretation using keys
2. Digital interpretation using computers.

Images Interpretation keys (visual)

1) Selection key :

- It contains numerous photography examples with supporting text. The interpreter selects the features or conditions found an the image under study.

2) Elimination key:

- It is arranged so that interpretation proceeds step by step, from general to specific and leads to the elimination of all features or conditions except the ones being identified.

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Lecture 4 - Soil Classification and Land Capability Classification

Soil Classification

Soil classification is the grouping of the objects in some orderly and logical manner in to compartments.

Purpose of soil classification

1. To organize knowledge leading to economy of thoughts.
2. To recognize properties of the objects classified.
3. To bring out and understand relationship among individuals and classes of the population being classified.
4. To establish groups or subdivisions of the objects under study in a manner useful for practical and applied purposes in :

- Predicting their behavior
- Identifying their potential uses
- Estimating their productivity
- Providing objects for research and
- Transferring agro-technology from research farm to cultivators fields.
- The latest comprehensive classification system is known as ‘Soil Taxonomy’, based on the properties of the soils as they are found today. The soil taxonomy permits classification of soils rather than soil forming processes.
- There are six categories of classification in Soil Taxonomy: (a) Order (the broadest category) (b) Suborder (c) Great group (d) Sub group (e) Family (f) Series (most specific category). The nature and kind of differentiating characteristics used in these six categories are given in the Table – 1

Table-1: Differentiating characteristics of different categories

Category	Number of taxa	Differentiating characteristics
Order	12	These are based largely on morphology, as produced by soil forming processes and indicated by the presence or absence of major diagnostic horizons
Suborder	63	Sub-division of orders according to presence or absence of properties associated with wetness, soil moisture regime, parent material, vegetational effect as indicated by key properties
Great group	240+	Sub-division of suborder, major emphasis is on the diagnostic horizon and presence and absence of diagnostic layers, base status, soil temperature and moisture regime.

Subgroup	1000+	The Typic is used to define the central concept of a great groups; the others are used to indicate integrated to great groups, suborders and orders and the extra graded to 'not soil'
Family		The soil properties that are most important for plant growth like texture, mineralogical class, soil temperature class and pH are used to differentiate families. They meet the need for making practical predictions for land use planning.
Series	200+ in India and 12000 in USA.	It is the lowest category in the system. The series is collection of soil individuals essentially uniform in differentiating characteristics like colour, texture, structure, consistencey, pH and EC and in arrangement of horizons.

Soil Orders

- There are twelve soil orders which are differentiated by presence or absence of diagnostic horizon (Table-2) or features that are marked in the soil of difference in the degree and kind of dominant sets of soil forming processes that have prevailed.
- The diagnostic horizon is defined as one, formed through pedogenic processes and having distinct properties or features that can be described in terms of measurable soil properties.
- The diagnostic surface horizon are called epipedons (Greek *epi,* over and *pedon,* soil). The epipedons includes the upper part of the soil darkned by organic matter, the upper eluvial horizons or both. The diagnostic subsurface horizons are called endopedons (Greek endodermis, subsurface or deep-seated and pedon, soil). The epipedons includes the lower part of the soil materials accumulate.

Designations of master horizons:

Horizon Designation	**Short description**
New	
O	Organic horizon
A	Mineral horizon
E	Mineral horizon
C	Horizons or layers excluding hard bed rock
R	Hard bed rock

Horizon designation

- Once horizons are recognized and demarcated, it becomes necessary to name each horizon.
- Capital letters, lower case letters and arabic numerals are used to designate horizons.
- The capital letters are used to designate master horizons e.g. A, B, C.
- The lower case letters are used as suffixes to indicate specific characteristics of the master horizon.

  - Example : A_p, B_t etc.,
  - p - tillage or other disturbance by cultivation
  - t - Accumulation of silicate clay.

- Arabic numerals are used as suffixes to indicate additional vertical subdivisions within master horizon,
  - Example : B_t1, B_t2, B_t3 etc.
- Lastly Arabic numerals are also used as prefixes to indicate discontinuities in a profile
  - Example : 2C, 2BC etc.,
- The names of the orders can best be recalled by remembering a coined compound word **'AVAAMIHOUSEG'**. Names of the orders along with formative elements and salient characteristics are presented in Table-3.

Table 2. Major features of diagnostic horizons

Diagnostic Horizon	**Major features**
Surface Horizons (Epipedons)- 9	
Mollic	Thick, dark coloured, high base saturation, strong structure
Umbric	Same as Mollic except low base saturation
Ochric	Light coloured, low organic content, may be hard and massive when dry
Histic	Very high in organic content, wet during some part of the year.
Anthropic	Man modified Mollic like horizon, high in available P.
Plaggen	Man made sod like horizoncreated by years of manuring
Folistic	Organic soil materials that remain saturated for less than one month
Melanic	A thick black horizon (>4.0 % OC) at or near, but within 30 cm of the soil surface.
Grossarenic	A sandy horizon , 100 cm or more thick over an Argillic horizon
Subsurface Horizons(Endopedons)- 19	
Argillic	Silicate clay accumulation
Natric	Argillic, high in sodium, columnar or prismatic structure
Spodic	Organic matter, Fe and Al oxide accumulation

Cambic Changed or altered by physical movement or by chemical reactions

Agric Organic and clay accumulation just below plough layer due to cultivation

Oxic Highly weathered, primarily mixture of Fe, Al oxides, and 1:1 type minerals

Duripan Hard pan, strongly cemented by silica

Fragipan Brittle pan, usually loamy textured, weakly cemented

Albic Light coloured, clay and Fe, Al oxides mostaly removed

Calic Accumulation of $CaCO_3$ or $CaCO_3.MgCO_3$

Gypsic Accumulation of gypsum

Salic Accumulation of salts

Sombric Draining horizon, formed due to illuviation of humus and not of aluminium or sodium

Kandic Low activity clayswith or without clay skins, it has CEC of < 16 cmol(p^+) kg^{-1}soil

Sulphuric A mineral or organic soil horizon that has a pH <3.5.

Glossic Albic horizon characteristics gradually intruding in to an argillic, a kandic or nitric horizon.

Petrocalcic An indurated calcic horizon that has hardness of 3 or more(Mho’s scale)

Petrogypsic Astrongly cemented gypsic horizon whose dry fragments do not slake in water.

Placic A thin , slowly permeable, dark reddish brown to black coloured Fe or Mn pan

Of these Argillic, Natric,Cambic, Kandic, Oxic, Calcic and Gypsic are commonly observed in India

Table 3: Soil orders with soil characteristics

S.No.	Soil Order	Derivation	Pronunciation	Soil Characteristics
1	Entisol	Nonsense symbol	Recent	Soils with little horizon development or beginning of soil formation
2	Inceptisol	L.*inceptum*, begining	Inception	Soils with altered horizons, but no illuvial horizon containing clay or Fe, Al oxides, may have umbric, ochric or cambic horizon
3	Gelisols	Gk, gel,ice	Frost churning	Soils that have permafrost within 100cm or gelic material with permanent frost within 2m of the surface
4	Histosols	Gk. Histos, tissue	Histology	Soils containing > 30 % organic matter to a depth of 40 cm
5	Spodosols	Gk. Spodos, ash	Podzol; odd	Soils with spodic horizon with in 2 m.
6	Andisols	Jap. And	Ando	Soils that have andic soil properties in 60% or more of the thickness between the soil surface and 60 cm or lithic or paralithic contact
7	Oxisols	Fr. Oxide, oxide	oxide	Highly weathered soils of tropical and subtropical regions with oxic horizon
8	Vertisols	L. verto, turn	Invert	Soils with more than 30% clay in all horizons and crack when dry
9	Aridisols	L. aridus	Arid	Dry soils, ochric epipedon, some have argillic, nitric or salic horizon
10	Ultisols	L.ultimus,last	ultimate	Soils in warm humid regions with argillic horizon and low base saturation(<35% at 2 m depth below the surface
11	Mollisols	L. mollis, soft	mollify	Dark colored, base rich soils of grass land areas, mollic epipedon, many with argillic, nitric, or calcic horizon

12	Alfisols	Nonsense symbol	Pedalfer	High base status (>35%) soils of the humid and sub humid regions with an ochric epipedon and argillic (or nitric) horizon.

Land Capability Classification

- Land capability classification (LCC) may be defined as a system of grouping land in to various classes based on inherent limitations imposed on sustained use by soil attributes, topography, drainage and climate.
- The guiding principle underlying LCC is "use land according to its capability and treat it as per its need". The capability classes falls in two groups, one **suited for cultivation** and other **not suited for cultivation**.
- Each group is further sub-divided in to four capability based on intensity of hazards and limitations of use. The subclasses are further divides in to unit based on a specific management practice.
- Thus land is classified in to eight land capability classes under two broad groups as:
    - Land suitable for agriculture and other uses which include class I to class IV lands.
    - Land not suitable for agriculture but very well suited for forestry, grass land and wild life which include class V to class VIII lands.
- On map, the capability classes are indicated in different colours as Green (I), Yellow (II), Pink (III), Blue (IV), Dark green (V), Orange (VI), Red (VII), Purple (VIII). Detailed characteristics of each class are given in Table 4.

Table 4: Salient features of Land Capability Classes (LCC)

LCC	Characteristics
Land Suitable for Cultivation	
I	Very good cultivable, deep, nearly level productive land with almost no limitation or very slight hazard. Soils in this class are suited for a variety of crops, including wheat, barely, cotton, maize, tomato and bean. Need no special practices for cultivation
II	Good cultivable land on almost level plain or on gentle slopes, moderate depth, subject to occasional overland flow, may require drainage, moderate risk of damage when cultivated, use crop rotations, water control system or special tillage practices to control erosion
III	Soils are of moderate fertility on moderate steep slopes subject to more sever erosion and severe risk of damage but can be used for crops provided adequate plant cover is maintained, hay or other sod crops should be grown instead of row crops.
IV	These are good soils on steep slopes, subject to severe erosion, with severe risk of damage but may be cultivated occasionally if handled with great care, keep in hay or pasture but a grain crop may be grown once in 5 or 6 years.
Land unsuitable for cultivation but suitable for permanent vegetation	

V	Land is too wet or stony which make it unsuitable for cultivation of crops, subject to only slight erosion if properly managed, should be used for pasture or forestry but grazing should be regulated to prevent cover from being destroyed.
VI	These are shallow soils on steep slopes, used for grazing and forestry; grazing should be regulated to preserve plant cover; if the plant cover is destroyed, use should be restricted until cover is re-established.
VII	These are steep, rough, eroded lands with shallow soils, also includes droughtly and swampy land, severe risk of damage even when used for pasture or forestry, strict grazing or forest management must be applied
VIII	Very rough land, not suitable even for woodland or grazing, reserve for wild life, recreation or wasteland consideration.

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Lecture - 5 Soil Physical Properties

Introduction

The physical properties of a soil play an important role in determining its suitability for crop production. These properties depend on the amount, size, shape, arrangement and mineral composition of its particles. These properties also depend on organic matter content and pore spaces.

- The plant support, root penetration, drainage, aeration, retention of moisture and plant nutrients are linked with the physical condition of the soil.
- Some important physical properties of soils are soil texture, structure, density, porosity, colour, consistence and soil water.

Soil Texture

Soil texture refers to relative proportion of mechanical / soil separates below 2 mm in diameter (viz. sand, silt and clay).
Three size classes are particularly important:

1. Sand (size as in beach sand)
2. Silt (size like talc/talcum powder)
3. Clay (small particles which stick together, like modeling clay)

- The determination of various sized particles (sand, silt and clay) helps in understanding various soil properties e.g. water retention, cation exchange capacity, soil workability, erodibility etc.
- The information about particle size analysis is also of utmost importance for judicious nutrient and water management.

Particle size classification:

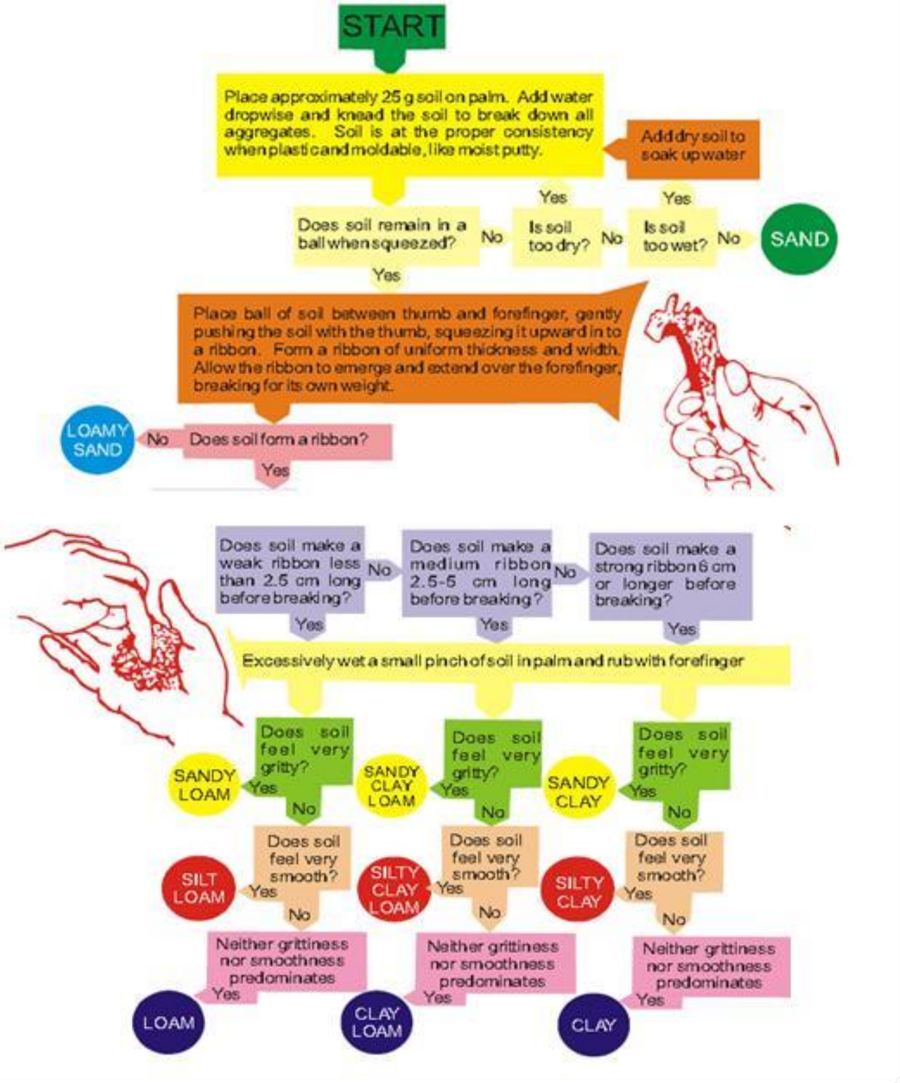
S.No.	**USDA Classification**		**International Soil Science Society classification**	
	Separate	**Particle Diameter (mm)**	**Separate**	**Particle Diameter (mm)**
1	Very coarse sand	2.0 - 1.0	Coarse sand	2.0 - 0.2
2	Coarse sand	1.0 - 0.5	Fine sand	0.2 - 0.02
3	Medium sand	0.5 – 0.25	Silt	0.02 - 0.002
4	Fine sand	0.25 – 0.1	Clay	< 0.002
5	Very fine sand	0.1 - 0.05		
6	Silt	0.05 - 0.002		
7	Clay	< 0.002		

Methods of textural analysis:

- 1. Rapid feel method
- 2. Hydrometer method
- 3. International pipette method.

1. Soil texture by feel method:
The common field method for determining the textural class of a soil is by its feel. It is of great practical value and depends upon the skill and experience of the worker. The principle underlying the determination of soil texture by this method is based on the properties, which the soil components exhibit. These are being described below:

- **Clay:** (Particles < 0.002 mm in diameter) Confers cohesion, stickiness and plasticity to the ball and increases its resistance to deformation.
- **Silt:** (between 0.02 and 0.002 mm in diameter) Confers a silky smoothness to the ball.
- **Sand:** (Particles between 0.02 and 2 mm in diameter) Confers grittiness.
- **Organic matter:** Imparts cohesion to sandy textures, greasiness to clayey textures and tends to produce a short thick ribbon from the balls.


Instructional diagram for determining soil texture by feel method (Modified from Thein, S.J.1979. Journal of Agronomic Education 8: 54-55, Madison, WI)

2. Hydrometer method (Using Bouyoucos hydrometer):

- The hydrometer method is based on the principle that the density of the suspension at a given depth decreases as an initially homogenous dispersed suspension settles. The rate of decrease in density at any given depth is related to the velocities of settling particles, which in turn, is related to their sizes.
- The time required by the particles of a given size to settle can be calculated using Stokes law.
- It however, gives approximate values that too for silt and clay only. Hydrometer method cannot be used for saline or organic soils or for soils which are known to be difficult to disperse.
- It also gives anomalous results with calcareous soils as the method does not involve any pre-treatment with hydrochloric acid to remove the calcium carbonate.

3. International pipette method:

- Pipette method is a standard method for particle size analysis of soils because of its accuracy, but it is time consuming and cannot be employed where large numbers of samples have to be analyzed.
- Particle size analysis is done by using sieves to separate out coarse sand from the finer particles. The silt and clay contents are then determined by measuring the rate of settling of these two separates from the suspension in water.
- The time required by the particles of a given size to settle can be calculated using Stokes law.

- ***Stoke's law:*** It states that the terminal velocity of a spherical particle settling under the influence of gravity in a fluid is directly proportional to the square of its radius and is expressed as:

$$V = \frac{2g(\rho_s - \rho_w)}{9n} r^2$$

Where,

V = *velocity of falling particles*
g = *Acceleration due to gravity*
ρ_w = *Density of liquid*
ρ_s = *Density of soil particles*
η = *viscosity of liquid*
r = *radius of the particles*

This method is widely used. Using a pipette, samples are drawn at a given depth (10 cm) after specific time and then dry matter is determined.

Assumptions of Stoke's law:

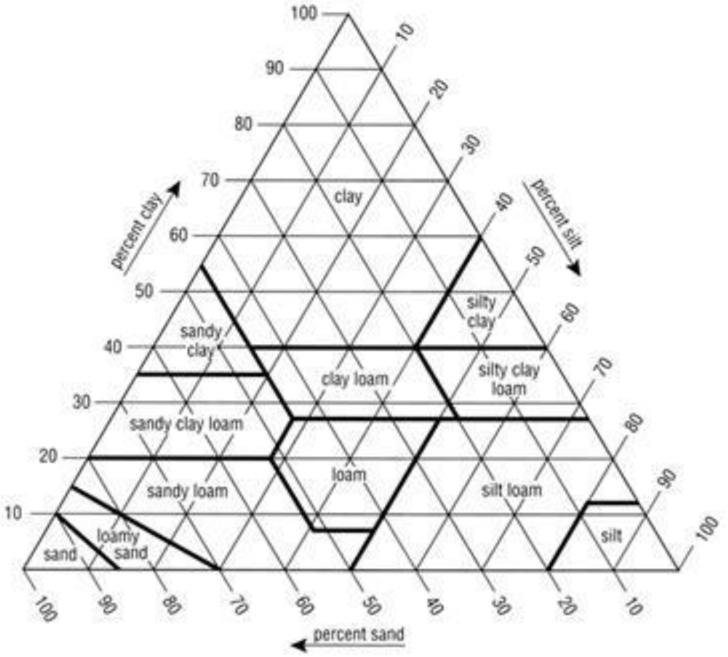
1. The particles must be large enough, so that Brownian movement will not influence their rate of fall.
2. There must be no slipping between the liquid and the particles.
3. The velocity of fall must not exceed a certain critical value.
4. The particles fall independently. This requires a suspension concentration of less than 5 per cent.
5. The particles must be rigid and smooth.

Limitations of Stoke's law:

1. It is necessary to maintain a constant temperature during analysis in the vessel filled with suspension. Otherwise, there will not be uniform settling of the particles and results will be wrong. This is not possible most of the times.
2. Since the density of clay particles decreases with the particle size, hence it may affect the accuracy of the stoke's law.

Textural Triangle:

- The horizontal lines mark percentages of clay (by mass). The lines angle upwards to the right mark percentages of silt. The lines angled upwards to the left mark percentages of sand.
- The percentage of sand, silt and clay are used to draw lines. When three lines so drawn intersect in a compartment then it is the textural class of the soil under study.



Range of soil separates in different textural classes:

Textural class	Ranges of soil separates (%)		
	Sand	**Silt**	**Clay**
Sand	85 - 100	0 - 15	0 - 10
Loamy sand	70 - 90	0 - 30	0 - 15
Sandy loam	40 - 80	0 - 50	0 - 20
Loam	23 - 52	28-50	7-27
Silt loam	0 -50	50-88	0-27
Silt	0-20	80-100	0-12
Sandy clay loam	45-80	0-28	20-35
Clay loam	20-45	15-53	27-40
Silty clay loam	0-20	40-73	27-40
Sandy clay	45-65	0-20	35-45
Silty clay	0-20	40-60	40-60
Clay	0-45	0-40	40-100

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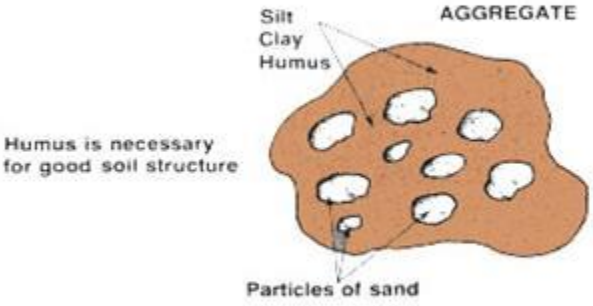
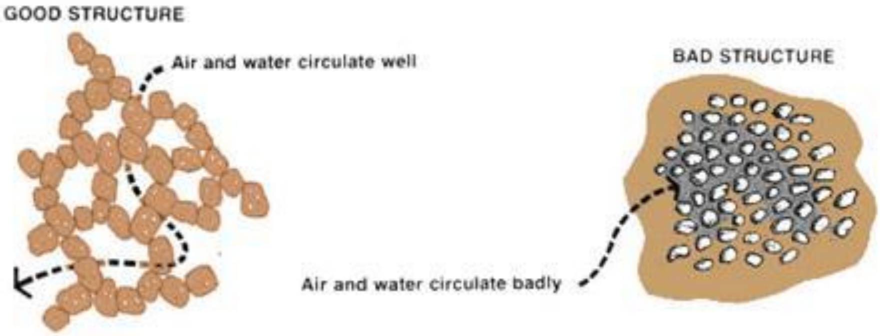
Lecture - 6 Soil Structure and Consistency

Introduction

- The term soil structure refers to the arrangement of primary and secondary particles in to a certain structural pattern.
- The primary particles are sand, silt and clay whereas the secondary particles are the cluster of the primary particles which are called aggregates and peds.



- Soil structure greatly influences the amount and nature of porosity and thus influences much soil physical process such as water retention and movement, porosity and aeration, transport of heat etc.
- Structure can be modified by cultivation and tillage operations while texture is an inherent property of soil and cannot be modified within short period of time.



- Soil structure is most usefully described in terms of

1. Type of aggregates (form),
2. Class (average size) and
3. Grade (degree of aggregation)

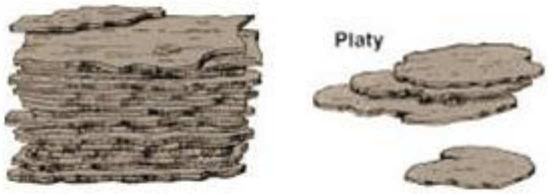
For naming a soil structure the sequence followed is grade, class and type.

Types of Soil Structure:

- Aggregation of soil particles can occur in different patterns, resulting in different soil structures.
- Based on the shape and arrangement of peds or aggregates, soil structure is classified into four principle type –plate like, prism like, block like and spheroidal structure.

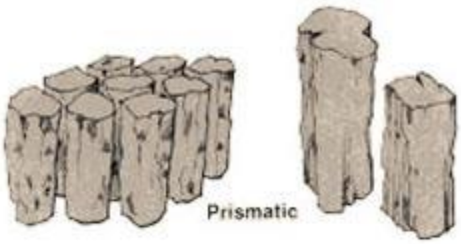
1. Plate like:

- In this type, the aggregates are arranged in relatively thin horizontal plates or leaflets. The horizontal axis or dimensions are larger than the vertical axis.Plates often greatly impair water circulation.
- It is commonly found in forest soils, in part of the A- horizon, and in claypan soils. Platy structure if often formed from parent materials and can also results due to compaction of heavy machinery on clayey soils. When the units/ layers are thick they are called " platy" and when they are thin then it is " laminar"



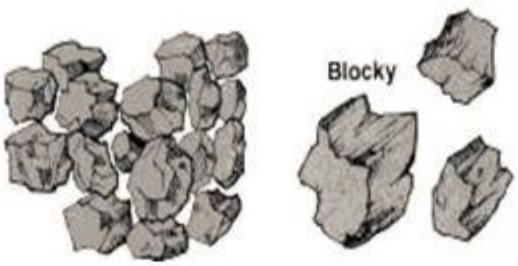
2. Prism-like:

- In prism like structure, the vertical axis is more developed than horizontal, giving a pillar like shape. They are commonly found in the subsurface horizons of semiarid and arid regions.
- The prisms having rounded tops are called columnar and mostly occur in subsoils of salt-affected soils. When the tops are flat or level the structure is termed as " prismatic".



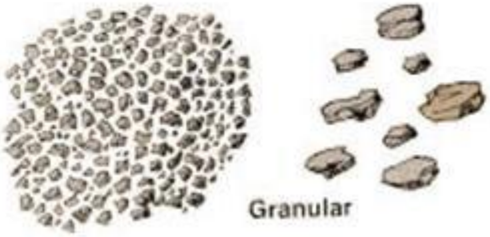
3. Block like:

- The structure is blocky when soil particles cling together in nearly square or angular blocks having more or less sharp edges.
- The peds have sizes varying from 1 cm to 10 cm. There are two types- angular blocky and sub-angular blocky. In the former, the edges are relatively sharp, whereas in later the edges are rounded.
- They are commonly found in the B-horizon where clay has accumulated.



4. Spheroidal:

- Here the individual particles of sand, silt and clay are grouped together in small, nearly spherical grains. These rounded complexes usually loosely arranged and readily separated.
- When the peds or aggregates are relatively non-porous, they are called granules and porous granules are termed as crumbs. They are commonly found in the A-horizon of the soil profile.



Class of soil structure:

- The class of structure describes the average size of individual aggregates. Usually, five distinct classes may be recognized in relation to the type of soil structure from which they come. They are: Very fine or very thin; Fine or thin; Medium; Coarse or thick; Very coarse or very thick.
- The terms thin and thick are used for platy types, while the terms fine and coarse are used for other structural types.

Grades of Soil Structure

- The grade of structure is the degree of aggregation, expressing the differential between cohesion within aggregates and adhesion between aggregates. In other words, it indicates the degree of distinctness of the individual peds.
- Grade of structure should be determined when the soil is neither unusually moist nor unusually dry.
- There are four major grades of structure rated from 0 to 3 as follows:
  - **Structure-less (0):** It represents the conditions in which there is no observable aggregation or no definite orderly arrangement of natural lines of weakness, such as:
    - **Massive structure (coherent):** where the entire soil horizon appears cemented in one great mass;
    - **Single-grain structure (non-coherent):** where the individual soil particles show no tendency to cling together such as pure sand.
  - **Weak structure (1):** These structures are poorly formed from indistinct aggregates. When removed from the profile, the soil material breaks down into a mixture of very few entire aggregates, many broken aggregates and much un-aggregated material.

  - **Moderate structure (2):** The structures are well formed from distinct aggregates, moderately durable and evident but not distinct in undisturbed soil. When removed from the profile, the soil material breaks down into a mixture of many distinct entire aggregates, some broken aggregates and little un-aggregated material;
  - **Strong structure (3):** These are well formed from distinct aggregates that are durable and quite evident in undisturbed soil. When removed from the profile, the soil material consists very largely of entire aggregates and includes few broken ones and little or no non-aggregated material.

Factors Influencing Genesis of Soil Structure:

- The genesis of soil structure refers to bonding of soil particles into structural units or aggregates. In aggregate formation, a number of primary particles such as sand, silt and clay are brought together by the cementing or binding effect of soil colloids.
- The cementing materials taking part in aggregate formation are colloidal clay, iron and aluminium hydroxides and decomposing organic matter.

1. Climate:

- Climate has considerable influence on the degree of aggregation as well as on the type of structure. In arid regions there is very little aggregation of primary particles.
- In semi arid regions, the degree of aggregation is greater.

2. Wetting and drying:

- It is a well known fact that alternate wetting and drying produce aggregation. When a dry soil is wetted, the soil colloids swell on absorbing water.
- On drying, shrinkage produces strains in the soil mass gives rise to cracks, which break it up into clods and granules of various sizes.
- The breaking of aggregates is due to unequal swelling and compression of the entrapped air.

3. Organic matter:

- Organic matter improves the structure of a sandy soil as well as of a clay soil. In case of a sandy soil, the decomposing organic matter and the associated microorganism cement the sand particles together to form aggregates.

4. Tillage:

- Cultivation implements break down the large clods into smaller fragments and aggregates.
- For obtaining good granular and crumby structure, optimum moisture content in the soil is necessary. If the moisture content is too high, it will form large clods on drying.
- If it is too low, some of the existing aggregates will be broken down.

5. Plants, Roots and Residues:

- Excretion of gelatinous organic compounds and exudates from roots serve as binding agents. Root hairs make soil particles to cling together. In grassland soils more granulation is observed. Pressure exerted by the roots hold the particles together.

- Plant tops and residues – shade the soil – prevent it from extreme and sudden temperature and moisture changes and also from rain drop impedance. Plant residues – serve as a food to microbes which are the prime aggregate builders.

6. Microbes:

- Growth of micro-organisms is responsible for binding together of soil particles and thus increases the soil aggregation.
- Algae, fungi and actinomycetes keep the soil particles together by the products of decomposition. Mycelial growth of fungi bind the particles together.

7. Animals:

- Among the soil fauna small animals like earthworms, moles and insects etc., that burrow in the soil are the chief agents that take part in the aggregation of finer particles.

Soil Consistency

- Soil consistency is a term used to describe the resistance of soil to mechanical stress or manipulation at various moisture contents.
- According to Russell and Russell (1950), "Soil consistency designates the manifestations of the physical forces of cohesion and adhesion acting within the soil at various moisture contents including the behaviour towards gravity, pressure, thrust and pull, tendency to adhere to foreign bodies and the sensations which are evidenced (by the fingers of the observer) as feel".

Soil consistence is described at three moisture levels namely 'wet', 'moist' and 'dry'.

1. Wet Soils:

- In wet soils the consistency is denoted by terms stickiness and plasticity.
- Stickiness is grouped into four categories namely i) non sticky, ii) slightly sticky, iii) sticky and iv) very sticky.
- Plasticity of a soil is its capacity to be moulded (to change its shape depending on stress) and to retain the shape even when the stress is removed.
- Soils containing more than 15% clay exhibit plasticity – pliability and the capacity of being molded. There are four degrees in plasticity namely i) non plastic, ii) slightly plastic, iii) plastic and iv) very plastic.

2. Moist Soil:

- Moist soil with least coherence adheres very strongly and resists crushing between the thumb and forefinger.
- The different categories are i. Loose-non coherent, ii. Very friable - coherent, but very easily crushed, iii. Friable - easily crushed, iv. Firm - crushable with moderate pressure, v. Very firm - crushable only under strong pressure and vi. Extremely firm - completely resistant to crushing. (type and amount of clay and humus influence this consistency)

3. Dry Soil:

- In dry soil, the degree of resistance is related to the attraction of particles for each other.
- The different categories are
  - Loose - non coherent
  - Soft - breaks with slight pressure and becomes powder
  - Slightly hard - break under moderate pressure
  - Hard - breaks with difficulty with pressure
  - Very hard - very resistant to pressure
  - Extremely hard - extreme resistance and cannot be broken.

Atterberg's Limits of Soil Consistency

- Atterberg's limits are used to measure the physical condition of soil at different water contents. These limits can be seen as the indices of workability of soil at various water contents. These depend on texture, organic matter content and amount of clay in the soil.
- It is generally described at three soil moisture levels such as dry, moist and wet and terms used to describe soil consistency are hard or harsh for dry soil, soft or friable for moist soil and plastic and sticky for wet soil.
- Friable consistency is the optimum condition for tillage and other agricultural operations and plastic consistency is optimum condition for puddling.
- Soils are rated for consistency as a part of describing a soil profile and for estimating suitability for traffic and tillage.
- Knowledge of plastic limit and plasticity index is required to characterize the shear strength, in terms of the normal stress applied and the water content of the soil.
- From a practical point of view, the sticky point provides an estimate of the maximum water content at which normal soils will scour during tillage.
- Based on water content, limits of soil consistency are briefly described below:
  - **Flocculation limit:** Moisture content at which soil suspension is transformed from liquid state to a semi-liquid state with appreciable increase in viscosity.
  - **Liquid limit (upper plastic limit):** Moisture content at which soil-water system changes from viscous fluid to a plastic body. Soil is near saturation, it behaves like softened butter.
  - **Lower Plastic limit:** Water content at which soil changes from a plastic to semi-rigid and friable state. Between upper and lower plastic limits, soil can be moulded into various shapes without breaking.
  - **Shrinkage limit:** Moisture content at which soil changes from semi-rigid to a rigid solid with no change in specific volume as drying proceeds further.
  - **Sticky limit:** Minimum moisture content at which soil paste will adhere to a steel spatula drawn over its surface.
  - **Plasticity index:** Difference in moisture contents between liquid limit and lower plastic limit. It indicates 'clayeyness' or potential plasticity of soil. It depends upon clay content and nature of clay.
  - **Friable (soft) consistency:** The water content in this range permits easier crumbling of the soil. Friable consistency presents the optimum conditions for tillage and preparation of seed-bed. This is reached at moisture contents slightly less than lower plastic limit.
  - **Harsh consistency:** Upon dehydration soil becomes hard due to clay cementation and the consistency is called harsh. It requires more power to plough soil at this water content and soil becomes cloddy when ploughed.

Lecture - 7 Densities of Soil, Porosity and Soil Color

Definition

- Density of any substance is its weight per unit volume. It is expressed in gram per cubic centimeter (g cm-3) or mega gram per cubic meter (Mg m-3).
- Two density measurements- particle density (absolute specific gravity) and bulk density (apparent density) are common for soils.

$$\text{Density } (\rho) = \frac{\text{Mass (M)}}{\text{Volume (V)}}$$

Particle Density or absolute specific gravity (Ps)

- Particle density of soil is a measure of the mass per unit volume of the soil solids only. It is expressed in terms of Mg m-3.
- Texture and structure do not affect particle density. However, organic matter, which is a soil solid, readily influences particle density. Organic matter weighs much less per unit volume than soil minerals. Soils high in organic matter have lower particle densities than soils similar in texture that are low in organic matter. Particle density varies with the type of soil minerals present as well as the amount of organic matter.
- The particle density of most mineral soils is in the range of 2.60 to 2.75 Mg m-3. When unknown, particle density of mineral soils is assumed to be 2.65 Mg m-3. Generally quartz, feldspars, and colloidal silicates dominate the mineral fraction of soils. The particle density of these minerals averages about 2.65 Mg m-3.
- When large amounts of heavy minerals, such as hornblende or magnetite, are present, the soil particle density is greater than 2.65 Mg m-3. Soils formed in volcanic parent materials, such as pumice or ash, generally have particle densities less than 2.65 Mg m-3.

Bulk Density (p_b)

- The mass of a unit volume of dry soil (both solids and pores) is known as bulk density. It is also expressed in terms of Mg m-3.
- Soils that are loose, porous, or well-aggregated will have lower bulk densities than soils that are compacted or non-aggregated. This is because pore space weighs less than solid space (soil particles). Sandy soils have less total pore than clayey soils, so generally they have higher bulk densities. Bulk densities of sandy soils vary between 1.2 to 1.8 Mg m-3. Fine-textured soils, such as clays, silty clays, or clay loams, have bulk densities between 1.0 and 1.6 Mg m-3.

Factors Affecting Bulk Density

1. Soil texture and structure:

- Fine textured soils like silt loam and clay loam have lower bulk density than sandy soils. This is mainly because of more granulation/ aggregation. As aggregation and clay content increase, bulk density decreases. Tillage operations do not affect texture, but they do alter structure (aggregation). Primary tillage operations, such as ploughing, generally decreases bulk density and increases pore space, which is beneficial.
- Secondary tillage (cultivation) generally increases bulk density and decreases porosity.

2. Pore space:

- Since the bulk density is related to the combined volume of solids and pore spaces, hence the soils with higher pore space will have lower bulk densities. Thus any factor that influences pore space will affect the bulk density.

3. Compaction:

- It leads to increase in bulk density. The movement of machinery over the field forces solid particles into spaces once occupied by water or air, resulting in less pore space and increased bulk density.
- The fine textured soils have low bulk densities when not compacted but very high when compacted in comparison to sandy soils. In fact sandy soils are less affected by compaction.

4. Organic matter:

- Since organic matter is lighter than an equal volume of solid soil and is more porous, hence a soil with higher organic matter will have lower bulk density.
- Manure additions in large amounts tend to lower the surface bulk density of mineral soils because of the addition of low bulk density material and the consequent promotion of soil aggregation.
- Usually surface soils are rich in organic matter than sub-surface soil and as a result lower bulk density is recorded in surface soil.

5. Crop and soil management:

- The crop and soil management also influences the bulk density. The addition of crop residues and FYM always lower the bulk density of surface soil. This is just similar to the effect of organic matter as discussed above.
- However, the intensive cultivation increases the bulk density because more cultural operations enhance the compaction of the soil. Cropped soils generally have higher bulk densities than uncropped soils.

Soil Porosity

- The pore space of a soil is defined as the portion of the soil volume occupied by air and water.
- It refers to the percentage of soil volume occupied by pore spaces.
- Pore-spaces directly control the amount of water and air in the soil and indirectly influence the plant growth and crop production.
- Size of individual pores, rather than total pore space in a soil, is more significant in its plant growth relationship.
- In general there are broadly two types of pores in soil.

- **Macro pores:**
  - The diameter of these pores is larger than 0.06 mm. Macro-pores allow air and water movement readily. Sands and sandy soils have a large number of macro-pores.

- **Micro or Capillary pores:**
  - The diameter of these pores is less than 0.06 mm. The movement of air and water is restricted to some extent in micro or capillary pores. Clays and clayey soils have a

greater number of micro or capillary pores. It has got more importance in the plant growth relationship.

- For optimum growth of the plant, the existence of approximately equal amount of macro and micro-pores which influence aeration, permeability, drainage and water retention favorably is essential.

Factors Affecting Porosity of Soil

Soil structure:

- Particle arrangement determines the total pore space in the soil. When the sphere like particles are arranged in columnar form (i.e. one after another on the surface forming column like shape) it gives the most open packing system resulting very low amount of pore spaces.
- When such particles are arranged in the pyramidal form it gives the closest packing system resulting high amount of pore spaces. Thus, a soil having granular and crumb structure contains more pore spaces than that of prismatic and platy soil structure.
- The well aggregated soil structure has greater pore space as compared to structure-less or single grain soil.

Soil texture:

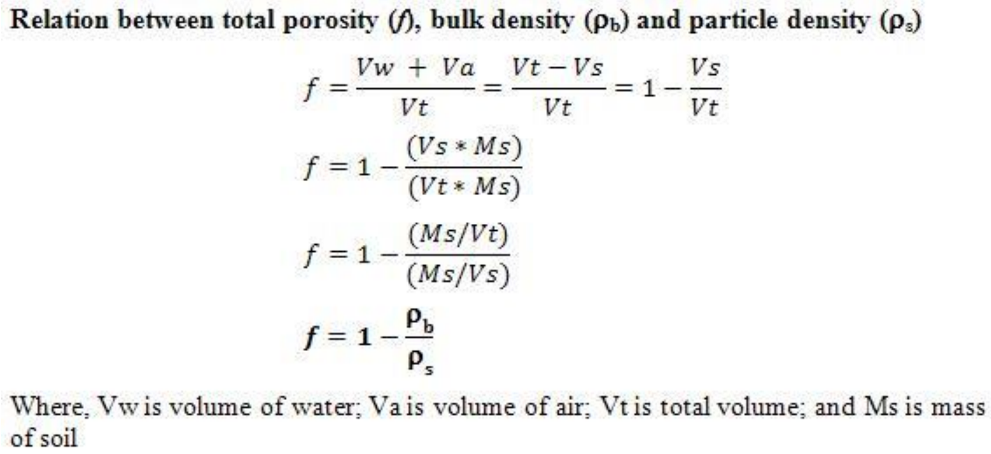
- Sandy soils have lesser total pore space and fine textured clay and clay loam soils have higher total pore space.

Organic matter:

- Addition of organic matter increases the volume of pore space by lowering the bulk density. It makes the soil more porous.

Compaction:

- If the soil is made more compact by movement of machinery and tillage implements and thus pore space is reduced.
- Intensive crop cultivation tends to lower the porosity of soil as compared to fallow soils.



Relation between total porosity (f), bulk density (ρ_b) and particle density (ρ_s)

$$f = \frac{Vw + Va}{Vt} = \frac{Vt - Vs}{Vt} = 1 - \frac{Vs}{Vt}$$

$$f = 1 - \frac{(Vs * Ms)}{(Vt * Ms)}$$

$$f = 1 - \frac{(Ms/Vt)}{(Ms/Vs)}$$

$$f = 1 - \frac{\rho_b}{\rho_s}$$

Where, Vw is volume of water; Va is volume of air; Vt is total volume; and Ms is mass of soil

Example: Find out the per cent pre space of a silt loam soil having bulk density (p_b) of 1.30 and particle density (p_s) of 2.65.

Solution:

$$\begin{aligned}\text{\% pore space} &= \{(1 - \rho_b/\rho_s)\} * 100 \\ &= \{1 - (1.30/2.65)\} * 100 \\ &= \{1 - 0.4906\} * 100 \\ &= 0.5094 * 100 \\ &= 50.94\ \%\end{aligned}$$

Soil Colour

- The colour of the soil is a result of the light reflected from the soil. Soil colour is an easily observable soil property and gives an immediate indication of the soil condition.
- Soil colour is inherited from its parent material and that is referred to as litho-chromic, e.g. red soils developed from red sandstone.
- Besides soil colour also develops during soil formation through different soil forming processes and that is referred to as acquired or pedo-chromic colour e.g. red soils developed from granite gneiss or schist.

Significance

- Soil colour gives us a clue regarding the drainage condition of the soil, amount of organic matter present and type of parent material from which soil has developed.
- In general, the dark coloured soils are considered fertile and rich in organic matter. The mottlings, when present in lower horizons of a profile indicates poor drainage conditions. Iron compounds, in various states of oxidation and reduction are major colouring agents of subsoil horizons.
- The colour of soil containing iron oxides varies from red and rust brown to yellow depending on the degree of hydration.
- Reduced iron normally displays a green-blue tinge. Soils in anaerobic conditions, such as those in poorly drained depressions, will normally have dull, grey B-horizons. Alternatively, aerobic soils have bright reddish-brownish colours.

Factors affecting soil colour

Various factors influencing the soil colour are as follows:

Parent material / Composition:

- Soils containing higher amount of iron compounds generally impart red, brown and yellow tinge colour. The red colour of the soils is due to unhydrated iron oxide. It indicates that the soils are old and more weathered.
- The yellow colour in the soil is due to iron oxide (limonite) and more moist conditions. Due to presence of large amounts of silica and lime or both in the soil the colour of the soil appears like white or light coloured.
- In case of black cotton soils, the black colour is due to titaniferrous magnetite. Such soils may have less organic matter but still they are black in colour. Thus the parent material has direct bearing on the colour of the soil formed from it.

Soil moisture:

- A well drained soil will have normal colours as compared to a poorly drained soil. The poorly drained soil will show the sign of graying due to anaerobic or reduced conditions.
- When soils are waterlogged for a longer period, the permanent reduced condition will develop. The presence of ferrous compounds resulting from the reducing condition in waterlogged soils impart bluish and greenish colour.
- During monsoon period due to heavy rain the reduction of soil occurs and during dry period the oxidation of soil also takes place. Due to this alternate oxidation and reduction (due to alternate wetting and drying), some coloured patches develop. These patches are known as mottles. This mottled colour is due to residual products of this process especially iron and manganese compounds.
- The background soil surface is known as matrix. The matrix and mottle colour are recorded separately.

Organic matter:

- Soils containing high amount of organic matter show the colour variation from black to dark brown. In forest soils and grassland soils, more organic matter is added to the soil every year. This makes the soil darker in colour.
- In hot and dry regions the organic matter is readily decomposed and lost. Hence, these soils are lighter in colour. Thus, organic matter is important clolour imparting constituent in soils.

Determination of soil colour:

- The soil colours are determined by using Munsell colour chart. In this chart, different colour chips are systematically arranged by three variables namely Hue, Value and Chroma.
    - **Hue** - it indicates the dominant spectral colour (red, yellow, blue and green).
    - **Value** - it indicates lightness or darkness of a colour (the amount of reflected light).
    - **Chroma** - it represents the purity of the colour (strength of the colour).
- The hue is written on the top right hand corner of the chart.
- The values are written on the left hand side and the colour becomes lighter as we move upward.
- The chroma is written at the bottom and increases towards right hand side.
- The combination of these variables is used to describe the colour of a soil as “Munsell notation”. The Munsell colour notations are systematic, numerical with letter designations of each of these three variables (Hue, value and chroma).
- English names of the colours are written on the left page. They have more uniformity for internation use.
- For example, the numerical notation 2.5 YR 5/6 suggests a hue of 2.5 YR, value of 5 and chroma of 6. The equivalent or parallel soil colour name for this Munsell notation is 'red'.

Munsell color chart

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Lecture - 8 Soil Air and Temperature

Introduction

- Soil atmosphere is the gaseous phase of the soil. Soil air occupies the pores which are not occupied by the liquid. Soil air is a continuation of the atmospheric air. It is in constant motion from the soil pores into the atmosphere and from the atmosphere into the pore space.
- The exchange of gases between the soil pore spaces and the atmospheric air is known as soil aeration. Soil aeration is essential for the respiration and survival of soil organisms and plant roots. This process controls the deficiency of oxygen consumed during respiration of plant roots and soil micro-organisms and prevents toxicity of carbon dioxide evolved during respiration in the soil air.

Composition of Soil Air

- Soil air contains gases like nitrogen, oxygen, carbon dioxide, water vapour and others. The composition of soil air is different from atmospheric air. Soil air contains more carbon dioxide and less oxygen than atmospheric air. It also contains more water vapour than atmospheric air. The nitrogen content of soil air is almost equal to atmospheric air.

Component	Per cent by volume	
	Soil air	**Atmospheric air**
Nitrogen	79.10	79.00
Oxygen	20.60	20.79
Carbon dioxide	0.25	0.03

Air Capacity:

- This term is used to describe aeration status of soil.The air capacity refers to the volume of pore space filled with air when the soil under a tension of 50 milli bar. The aeration capacity can be characterized in three ways as given below.

1. Content of oxygen and other gases (as discussed above).
2. Oxygen Diffusion Rate (ODR):
    - It is the best and most reliable measurement of aeration capacity. It determines the rate at which O_2 in soil air is replenished. ODR decreases with soil depth. ODR should be above 40×10^{-8} g/cm^2/minute for good growth of most of the crops. However, the root growth is drastically reduced when the ODR decreases to about 20×10^{-8} g/cm^2/minute
3. Oxidation - Reduction potential (Eh) of soil:

    - It is an important chemical characteristic of soil related to soil aeration. It indicates the oxidation and reduction states of soil system.
    - In oxidized soil, ferric (Fe^{3+}),manganic (Mn^{4+}), nitrate (NO_3^-) and sulphate (SO_4^{2-}) ions dominate.

- In reduced soil, ferrous (Fe^{2+}), manganous (Mn^{2+}), ammonium (NH^{4+}) and sulphides (S^{2-}) are present.
- The redox potential is measured using platinum electrodes and expressed in millivolts. A positive Eh value indicate oxidized state and a negative Eh value indicate reduced state.

Factors Affecting Soil Aeration

1. Amount of air space:

- The top soil contains much more pore spaces than the sub-soil, thus the opportunity for gaseous exchange is more in the top soil than in sub-soil. Hence the oxygen content of the top soil is greater that the sub-soil.
- The soil properties such as soil texture, bulk density and aggregation affect the amount of pore space and hence the soil aeration.

2. Soil organic matter:

- When organic matter is added to the soil, it is readily decomposed by the micro-organisms to liberate the CO_2 in soil air. Thus the concentration of both O_2 and CO_2 are affected by microbial decomposition of the organic residues.
- Besides, the respiration of higher plants and the micro-organisms around the roots is also a significant process affecting the soil aeration.

3. Soil moisture:

- The macro-pores are filled up with water immediately after heavy rain or irrigation and level of oxygen content falls to zero.
- When the soil is artificially drained again, the macro-pores are filled up with air and the oxygen content of the soil increases.

4. Seasonal differences:

- There is a considerable seasonal variation in the composition of soil air.
- In the spring time in temperate-humid regions the soils are wet and cold and the gaseous exchange is poor.
- In summer months, when the soils are dry, the gaseous exchange will increase. This will result in relatively high content of O_2 and low CO_2.

Renewal of soil air:

The exchange of gases between the soil air and the atmosphere takes place mainly by the following two mechanisms as given below:

1. Mass flow:

- The mass flow occurs due to total pressure gradient of gas. The pressure gradient causes movement of entire mass of air from a zone of high pressure to that of low pressure. Such a flow of air occurs within the soil or from atmospheric air to soil air or vice-versa.
- When the soil temperature is higher than the atmospheric temperature during mid-day then the soil gases will expand and move out of the pore space into the atmosphere.
- When the soil is cooler than the atmosphere during night, then the atmospheric gases enter the soil. When the atmospheric pressure is high, the atmospheric gases will enter in to the soil.

2. Diffusion:

- The gaseous interchange between the soil and atmosphere takes place by diffusion.
- It is the process by which each gas tends to move in the space occupied by another as determined by the partial pressure of the gas.
- The partial pressure of O_2 is higher in the atmospheres than in soil pore space and the partial pressure of CO_2 is higher in the soil pore space than the atmosphere. However, total pressure both in the soil and the atmosphere may be the same. Thus O_2 will move into the soil and the CO_2 will move out of the soil.

The renewal of gases by mass flow is less important than the diffusion in determining the total exchange that occurs between soil and the atmosphere.

Soil Temperature

- Soil temperature greatly affects the physical, chemical and biological processes which occur in the soil. Since, with every 10oC rise in temerature, rate of chemical reaction get almost doubled
- Hence, it affects plant growth directly and also indirectly by influencing moisture, aeration, structure, microbial and enzyme activities, rate of organic matter decomposition, nutrient availability and other soil chemical reactions.

Sources of heat to soil

- Solar radiation (sun rays) is the primary source of energy to warm the soil.
- The dust particles, clouds and other suspended particles intercept the sun rays. They absorb, scatter or reflect the solar energy. Only a small part of the total radiation actually reaches earth.
- Thermal energy is transmitted in the form of thermal infrared radiation from the sun across the space and through the atmosphere.
- Other sources of heat for soil are processes like microbial decomposition of organic matter and respiration by soil organisms including plants.

Factors influencing soil temperature:

There are three main factors affecting soil temperature as described below:

1. Solar radiation:

- Amount of solar energy received by soil depends on the constituents of the atmosphere. Clouds, water vapour and dust particles reduce the solar energy reaching soil surface.
- Some energy is used for evaporation and transpiration, and some reflected back. Only 10 per cent energy is used to warm the soil.

2. Aspect and slope:

- The land in three situations viz. southern aspect, level and northern aspect receive different amounts of solar energy, and the soil will warm accordingly.
- Solar radiation reaching perpendicular to the soil surface will heat it more as these concentrate on a smaller area than when the same amount of radiation reach a slope where they get spread on a larger area. Thus, equatorial zones are warmer than temperate and arctic regions.
- In Northern hemisphere, south facing slope is warmer than the north facing slope.

3. Soil factors:

- These factors are soil colour, soil moisture, mulching, vegetative cover and organic matter content. These affect the warming of soils through solar radiation.

Measurement of soil temperature:

- The soil temperatures are less variable. They are by and large similar to the temperature of the atmosphere. However, the temperature in the sub-soil lags behind that of the surface soil. That is why the sub-soil temperature is higher in winters and lower in summers as compared to surface soil temperature.
- The soil temperature is measured using contact or non-contact thermometric methods.
- In most of the commonly used contact methods, changes in temperature are recorded using mercury thermometers and thermocouple and thermister based devices.
- The non-contact type methods include optical pyrometers, total intensity radiometers and infra red thermometers.
- The International Meteorological Organization recommends standard depths viz. 10, 20, 50 and 100 cm, to measure soil temperatures.

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Lecture - 9 Soil Water

Introduction

- Water present in soil pores is called soil water.
- It is an important component of the soil which influences soil organisms and plant growth.
- It serves as a solvent and carrier of nutrients for plant growth.
- It regulates soil temperature and helps in chemical and biological activities of soil.
- It is essential for soil forming processes and weathering.

Forms of soil water:

1. Gravitational water (free water):

- This form of water is loosely held in soil (in macro pores) and move downwards freely under the influence of gravity.
- Water in excess of the field capacity is termed gravitational water.
- The drainage or deep percolation loss of water results from downward movement of this gravity water.
- It has a suction of less than 1/3 atmosphere.
- The plants can not absorb it as it drains out of root zone in short period of time.

2. Capillary water:

- Capillary water is held in the capillary pores (micro pores) with a suction ranging from 1/3 and 31 atmospheres. Capillary water is retained on the soil particles by surface forces.
- It is held so strongly that gravity cannot remove it from the soil particles.
- The availability of capillary water to plant roots depends on pore diameter which controls the pressure of water. The narrower the capillary pore, lesser is the availability.

3. Hygroscopic water:

- This form of soil water is held with a high suction ranging from 31 to 10000 atmospheres. It is held tightly on the surface of soil colloidal particles.
- Generally, it includes first two molecular layers of water on soil particles. Plants can not absorb this form of water.

Soil moisture constants

- These are of practical importance for irrigation and drainage management. These are also used to compare water retention capacity of different soils.

1. Field capacity:

- If a soil is saturated, gravity water starts moving downwards. When all the gravitational water is drained away, and then the wet soil is almost uniformly moist.

- The amount of water held by the soil at this stage is known as the field capacity of that soil. It is the capacity of the soil to retain water against the downward pull of the force of gravity.
- At this stage only micro-pores or capillary pores are filled with water and plants absorb water for their use.
- At field capacity water is held with a suction of 1/3 atmosphere.

2. Wilting coefficient:

- As the soil water content decreases, a point is reached when the water is so firmly held by the soil particles that plant roots are unable to extract water at a rate sufficient to meet the transpiration needs.
- The plant begins to wilt. At this stage even if the plant is kept in a saturated atmosphere it does not regain its turgidity and wilts unless water is applied to the soil.
- The stage at which this occurs is termed the ***wilting point*** and the percentage amount of water held by the soil at this stage is known as the ***wilting coefficient***.
- Water at wilting coefficient is held with a force of 15 atmospheres (pF=4.2).

3. Hygroscopic coefficient: Þ

- The hygroscopic coefficient is the maximum amount of hygroscopic water absorbed by 100 g of dry soil under standard conditions of humidity (50% relative humidity) and temperature (15°C).
- This tension is equal to a force of 31 atmospheres (pF=4.5).
- Water at this tension is not available to plant but may be available to certain bacteria.

Available water capacity:

- The available water is the difference in the amount of water at field capacity (- 0.3 bar) and the amount of water at the permanent wilting point (- 15 bars).

Maximum water holding capacity:

- It is the amount of moisture in a soil when all of its pore spaces both micro and macro are completely filled with water.

Energy concept of soil water

- The retention and movement of water in soils, its uptake and translocation in plants and its loss to the atmosphere are all energy related phenomenon.
- The more strongly water is held in the soil, the greater is the heat (energy) required. In other words, if water is to be removed from a moist soil, work has to be done against adsorptive forces.
- Conversely, when water is adsorbed by the soil, a negative amount of work is done. The movement is from a zone where the free energy of water is high (standing water table) to one where the free energy is low (a dry soil). This is called energy concept of soil water.
- The difference between the energy states of soil water and pure free water is known as soil water potential.

Forces influencing free energy of water:

1. Gravitational force:

- This acts on soil water, the attraction is towards the earth's center, which tends to pull the water down ward. This force is always positive.

2. Matric force:

- It is the attraction of the soil solids for water (adsorption) which markedly reduces the free energy (movement) of the adsorbed water molecules.

3. Osmotic force:

- It is the attraction of ions and other solutes for water which reduces the free energy of soil solution.
- Matric and Osmotic potentials are negative and reduce the free energy level of the soil water. These negative potentials are referred as suction or tension. Total soil water potential (ψ_t) is the sum of gravitational potential (ψ_g), matric potential (ψ_m) and the Osmotic potential or solute potential (ψ_o).

o $\psi_t = \psi_g + \psi_m + \psi_o$

- Soil water potential is expressed in terms of atmospheres or bars. Atmosphere is the average air pressure at sea level.

Units: Soil water potential is expressed in different units i.e. pF, height in cm of unit water column whose weight is just equals to the potential under consideration, bar, standard atmospheric pressure at sea level which is equal to 14.7 lb/inch2, 760 mm of Hg, or 1020 cm of water. Now a days, megapascal (MPa) which is numerically equal to 10 bars is also used.

10cm height of water column=1 pF= - 0.01 bar = 0.01 atm = -0.001MPa

Soil Water Movement

Soil Water Movement

- Water is highly dynamic component in soil system. It moves in all the three phases viz. solid, liquid and vapour.
- In a flooded or saturated soil, soil water moves in liquid phase, while in a partially dry or unsaturated soil, it moves in both liquid and vapour phases.
- Movement in solid phase, commonly occurring in the frozen soil, takes place close to clay surface.
- Movement of water within the soil influences water supply to roots and also contributes to underground water table.
- Water movement in the soil occurs in three distinct ways namely saturated flow, unsaturated flow and vapour movement.

Saturated flow:

- This flow occurs when the soil pores are completely filled with water. Water in liquid form flows through water filled macro-pores under the influence of gravity.
- It begins with infiltration, which is water movement into soil when rain or irrigation water is on the soil surface. When the soil profile is wetted, the movement of more water flowing through the wetted soil is termed percolation.

Unsaturated flow:

- In this type of flow, water moves in thin films surrounding soil particles under the influence of surface tension (matric forces) that are much stronger than gravity.
- Even though the driving force is usually greater than for saturated flow, the resistance to flow is enormous. Water will flow toward a lower (more negative) potential regardless of direction.

Vapour movement: In this water vapour moves through air filled pore spaces under the influence of vapour pressure gradient.

Comparison of three types of water movement in soil:

S.No.	Particulars	Saturated flow	Unsaturated flow	Vapour movement
1	Major driving force	Gravitational	Matric potential difference	Vapour pressure gradient
2	Water form	Liquid	Liquid	Vapours
3	Major direction of flow	Downward	All directions	All directions
4	Pore space used	All pores	Micropores	All empty pores
5	Rate of flow	Fast (1-100 cm/day)	Slow (< 1 cm/day)	-

Measurement of Soil Moisture

The different methods for soil moisture measurements are discussed below:

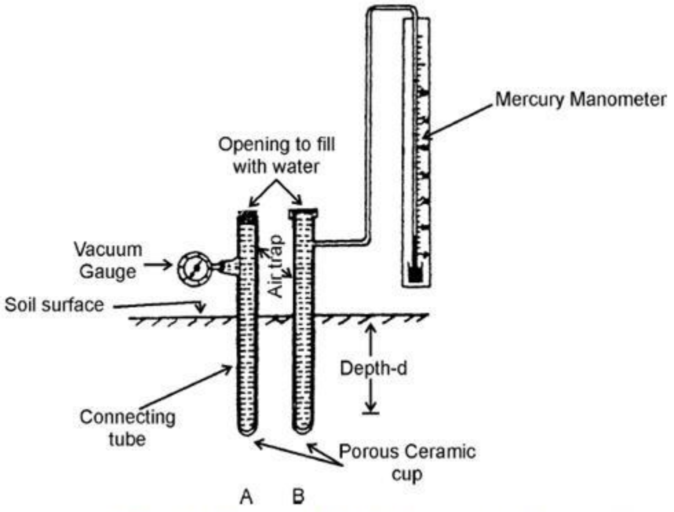
1. Gravimetric method:

- This is the simplest and most widely used method for determining the soil moisture.
- This consists of obtaining a moist sample, drying it in an oven at 105°C until it losses no more weight and then determining the percentage of moisture.
- The gravimetric method is time consuming and involves laborious processes of sampling, weighing and drying in laboratory.

2. Tensiometric method:

- For measuring the tension of water in soil (soil suction), the most widely used instrument is the ‘tensiometer’.
- The tensiometer essentially consists of a porous ceramic cup, connected through a tube to a manometer with all parts filled with water. The cup is positioned in the soil, where information, regarding soil water is desired. Indexing soil suction value for evaluating soil-water relation recognizes that the soil water is a dynamic system.
- Water moves into and out of soil because of energy differences within the system.
- The tensiometer may not respond to the changes in the soil suction as fast as they occur. Though, its readings, at different locations in a soil, may be interpreted in terms of direction and intensity of water flux.

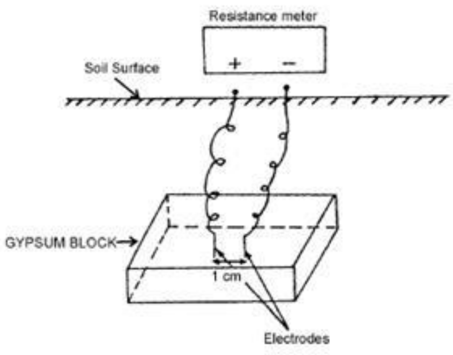
- Tensiometer is used to obtain energy status of water in soil directly and water content indirectly assuming that the former is in equilibrium with soil water.
- As the water content of the soil surrounding the water-filled porous cup decreases, the energy level of soil water decreases relative to that of the water in the tensiometer cup and water moves out of the tensiometer through the pores into the soil. The pressure of water in the tensiometer is reduced.
- If the soil surrounding the porous cup receives additional water, the soil water pressure is increased and the water flows through the walls of the porous cup into the tensiometer.
- The tension or suction reading on the tensiometer is related to soil water content with the help of a calibration curve called soil moisture characteristic curve



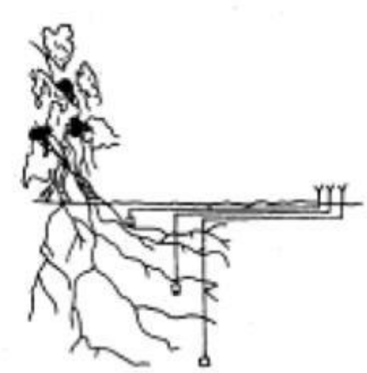
Schematic diagram of the tensiometer (A) Vacuum gauge type (B) Manometer type

3. Electric resistance block method:

- Bouyoucos and Mick (1940) proposed that electrodes be placed in a block of porous material which in turn is placed in a soil.
- The water content in the block changes with corresponding changes in water content in the soil, and changes within the block are reflected by changes in resistance between the electrodes.
- Plaster of Paris or gypsum, glass fibre, ceramic and nylon cloth can be used as the porous materials of electrical resistance units. These are used for indirect measurement of soil moisture in situ.



A



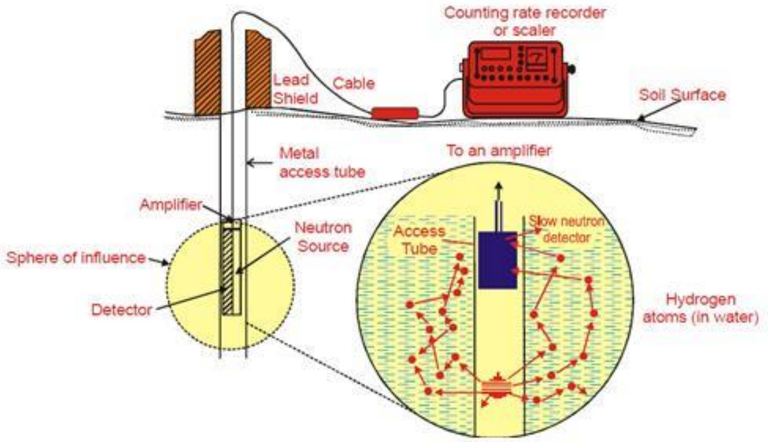
B

A. Gypsum block for measuring resistance; B. Blocks installed at different depths

- It works on the principle of conductance of electricity. Flow of electric current between electrodes embedded in a porous block kept in intimate contact with the soil is a function of soil water content.
- The resistance to flow of electric current in the block is inversely proportional to the moisture content. Thus when block is wet, conductivity is high and resistance is low and vice-versa.
- The actual resistance reading of a block varies with the type of electrodes, their length and distance between them, matrix material, its density and temperature. The resistance blocks read low resistance at field capacity and high resistance at wilting point.

4. Neutron scattering method:

- The most rapid and indirect method for measuring soil water content is probably that of neutron scattering. In this method number of hydrogen nuclei present per unit volume of soil is measured.

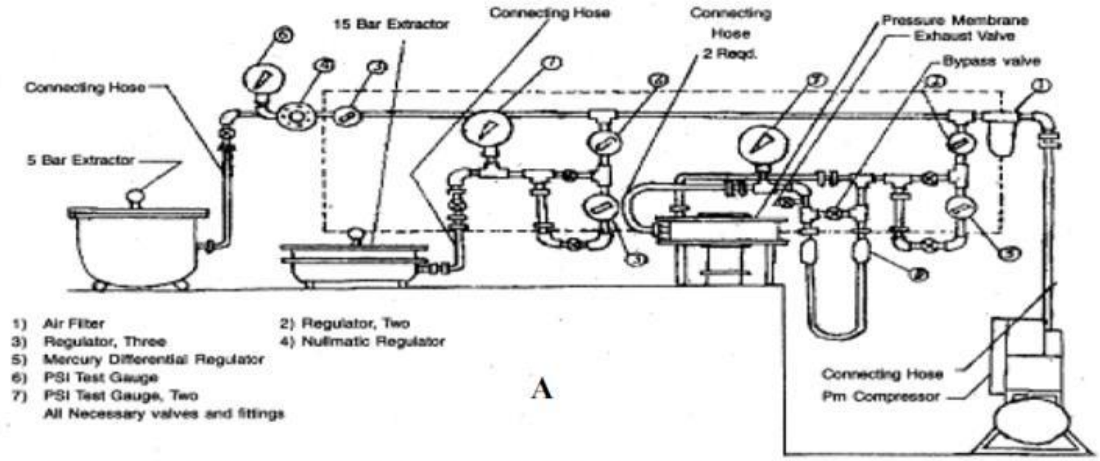


Neutron moisture meter in use for measuring soil water content

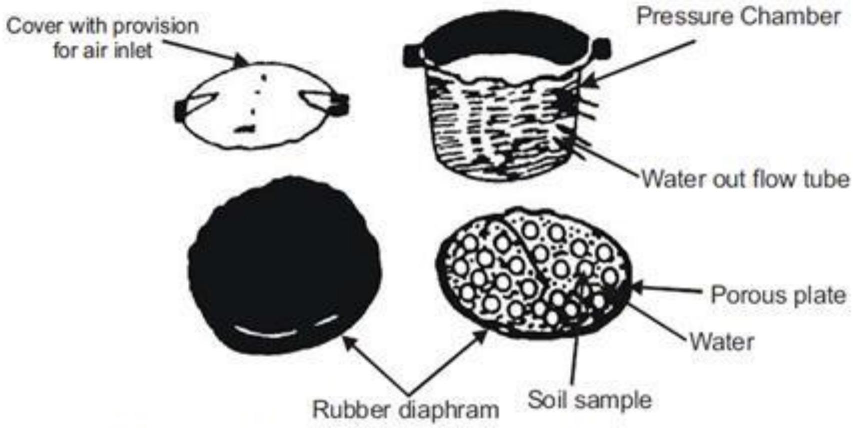
- Fast moving neutrons emitted from a radioactive source (usually Radium- Beryllium or Americium-Beryllium) when collide with particles having mass nearly equal to their own, like hydrogen atom in the soil, release their energy and are thermalised or slowed down.
- The slowed down neutrons are detected by a detector and recorded on a scaler. Commonly used detector of slowed down neutron is a tube containing BF3 gas.
- More the neutrons are slowed down, higher will be the water content of the soil. The zone of influence is generally 15-20 cm around the detector.

5. Pressure plate apparatus:

- Pressure plates are used to apply matric potentials from -10 to -1500 kPa (-0.1 to -15 bar). An external source of compressed air is used to push water out of an initially saturated soil sample kept in pressure plate/membrane apparatus.
- The pressure applied within the container decreases the matric potential of water in the plate.



(A) Pressure plate apparatus for soil moisture characteristics (Schematic)



(B) Few working components of the apparatus

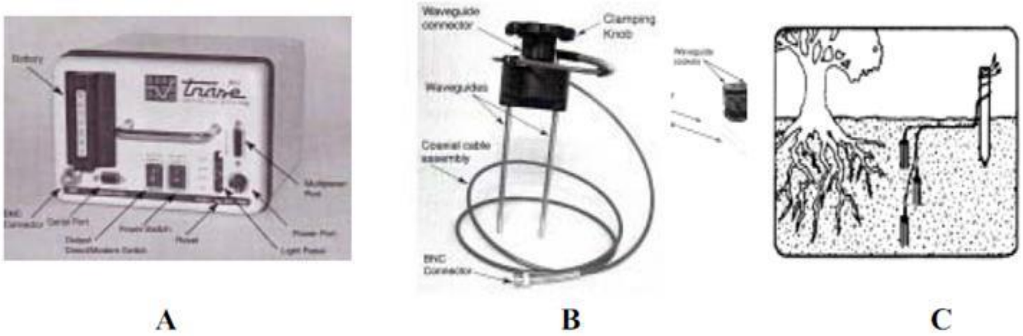
- Under the influence of the applied pressure, water held by the soil is forced out until the equilibrium is attained between the applied pressure and the force binding the water to the soil (matric suction).
- Field capacity (FC) and permanent wilting point (PWP) can also be determined in the laboratory with this equipment using applied pressure of 0.33 bar (0.33 bar for clayey and 0.1-0.2 bar for sandy soils) and 15 bars, respectively.
- As far as possible, undisturbed cores should be used for laboratory determination of field capacity and permanent wilting point.
- For disturbed samples, soil should be air dried, pulverized and passed through 2 mm sieve.

6. Time domain reflectometry method:

- Time domain reflectometry (TDR) is the latest mehod of measuring soil water contents. It makes use of the unique electrical properties of water molecule to determine the water content of soil.
- The speed with which an electromagnetic pulse of energy travels down a parallel transmission line depends on the dielectric constant, (Ka), of the material in contact with and surrounding the transmission line.
- Higher the dielectric constant, slower is the speed.
- Soil is composed, in general, of air, mineral and organic particles and water. The dielectric constants (Ka) for these materials are 1, 2-4 and 80, respectively. Because of the great difference in the dielectric constant of water from the other constituents in the soil, the speed of travel of a

microwave pulse of energy in a parallel transmission line buried in the soil is very much dependent on the water content of the soil.

- When soil is completely dry, Ka will be 2 to 4.
- If volumetric wetness is 25 per cent, Ka will be approximately 11-12.
- For agricultural soils the value of Ka depends primarily on the volumetric water content of the soil and is largely independent of the type of soil.



A. Mini trase system B. Wave guide C. Wave Guides installed vertically

A. Mini trase system B. Wave guide C. Wave Guides installed vertically

- When a microwave pulse travels down a transmission line it behaves in many ways like a beam of light.
- At radio frequencies, the dielectric constant of water is about 80. Most of the other solid components of soil have dielectric constants in the range 2 to 7, and that of air is effectively 1.
- Thus, a measure of the dielectric constant of soil is a good measure of the water content of the soil. The TDR technique measures the transit time of microwave pulse in frequency range of 1 MHZ to I GHZ launched along a parallel wave guide of known distance.
- The apparent dielectric constant, Ka, of the air-soil-water complex can then be determined by the formula:

$Ka = (ct/2L)^2$

Where 'L' is the length of the waveguides in centimeters,'t' is the transit time in nanoseconds (billionths of a second), and 'c' is the speed of light in centimeters per nanosecond.

- The transit time is defined as the time required for the pulse to travel in one direction from the start of the waveguide to the end of the waveguide.

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Lecture 10 Soil Colloids

Introduction

- The word colloid is derived from Greek word colla meaning glue, and eidos meaning like.The colloidal state refers to a two phase system in which one phase in a very finely divided state is dispersed through a second continuous medium.
- The continuous medium is termed as the dispersion medium. When the dispersed phase is solid (e.g. soil colloidal particles) and the dispersion medium is water (e.g. soil water) the colloidal system is referred to as sol. The seat of chemical activity in the soil is the soil colloids.

Properties of Soil Colloids

1.Size:

- Colloidal particles are generally smaller than 1 micrometer (um) in diameter. Since the clay fraction of soil is 2um and smaller, not all clay is strictly colloidal, but even the lager clay particles have colloid like properties.
- Colloidal particles can be seen only by using electron microscope

2. Surface area

- Soil colloids are minute and, therefore, have a large surface area per unit mass. The external surface area of 1 g of colloidal clay is 1000 times that of 1 g of coarse sand.
- Certain silicate clays have extensive internal surfaces occurring between plate like crystal units that make up each particle and often greatly exceed the external surface area.
- The total surface area of soil colloids ranges from 10 m^2/g for clays with only external surfaces to more than 800 m^2/g for clays with extensive internal surfaces. The colloid surface area in the upper 15 cm of a hectare of a clay soil could be as high as 700,000 km^2 g^{-1}

3. Surface charges

- Soil colloids also carry electrostatic charges (- and +) . Most of the organic and inorganic soil colloids carry a negative charge.
- When an electric current is passed through a suspension of soil colloidal particles they migrate to anode, the positive electrode indicating that they carry a negative charge.

4. Adsorption of cations:

- The minute silicate clay colloidal particles are called as micelles (microcells), ordinarily carry negative charges, consequently, attract and attach the ions of positive charge on the colloidal surfaces. This gives rise to an ionic double layer.
- The colloidal particles constitutes the inner ionic layer, being essentially a huge anion, the external and internal surfaces of which are highly negative in charge.
- The outer ionic layer is made up of a swarm of loosely held (adsorbed) cations attracted to the negatively charged surfaces.

5. Adsorption of water:

- A large number of water molecules are associated with soil colloidal particles. Some water molecules are carried by adsorbed cations and the cation is said to be in hydrated state.
- Some silicate clays hold numerous water molecules as well as cations packed between the plates that makes up the clay micelle.

6. Cohesion:

- Attractive force between similar molecules or materials are called cohesion. Cohesion indicates the tendency of clay particles to stick together.
- This tendency is due to the attraction of clay particles for water molecules held between them.
- When colloidal substances are wetted, water first adheres to individual clay particles and then brings about cohesion between two or more adjacent colloidal particles.

7. Adhesion:

- Attractive force between different molecules or materials are called adhesion. Adhesion refers to the attraction of colloida1 materials to the surface of any other body or substance with which it comes in contact.

8. Swelling and shrinkage:

- Some soil clay colloids belonging to smectite group like montmorillonite swell when wet and shrink when dry.
- After a prolonged dry spell, soils high in smectite clay (e.g. Black soil -Vertisols) often show criss-cross wide and deep cracks.
- These cracks first allow rain to penetrate rapidly. Later, because of swelling, the cracks will close and become impervious.
- But soils dominated by kaolinite, chlorite, or fine grained micas do not swell or shrink. Vermiculite is intermediate in its swelling and shrinking characteristics.

9. Dispersion and flocculation:

- As long as the colloidal particles remain negatively charged, they repel each other and the suspension remains stable.
- If on any account they loose their charge, or if the magnitude of the charge is reduced, the particles coalesce, form flock or loose aggregates, and settle down.
- This phenomenon of coalescence and formation of flocks is known as flocculation. The reverse process of the breaking up of flocks into individual particles is known as de-flocculation or dispersion.

10. Brownian movement:

- When a suspension of colloidal particles is examined under a microscope the particles seem to oscillate.
- The oscillation is due to the collision of colloidal particles or molecules with those of the liquid in which they are suspended.

- Soil colloidal particles with those of water in which they are suspended are always in a constant state of motion called Brownian movement. The smaller the particle, the more rapid is its movement.

11. Non permeability:

- Colloids, as opposed to crystalloids, are unable to pass through a semi-permeable membrane.
- Even though the colloidal particles are extremely small, they are bigger than molecules of crystalloid dissolved in water.
- The membrane allows the passage of water and of the dissolved substance through its pores, but retains the colloidal particles.

Classification of Soil Colloids

Soil colloids can be broadly classified in two types, depending on the nature of the linkages present and the types of compound formed.

These are:
i) Inorganic colloids
ii) Organic colloids.
Both inorganic and organic colloids are intimately mixed with other soil solids. Thus, the bulk of the soil solids are essentially inert and the majority of the soil's physical and chemical character is a result of the colloids present.
Inorganic soil colloids:

- Layer aluminosilicates which consist of thin layers of repeated structural units. These are the dominant clay minerals in temperate regions.
- Amorphous aluminosilicates that form from volcanic ash
- Al and Fe oxides which may be crystalline or amorphous. These are common in subtropical and tropical regions.

Organic colloids:

- Include highly decomposed organic matter generally called humus.
- Organic colloids are more reactive chemically and generally have a greater influence on soil properties per unit weight than the inorganic colloids.
- The negative charges of humus are associated with partially dissociated enolic (-OH), carboxyl (-COOH), and phenolic groups; these groups in turn are associated with central units of varying size and complexity.
- The complex humus colloid is composed of C,H and O rather than Al, Si and O like the silicate clays.
- Humus is amorphous and its chemical and physical characteristics are not well defined. The organic colloidal particles vary in size, but they may be at least as small as the silicate clay particles.
- They are not stable as clay and thus more dynamic, being formed and destroyed more rapidly than clay.

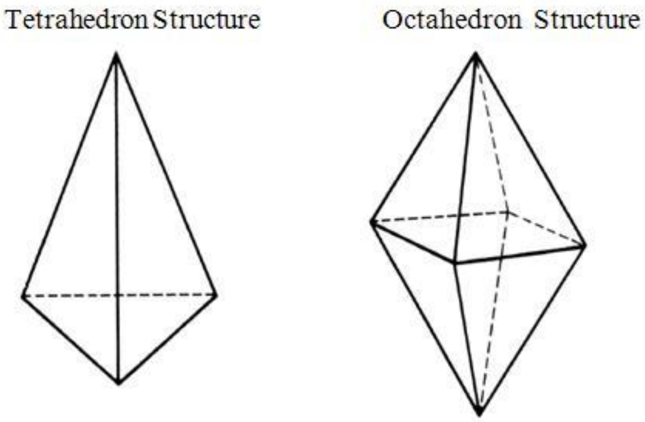
Layer Aluminosilicates:

- The most important silicate clays are known as phyllosilicate (Gr. Phullon, leaf) because of their leaf or plate like structure.
- Two types of structural units are basic in the layer lattice structure of most clay minerals that are tetrahedral and octahedral unit.

Silica tetrahedron:

- The tetrahedral unit is SiO^{4-} in which silicon ion is equidistant from the four oxygen anions (Fig.1). It is called silica tetrahedron because of its four sided configuration.
- Many tetrahedra are linked together horizontally by shared oxygen anions gives a tetrahedral sheet.

Tetrahedron Structure Octahedron Structure



Alumina octahedron:

- Aluminium and/or magnesium ions are the key cations surrounded by six oxygen atoms or hydroxyl group giving an eight sided building block termed octahedron (Fig.1)
- Many octahedra are linked horizontally to form an octahedral sheet. An aluminum-dominated sheet is known as a di-octahedral sheet, whereas one dominated by magnesium is called a tri-octahedral sheet.
- The distinction is due to the fact that two aluminum ions in a di-octahedral sheet satisfy the same negative charge from surrounding oxygen and hydroxyls as three magnesium ions in a tri-octahedral sheet.
- The tetrahedral and octahedral sheets are the fundamental structural units of silicate clays. These different sheets are bonded together to form crystalline units composed of alternating sheets of Si tetrahedra and Al (or Mg) octahedra.
- The Si tetrahedral sheet is chemically bonded to the one or two adjacent Al (or Mg) octahedral sheet(s) via shared oxygen atoms.
- The specific nature and combination of sheets, called layers, vary from one type of clay to another and control the physical and chemical properties of each clay.

Types of layer Silicates

- On the basis of the number and arrangement of tetrahedral (silica) and octahedral (alumina-magnesia) sheets contained in the crystal units or layers, silicate clays are classified into three different groups:

(a) 1 :1 Type clay minerals
(b) 2:1 Type clay minerals
(c) 2: 1: 1 (or) 2:2 Type clay minerals (Fig.1)

a)1:1 layer Silicates:

- In soils, kaolinite group is the most prominent 1:1 clay mineral, which includes kaolinite, hallosite, nacrite and dickite.
- These have one Si tetrahedral and one Al octahedral sheet per crystalline unit
- The tetrahedral and octahedral sheets in a layer of a kaolinite crystal are held together tightly by oxygen anions, which are mutually shared by the silicon and aluminum cations in their respective sheets.
- These layers, in turn, are held together by hydrogen bonding. Consequently, the structure is fixed and no expansion ordinarily occurs between layers when the clay is wetted.
- Cations and water do not enter between the structural layers of a 1:1 type mineral particle. The effective surface of kaolinite is restricted to its outer faces or to its external surface area.
- Kaolinite crystals usually are hexagonal in shape.
- Because of the strong binding forces between their structural layers, kaolinite particles are not readily broken down into extremely thin plates.
- Kaolinite exhibits very little plasticity, cohesion, shrinkage, and swelling.

b) 2:1layer Silicates

- The crystal units (layers) of these minerals are characterized by an octahedral sheet sandwiched between two tetrahedral sheets. Three general groups have this basic crystal structure. Two of them, *smectite* and *vermiculite* are expanding type minerals, while the third *mica group* (*illite*), is non-expanding

Expanding Minerals:

- The smectite group of minerals includes *montmorillonite,beidellite,nontronite* and *saponite*
- This group of minerals are noted for their interlayer expansion and swelling when wetted. The water enters the interlayer space and forces the layers apart. Montmorillonite is the most prominent member of this group in soils.
- The flake-like crystals of smectite are composed of an expanding lattice 2:1 type clay mineral. Each layer is made up of an octahedral sheet sandwiched between two tetrahedral (silica) sheets.
- The layers are loosely held together by very weak oxygen – oxygen and cation-to-oxygen linkages.
- Exchangeable cations and associated water molecules are attracted between layers causing expansion of the crystal lattice.
- The internal surface exceeds the external surface of clay crystal. In montmorillonite, magnesium replaces replaced aluminum in some sites of octahedral sheet.

- Likewise, some silicon atoms in the tetrahedral sheet may be replaced by aluminum. These substitutions give rise to a negative charge.
- These minerals show high cation exchange capacity, swelling and shrinkage properties. Wide cracks commonly form in smectite dominated soils (e.g., Vertisols) when dried. The dry aggregates or clods are very hard, making such soils difficult to till.

Vermiculites

- Vermiculites have structural characteristics similar to those of montmorillonite in that an octahedral sheet is found between two tetrahedral sheets.
- In the tetrahedral sheet of most vermiculite, aluminum is substituted by silicon in most of the sites. This accounts for most of the very high net negative charge associated with these minerals.
- Water molecules, along with magnesium and other ions, are strongly adsorbed in the interlayer space of vermiculites. They act primarily as bridges holding the units together rather than as wedges driving the units apart.
- The degree of swelling is less for vermiculites than for smectite. Therefore, vermiculites are considered *limited expansion* clay minerals, expanding more than kaolinite but much less than the smectite.
- The cation exchange capacity (CEC) of vermiculite is higher than all other silicate clays because of very high negative charge in the tetrahedral sheet. Vermiculite crystals are larger than those of the smectite but much smaller than those of kaolinite.

Non-expanding minerals:

- Micas are the type of minerals in this group-*muscovite* and *biotite.*
- Weathered minerals similar in structure to these micas are found in the clay fraction of soils.They are called *fine-grained micas* or *illite*.
- The basic structure of illite or micaceous mineral is similar to that of montmorillonite. However, the particles are much larger than those of the smectite.
- Some of the silicon ions are replaced by aluminium ions in the tetrahedral sheet (20%). This results in a net negative charge in the tetrahedral sheet which is compensated by potassium ions
- The potassium as a binding agent, preventing expansion of the crystal. Hence, fine-grained micas are quite non-expanding.
- The properties such as hydration, cation adsorption, swelling, shrinkage and plasticity are less intense in fine grained micas.The specific surface area varies from 70 to 100 $m^2 g^{-1}$, about one eighth that for the smectite.

c) 2:1:1 layer Silicates :

- This silicate group is represented by **chlorites**. Chlorites are basically iron magnesium silicates with some aluminum present.
- The crystal unit is composed of one 2:1unit like mica or montmorillonite and one octahedral unit, Brucite, $Mg_3(OH)_6$ layer.
- Mg dominates the octahedral sheet in the 2:1 unit.
- There is no water adsorption between the chlorite crystal units, which accounts for the non expanding nature of this mineral.

Mixed and interstratified layers:

- Specific groups of clay minerals do not occur independently of one another. In a given soil, it is common to find several clay minerals in an intimate mixture.
- Furthermore, some mineral colloids have properties and composition intermediate between those of any two minerals.
- Such minerals are termed *mixed layer* or *interstratified* because the individual layers within a given crystal may be of more than one type.
- Terms such as "chlorite-vermiculite" and "mica - smectite" are used to describe mixed layer minerals.

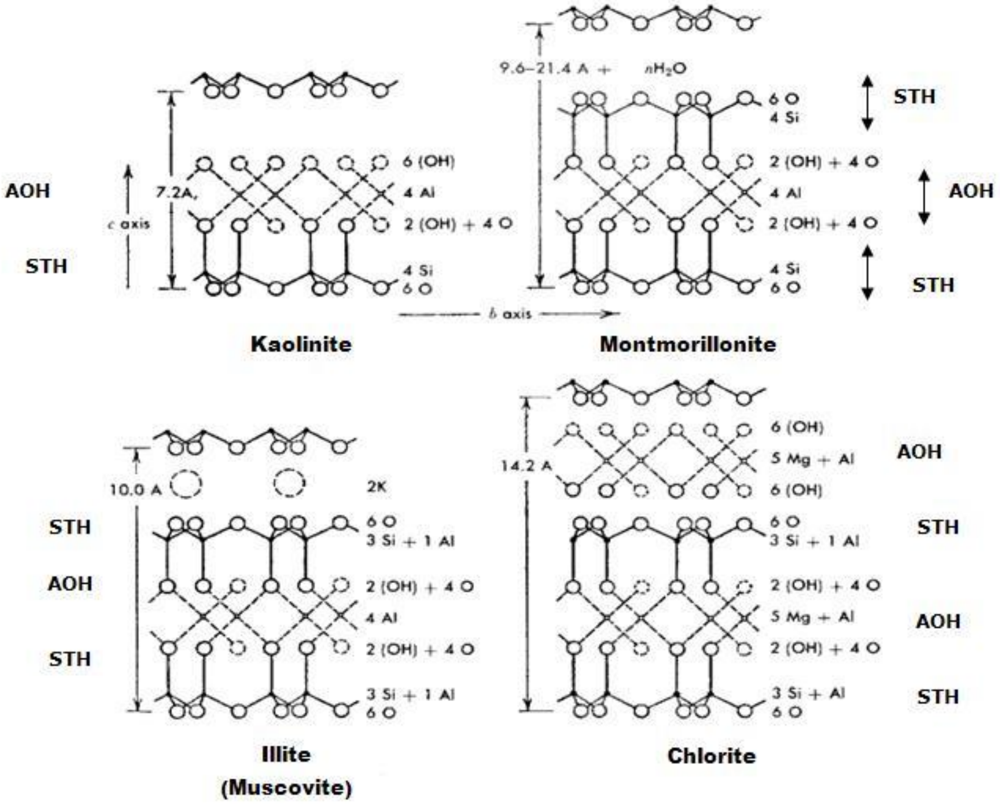


Fig.1.The structural component of silicate clays

Comparative properties of silicate clay minerals

Property	Kaolinite	Monotmorillonite	Vermiculite	Mica or Illite
Structure size (microns)	1:1 lattice 0.5 to 5.0	2:1 0.01 to 1.0	2:1 0.1to5.0	2:1 0.1 to 2.0
Shape	Hexagonal crystals	Irregular flakes	Plates; flakes	Flakes
Specific surface (m^2/g)	5-20	700-800	500-600	100-200
External and internal surface	Low	Very High	High	Medium
Cohesion and plasticity swelling capacity	Low	High	High	Medium
Cation exchange capacity (cmol (P^+) kg^{-1})	3-15	80-120	100-180	15-40
Anion exchange capacity	High	Low	Low	Medium

Oxides and hydroxides of Iron and Aluminum (sesquioxide clays):

- The most common examples of iron and aluminum oxides are gibbsite ($Al_2O_3.3H_2O$) and geothite ($Fe_2O_3.H_2O$). Less is known about these clays than about the layer silicates.
- Under conditions of extensive leaching by rainfall and long time intensive weathering of minerals in humid warm climates, most of the silica and alumina in primary minerals are dissolved and slowly leached away. The remnant materials, which have lower solubility are called sesquioxides.
- Sesquioxides (metal oxides) are mixtures of aluminum hydroxide, Al $(OH)_3$, and iron oxide, Fe_2O_3, or iron hydroxide, $Fe(OH)_3$.
- Some of these clays have crystalline structure.
- They carry a small negative charge at high pH values which attract cations. However, their capacity to adsorb cations is less than kaolinite.
- These clays do not swell, not sticky and have high phosphorus adsorption capacity.

Allophane and other amorphous minerals:

- These are amorphous, hydrated alumino-silicate. Typically, these clays occur where large amount of weathered products existed. These clays are common in soils forming from volcanic ash (e.g. Allophane). Its approximate general composition is $Al_2O_3.2SiO_2.H_2O$.
- These clays have high anion exchange capacity or even high cation exchange capacity.

SOURCES OF NEGATIVE CHARGE ON SILICATE CLAYS :

- The sources of negative charge on clays are:
    - ionizable hydrogen ions
    - isomorphous substitution.

Ionizable hydrogen ions:

- Hydrogen ions dissociate from the hydroxyl group on the broken edges of clay minerals (Kaolinite).
- The extent of ionized hydrogen depends on solution pH and hence these negative charges are also known as pH dependent charges. The ionization of hydrogen increases in alkaline (basic) solutions.

Isomorphous substitution (Permanent negative charge):

- This is due to the substitution of a cation of higher valence with another cation of lower valence but similar size in the clay crystal structure.
- In clay crystals some ions fit exactly into mineral lattice sites because of their convenient size and charge.
- Si^{4+} are substituted from the tetrahedral positions of illite, vermiculite and smectite groups of clay minerals by Al^{3+}. Similarly, Al^{3+} are substituted from the octahedral positions of smectite groups, illite and vermiculite by Fe^{3+}, Fe^{2+}, Mg^{2+} or Zn^{2+}.

* * *

Lecture 11- Ion Exchange

Introduction

- Ion exchange in soil system refers to exchange of equilavent amounts of ions between two phases in equilibrium in contact in reversible process.
- When cations are involved , the process is termed as cation exchange, while for anions, it is referred to as anion exchange. Cation exchange reaction is considered as the second most important reaction next to photosynthesis.
- The exchanges may take place between soil solid phase and the soil solution phase, or less commonly between the soil solid phases in contact or soil solid phase and growing plant in contact (contact exchange).

Cation Exchange:

- The Cation Exchange phenomenon was first identified by Harry Stephen Thompson in England during 1850. When soil was leached (washed) with ammonium sulphate, and upon filtration,calcium, and to lesser extent magnesium, potassium ions were detected in the leachate. The total amount of calcium and other cations so released is equivalent to that of ammonium retained.

$(NH_4)_2SO_4$ + Soil Ca = Soil $(NH_4)_2$ + CaSO4

- The various cations adsorbed by negatively charged colloids are subject to replacement by other cations through a process called cation exchange.
- The cation exchange reactions takes place reversibly, and the interchange is chemically equilavent.

$$\text{Ca} - \text{Clay} \quad + \quad 2\text{H}+ \leftrightarrows \text{Clay-2H}^{+} \quad + \text{Ca}^{2+}$$

Cation Exchange Capacity (CEC)

- The CEC is the capacity of soil is defined as the capacity of soil to adsorb and exchange cations.
- The cation exchange capacity is the sum total of the exchangeable cations that a soil can adsorb. The higher the CEC of soil the more cations it can retain. Soils differ in their capacities to hold exchangeable cations.

Unit of expression

- CEC is expressed as milliequivalents of cations per 100 grams of soil (meq /100g soil). After 1982, in the metric system the term equivalent is not used but moles are the accepted chemical unit. The recent unit of expression of CEC is *centi moles of protons per kilo gram soil* [cmol (p^+) kg^{-1} soil]. One meq/100 g is equal to one cmol (p^+) kg^{-1} soil.

Factors affecting Cation Exchange Capacity

- ***Soil texture*:** The negatively charged clay colloids attracts positively charged cations and holds them. Therefore, the cation exchange capacity of soils increases with increase in per centage of clay content .
- Clay soils with high CEC can retain large amounts of cations and reduce the loss of cations by leaching. Sandy soils, with low CEC, retain smaller quantities of cations and therefore cations are removed from soil by leaching.
- ***Soil organic matter*:** High organic matter content increases CEC. The CEC of clay minerals range from 10 to 150 [cmol (p^+) kg^{-1}] and that of organic matter ranges from 200 to 400 [cmol (p^+) kg^{-1}].
- ***Nature of clay minerals:*** The CEC and specific area of the clay minerals are in the order : smectite>fine mica>kaolinite. Hence the CEC of a soil dominated by smectite type of clay minerals is much higher than kaolinite type dominated soils
- ***Soil Reaction*:** As the pH is raised, the hydrogen held by the organic colloids and silicate clays (Kaolinite) becomes ionized and replaceable. The net result is an increase in the negative charge on the colloids and in turn an increase in CEC.

Importance of Cation Exchange

- Cation exchange is an important reaction in soil fertility, in causing and correcting soil acidity and basicity, in changes altering soil physical properties, and as a mechanism in purifying or altering percolating waters.
- The plant nutrients like calcium, magnesium, and potassium are supplied to plants in large measure from exchangeable forms.
- The exchangeable K is a major source of plant K.
- The exchangeable Mg is often a major source of plant Mg.
- The amount of lime required to raise the pH of an acidic soil is greater as the CEC is greater.
- Cation exchange sites hold Ca^+, Mg^+, K^+, Na^+, and NH_4^+ ions and slow down their losses by leaching.
- Cation exchange sites hold fertilizer K^+ and NH_4^+ and greatly reduce their mobility in soils.
- Cation exchange sites adsorb many metals (Cd^{2+} , Zn^{2+}, Ni^{2+}, and Pb^{2+}) that might be present in wastewater adsorption removes them from the percolating water, thereby cleansing the water that drains into groundwater.

Anion Exchange

- Adsorption of negative ion (anions) e.g. Cl^-, NO_3^-, SO_4^{2-}, and $H_2PO_4^-$ on positively charged sites of clay and organic matter is known as anion adsorption. These anions are subject to replacement by other anions through a process known as anion excange.

Clay NO_3^- + solution Cl^- = Clay Cl^- + Solution NO_3^-

Source of positive charge:

1. Isomorphous substitution: Low valence cations replaced by high valence cations.

2. Surface and exposed broken bonds of clay lattice: OH group in certain acid soils.

$$\text{Al - OH} \quad + \quad H^+ \quad \rightarrow \quad \text{Al - OH}_2^+$$

No charge (soil solution) Positive charge

(Soil solids) (Soil solids)

3. Complex aluminium and iron hydroxy ions in acid soils.

$$\text{Al (OH)}_3 \quad + \quad H^+ \quad \rightarrow \quad \text{Al (OH)}_2^+ \quad + \quad H_2O$$

No charge Positive charge

4. pH dependent charges are important for anion exchange of organic matter

- The basic principles of cation exchange apply also to anion exchange, except that the charges on the colloids are positive and the exchange is among negatively charged anions.
- Anion exchange is an important mechanism for interactions in the soil and between the soil and plant. Together with cation exchange it largely determines the ability of soil to provide nutrients to plants.

Anion exchange capacity

- "The sum total of exchangeable anions held exchangebly by a unit mass of soil , termed as its anion exchange capacity(AEC.)". It is expressed as cmol / kg or m.eq./ 100 g soil.
- The AEC is much less than CEC of the soil.
- Kaolinitic minerals have a greater anion adsorbing and exchange capacity than montmorillonitic and illitic clays because the exchange is located at only a few broken bonds.
- The capacity for holding anions increases with the increase in acidity.
- Some anions such as H_2PO_4 are adsorbed very readily at all pH values in the acid as well as alkaline range.
- Cl and SO_4 ions are adsorbed slightly at low pH but none at neutrality, while NO_3 ions are not adsorbed at all.
- The affinity for adsorption of some of the anions commonly present in soil is of the order: $NO_3 < Cl < SO_4 < PO_4$.
- Hence at the pH commonly prevailing in cultivated soils, nitrate, chloride and sulphate ions are easily lost by leaching.

Importance of anion exchange

- The phenomenon of anion exchange assumes importance in relation to phosphate ions and their fixation.
- The adsorption of phosphate ions by clay particles from soil solution reduces its availability to plants. This is known as phosphate fixation. As the reaction is reversible, the phosphate ions again become available when they are replaced by OH ions released by substances like lime applied to soil to correct soil acidity.
- Percent Base Saturation
- The extent to which the adsorption complex of a soil is saturated with exchangeable basic cations is termed as base saturation. It is expressed as a percentage of the total cation exchange capacity.

% base saturation = Excaneable bases(cmol/kg) / CEC(cmol/kg) x 100

- Percent base saturation tells what percent of the exchange sites are occupied by the basic cations. If the percetage base saturation is 50, half of the exchane capacity is satisfied by bases, the other by hydrogen and aluminium.

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Lecture 12 Concept of Soil pH and Nutrient Availability

Introduction

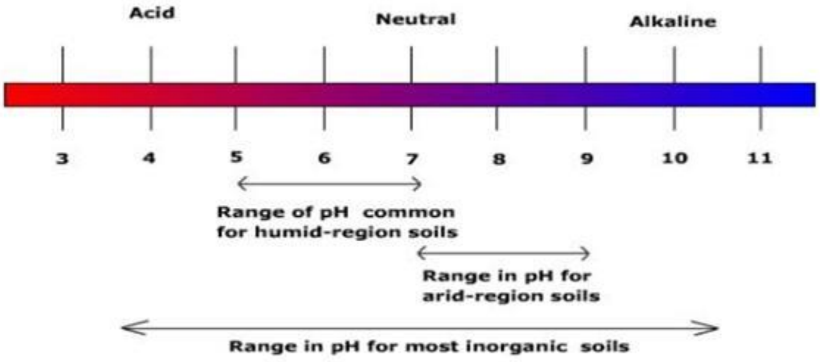
- The term pH is from the French “pouvoir hydrogen” or hydrogen power. Soil pH or soil reaction is an indication of the acidity or alkalinity of soil and is measured in pH units.
- The pH scale goes from 0 to 14 with pH 7 as the neutral point. As the amount of hydrogen ions in the soil increases, the soil pH decreases, thus becoming more acidic. From pH 7 to 0, the soil is increasingly more acidic, and from pH 7 to 14, the soil is increasingly more alkaline or basic.
- Sorenson (1909) defined the pH and gives the pH scale. Using a strict chemical definition, **pH is the negative log of hydrogen ion (H^+) activity in an aqueous solution in moles/ L**.
- The point to remember from the chemical definition is that pH values are reported on a negative log scale. So, a 1 unit change in the pH value signifies a 10-fold change in the actual activity of H^+, and the activity increases as the pH value decreases.
- To put this into perspective, a soil pH of 6 has 10 times more hydrogen ions than a soil with a pH of 7, and a soil with a pH of 5 has 100 times more hydrogen ions than a soil with a pH of 7.Activity increases as the pH value decreases.

$pH= -\log_{10} (H^+)$

Where: (H^+) is the activity of hydrogen ions in moles/lt.

- Pure water is weakly dissociated in to H^+ and OH' ions according to following equations

$H_2O = H^+ + OH'$
According to law of dissociation
$[H^+] \times [OH] / H_2O = K$
Where;
H_+ etc are the concentration and K is the dissociation constant. Since concentration of undissociated water remains practically the same because of very little ionization of H_2O molecules the above relationship becomes:
$[H^+] \times [OH'] = Kw = 10^{-14}$ at 200C Kw=Ion product constant of water
At neutrality $H^+ = OH'$ and $H^+ = 10^{-7}$or pH=7. Pure water has a pH value of 7. As the hydrogen activity increases the pH value will decrease while it will go up with rise in hydroxyl ion activity.



Importance of Soil pH:

The pH of of soilis an important physico-chemical characteristics because it influences:

- Sutability of soil for crop production
- Availability of soil nutrients to plants
- Microbial activity in the soil
- Lime and gypsum requirement of soil
- Physical properties of soil like structure, permeability etc.

Factors affecting soil pH:

Percent base saturation:

- A low percent base saturation means acidity, whereas a percent base saturation of 50-90 will result in to neutrality or alkanity.

Nature of soil colloids:

- The colloidal particles of the soil influence soil reaction to a very greatest extent.
- Different types of colloids vary in their pH at the same percent base saturation . This is due to the difference in the ability of different colloids to release H^+ ions to the soil solution. For example at the same percent base saturation the smectite has much lower pH than kaolinite.
- When hydrogen (H^+) ion forms the predominant adsorbed cations on clay colloids, the soil reaction becomes acid.

Soil solution:

- The more dilute the solution, the higher the pH value. Hence the pH tends to drop as the soil gets progressively dry. Soil reaction is also influenced by the presence of CO_2 in soil air.
- As the CO_2 concentration increases, the soil pH falls and increases the availability of the nutrients. Under field conditions, plant roots and micro-organism liberate enough CO_2, which results in lowering the pH appreciably.

Adsorbed basic cations:

- The comparative quantity of exchangeable Ca, Mg, Na and K adsorbed on the colloids will determine the pH. The dominance of Na^+ will raise pH much higher than other basic cations.

Climate:

- Rainfall plays important role in determining the reaction of soil. In general, soils formed in regions of high rainfall are acidic (low pH value), while those formed in regions of low rainfall are alkaline (high pH value).

Native Vegetation:

- Soils become more acidic when develops under conifer ecosystem
- Soils often become more acid when crops are harvested because of removal of bases.

- Type of crop determines the relative amounts of removal. For example, legumes generally contain higher levels of bases than do grasses.

Nitrogen fertilization:

- Nitrogen from fertilizer, organic matter, manure and legume N fixation produces acidity.
- Nitrogen fertilization speeds up the rate at which acidity develops. At lower N rates, acidification rate is slow, but is accelerated as N fertilizer rates increase.

Flooding:

- The overall effect of submergence is an increase of pH in acid soils and a decrease in basic soils.
- Regardless of their original pH values, most soils reach pH of 6.5 to 7.2 within one month after flooding and remain at the level until dried.

Nutrient Availability:

The availibility of plant nutrients are more at a pH range of 6-7 except Mo (Fig 2.)

Nitrogen

- One of the key soil nutrients is nitrogen (N). Plants can take up N in the ammonium (NH_4^+) or nitrate ($N0_3^-$) form.
- At pH near neutral (pH 7), the microbial conversion of NH_4^+ to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH < 6), nitrification is slow, and plants with the ability to take up NH_4^+ may have an advantage

Phosphorus

- The form and availability of soil phosphorus is highly pH dependent.
- When the soil is neutral to slightly alkaline , the HPO_4^{--} ion is the most common form. As the pH is lowered both the $HPO4^{--}$ and H_2PO4^- ion prevail. At higher acidities H_2PO4^- ions tends to dominate. The most plants absorb phosphorus in HPO_4^{--} .
- Between pH 6-7, phosphorus fixation is at minimum and availability to higher plants is maximum.

Potassium:

- The fixation of potassium (K) and entrapment at specific sites between clay layers tends to be lower under acid conditions. This situation is thought to be due to the presence of soluble aluminum that occupies the binding sites.

Calcium, Magnesium and Sulphur:

- The availibilty of Ca and Mg is more above pH 7.0.
- Sulphate ($S0_4^{2-}$) sulphur, the plant available form of S, is little affected by soil pH.

Micronutrients

- The availability of the micronutrients manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B) tend to decrease as soil pH increases.

- The exact mechanisms responsible for reducing availability differ for each nutrient, but can include formation of low solubility compounds, greater retention by soil colloids (clays and organic matter) and conversion of soluble forms to ions that plants cannot absorb.
- Molybdenum (Mo) behaves counter to the trend described above. Plant availability is lower under acid conditions.

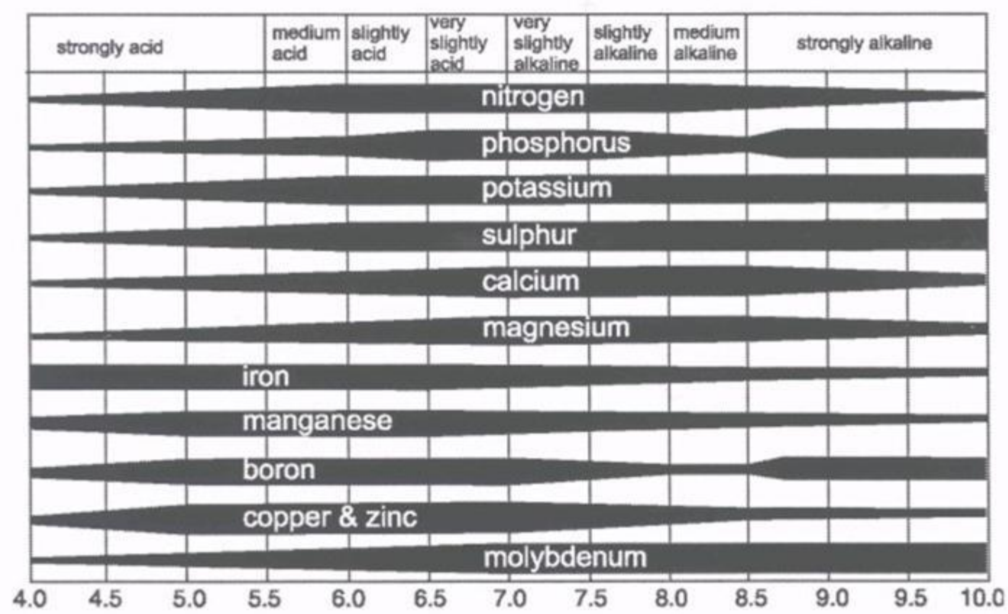


Fig.2. Effect of Soil pH on Nutrient Availability

Soil pH and soil organisms:

- Growth of many bacteria and actinomycetes is inhibited as soil pH drops below 6
- Fungi grow well across a wide range of soil pH
- Therefore fungi are dominant under acid conditions
- Less competition from bacteria and actinomycetes
- Earthworms do best when soil pH >6.5
- Nitrification greatly inhibited at pH <5.5
- N fixation greatly restricted a pH <6
- Decomposition of plant residues and OM may be slow in acid conditions (pH <5.5)

Soil Buffering Capacity

- The ability to resist a change in pH refers to buffering capacity of the soil
- The buffering capacity increases as the cation exchange capacity increases. Thus, heavier the texture and the greater the organic matter content of a soil, the greater is the amount of acid or alkaline material required to change its pH.
- The colloidal complex acts as a powerful buffer in the soil and does not allow rapid and sudden changes in soil reaction.
- Buffering depends upon the amount of colloidal material present in soil. Clay soils rich in organic matter are more highly buffered than sandy soils.
- Importance of buffering in agriculture
- The stabilization of soil pH through buffering act as a effective guard against deficiency of certain plant nutrients and excess availability of others in toxic amounts which would seriously upset the nutritional balance in the soil.

Lecture 13 Soil Organic Matter

Importance

- Organic materials are intrinsic and essential component of all soils. Whereas the body of the soil is constituted by the inorganic materials, one may look upon the organic matter as its life.
- Organic matter makes the soil a living, dynamic system that supports all life on this planet.
- Soil Organic Matter (SOM) comprises an accumulation of
    - Partially disintegrated and decomposed plant and animal residues
    - Other organic compounds synthesized by the soil microbes upon decay.
- SOM is frequently said to consist of humic substances and nonhumic substances.
- The term SOM is generally used to represent the organic constituents in the soil, including undecayed plant and animal tissues, their partial decomposition products, and the soil biomass.

Importance of organic matter

- It is the food source for soil microorganisms and soil fauna. If there is no organic matter the soil would be almost sterile and consequently, extremly infertile . Organic matter also supplies hormones (Auxin ,Gibberellins , IAA) and antibiotics for plant growth.
- Organic matter is an index of the productivity of the soil since it is a store house of essential plant nutrients for plant growth. It functions as a reservoir of nitrogen, phosphorus and sulphur and thereby contribute significantly to the supply of these nutrients to higher plants.
- Humus (a highly decomposed organic matter) provides a storehouse for the exchangeable and available cations.
- Soil organic matter contributes to nutrient release from soil minerals by weathering reactions and thus helps in nutrient availability in soils. Organic acids released from decomposing organic matter help to reduce alkalinity in soils; organic acids along with released CO_2 dissolve minerals and make them more available.
- It acts as a buffering agent which checks rapid chemical changes in pH and soil reaction.
- Organic matter creates a granular condition of soil which maintains favorable condition of aeration and permeability.
- Water holding capacity of soil is increased and surface runoff, erosion etc., are reduced as there is good infiltration due to the addition of organic matter.
- Surface mulching with coarse organic matter lowers wind erosion and lowers soil temperatures in the summer and keeps the soil warmer in winter.
- The organic substances influence various soil processes leading to soil formation
- It is the prime decider of soil health and soil quality.

Sources of Soil Organic Matter

Primary sources

- Plant, animal and microbial materials are the primary source of organic matter. Plant tissues and microbial cells contains approximately 40 to 50 per cent carbon on dry weight basis.

Secondary sources

- **On –farm sources:** Crop residues,roots,root exduates, organic manures,composts and green manure crops contribute significantly towards build up of soil organic matter.
- **Off- farm sources:** Biodegradable wastes like agro-industrial wastes and muncipal wastes

Decomposition of Soil Organic Matter

- The organic materials (plant and animal residues) incorporated in the soil are attacked by a variety of microbes, worms and insects in the soil if the soil is moist.
- Some of the constituents are decomposed very rapidly, some less readily, and others very slowly .The constituents in terms of ease of decomposition are:
    - Sugars, starches and simple proteins = easy to decompose
    - Crude proteins
    - Hemicelluloses
    - Cellulose
    - Fats, waxes, resins
    - Lignins = Very difficult to decompose

The organic matter is also classified on the basis of their rate of decomposition

- Rapidly decomposed : Sugars, starches, proteins etc.
- Less rapidly decomposed : Hemicelluloses, celluloses etc.
- Very slowly decomposed : Fats, waxes, resins, lignins etc.

- The organic/ humic substances are produced when plant residue and other organic debries are broken down or chemically altered. Fungi dominate over others in the initial stages while bacteria are the important agents of decomposition during the later stages.
- At first, the easily decomposable substances like sugars, starches and water soluble proteins are acted upon by the microorganisms and decomposition and digestion is rapid. Crude protein is next in order, followed by hemicelluloses.
- Cellulose, which is more resistant to microbial attack than hemicellulose decomposes much more rapidly than oils, fats, waxes, resins etc. Lignin decomposes very slowly and continues to dominate soil organic matter when the decay process slows down.
- The sugars, starches, hemicelluloses and celluloses are ultimately decomposed to carbon dioxide and water and energy is liberated which is utilized by microorganisms. Some oils, fats, waxes and resins are also slowly decomposed to carbon dioxide and water and some energy liberated for use by microorganisms.
- A small portion of lignin may be slowly decomposed to form aromatic compounds. Other portions may be chemically altered. Some other portions may chemically unite with protein to form part of the soil humus.
- Proteins are gradually decomposed to amino acids and amides which are further decomposed to ammonium compounds by microorganisms. Ammonium compounds are oxidised to nitrites by Nitrosomonas bacteria. Nitrites are further oxidized to Nitrates by Nitrobacter bacteria.
- Phosphorus is present in the organic matter as phytin, nucleic acid and phospholipids, which are decomposed to liberate the phosphorus present in them as orthophosphate ions, $H_2PO_4^-$.
- Similarly, sulphur containing amino acids like methionine, cysteine etc. Are decomposed by microorganisms to liberate the sulphur contained them as sulphate. When organic

matter decomposes, other complex organic forms of nutrients are converted to simple ionic forms like K^+, Ca^{++}, Mg^{++} , etc.

- This process of conversion of complex organic forms of nutrients to simple inorganic forms by microorganisms is called the mineralisation of nutrients.
- A portion of the nutrients thus mineralized is assimilated by the microorganisms themselves for synthesis of their cell protoplasm. Thus the simple inorganic form of the nutrient is recovered to the complex organic form of nutrients. This process of conversion of the simple inorganic form of nutrients to the complex organic form of nutrients is called immobilization of nutrients.
- During the earlier stages of decomposition of organic matter all the simple inorganic forms of nutrients are assimilated by microorganisms which multiply rapidly and continue to decompose the organic matter.
- When almost all the carbon compounds have been decomposed, the microorganisms die due to the lack of sufficient a mounts of energy giving carbon compounds. Their bodies decay when the complex organic forms of the nutrients are reconverted to simple inorganic forms.
- Some proteins combine with organic compounds like lignins, tannins, humic acids etc. Some proteins are absorbed by the clay, especially the expanding ones. All these reactions protect the proteins from microbial decomposition. At this stage, almost all the original organic material has been converted to dark heterogeneous mass called humus.
- Humus is a resistant complex mixture of dark brown to black coloured colloidal and amorphous substances synthesized or modified from the original organic materials by various microorganisms.
- Simple decomposition products under aerobic decomposition are CO_2,NH_4, NO_3, H_2PO_4, SO_4 and H_2O
- Simple decomposition products under anaerobic decomposition are CH4, H2S, dimethyl sulphide, ethylene, ammonium ions, amine residues and organic acids

C: N ratio

- A close relationship exists between organic matter and nitogen content of the soil (Fig.2). The ratio of organic carbon to nitrogen in soils is known as Carbon: Nitrogen ratio or C/N ratio of the soils.
- The C / N ratio of residue affects the rate of decomposition of organic matter.
- The organisms that decompose residues need N (and other essential elements) as well as C, if there is little N in the residue, decomposition is slow
- Also, if there is little N in the residue, microorganisms will utilize inorganic N in the soil to satisfy their N requirement, thereby competing with plants for N and reducing the amount of soil N available for plant growth.
- The C / N ratio in soil is relatively constant and = 12. In plant residues, it is highly variable and increases with maturity.
- The C / N is lower in microorganisms and = 8. Since microbes incorporate only about 1/3 of the C metabolized into biomass, the substrate material must have C / N = 24 to satisfy the N requirement of microbes.
- Generally, when organic substances with C/N ratios greater than 30:1 are added to soil , there is immobilization . For ratios between 20 and 30 , there may be neither immobilization nor release of mineral N. If the C / N ratio of residue is < 20:1 , there is usually release of mineral n.soil N is consumed by microbes and plant- available N decreases

C:N Ratios as Related to Organic Matter Decomposition

In general, the following C:N ratios are considered to be a general rule of thumb in terms of what is expected for immobilization and mineralization.

C:N Ratio	Effect
30:1	immobilization
<20:1	mineralization
20-30:1	**immobilization= mineralization**

C:N ratios say nothing about the availability of carbon or nitrogen to microorganisms

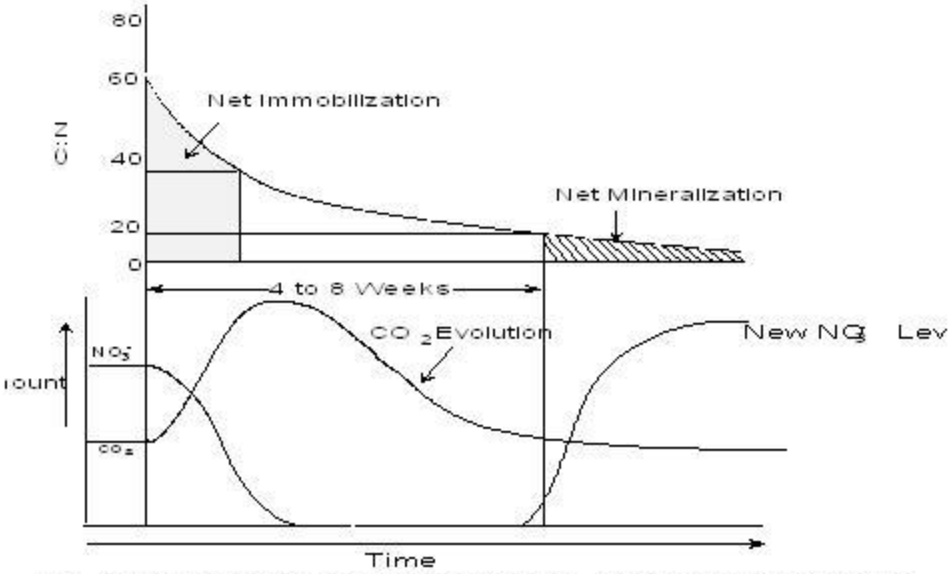


Fig.2. INFLUENCE OF C/N RATIO ON MINERALIZATION AND IMMOBILIZATION IN SOILS

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Lecture 14 Problem Soils

Introduction

- The problem soils are those which owing to land or soil characteristics can not be economically used for cultivation of crops. These soils require remedial measures and management practices for satisfactory crop production.

Types of problem soils:

- The problem soils have been classified in two main categories on the basis of nature of constraints.

1. Physical nature: a) Highly eroded soils, ravines and soils on sloping lands b) Soil physical constraints
2. Chemical nature: i) Saline soils ii) Saline alkali soils iii) Alkali soils and iv) Acid soil

Physical nature:

- Highly eroded soils, ravines and soils on sloping lands: The areas affected by this problem are Western Rajsthan, Saurashtra region of Gujrat, Maharastra, ravines along the Jamuna and Chambal rivers. Kotar lands in Gujarat, steep slopes of hilly areas. The erosion is mainly caused by wind, water and land slides.
- Wind erosion: It occurs in arid and semiarid areas devoid of vegetation due to high wind velocity. Soil particles are lifted and blown off and when the velocity of the dust bearing wind is retarded, coarser soil particles are deposited in the form of dunes and thus fertile lands are unfit for cultivation.
- Water erosion: Water removes a thin covering of soil from large area uniformly during every rain which produces runoff. Its existence can be detected by muddy colour of the runoff from the fields. This is called sheet erosion. Later on , the silt laden runoff forms a well defined but minute finger shaped grooves over the entire field. Such thin channeling is known as rill erosion. The tiny grooves develop in to wider and deeper channels which may assume a huge size is known as gully erosion.
- Land slides or slip erosion: The outward and downward movement of the slope forming material composed of natural rocks, soil etc. is known as land slides or slip erosion. The main cause of land slides are topography, geological structure, type of rocks and their physical characteristics.

Agronomic measures for soil and water conservation:

- Interception of rain drops reduces the splash effect. The overland runoff can be reduced through use of contour cultivation, mulches, dense growing crops, strip cropping and mixed cropping.
- A simple practice of farming across the slope, keeping the same level as for as possible is called contour farming. It reduces runoff, soil erosion and loss of plant nutrients and increases crop yields.

- Surface mulches are used to prevent soil from being blown and washed away to reduce evaporation, increase infiltration, check weeds, improved soil structure and eventually to increase crop yields.
- Grow the crop which can provide and reduce runoff and soil losses. Legume furnishes better cover and hence provides better protection to cultivated land against erosion than ordinary crops.
- Grow the crops in strips of suitable width across the slopes by alternating the strips of soil protecting and erosion resisting crops.

Soil physical constraints:
1. Permeable soils:
Highly permeable coarse textured soils:

- The high permeability of these soils are associated with their sand and loamy sand texture. The soils has low bulk density and high hydraulic conductivity and infiltration rate which results in to high permeability and low water retention capacity.
- The fertilizer and water use efficiency is very low and nutrient losses are very high. Soil compaction and clay mixing should be done to improve these type of soils.

Slowly permeable soils:

- The slowly permeable soils occur in Madhya Pradesh, Maharashtra, parts of Rajsthan, Uttar Pradesh, Bihar and Tamil Nadu.
- The infiltration rate and hydraulic conductivity is low which results in to slow permeability of the soil and possibility of submergence during rainy season.
- The preavailing anaerobic conditions cause the accumulation of carbon dioxide and other by products which restrict the plant growth.
- These soils are associated with black clay soils. The black soils are sticky when moist, therefore, could be cultivated only within limited soil moisture range.
- These type of soils can be reclaimed by growing crops on raised beds, broad beds with drainage furrow in between, deep tillage through ploughing and chiseling to break the hard pan in sub-soil.

Crusting soils:

- When the rain drop strikes the exposed dry soil surface, there is disintegration and dispersion of soil aggregates.
- The finer clay particles moves down along with infiltrating water and clog the soil pores. As the water evaporates and soil dries, a thin layer of hard crust of soil is formed. The crust present a serious barrier for seedling emergence.
- Crusting of alluvial soils is a serious problem all over the country especially in the states of Haryana, Punjab, Rajasthan, Bihar and West Bengal.
- Application of farm yard manure or green manuring will improve these type of soils.

Chalka soils:

- The red sandy loam soils “Chalka soils” which cover a large area in Andhra Pradesh become very hard on drying with the result that growth of the crops are adversely affected.
- Incorporation of slow decomposing crop residues and other materials such as powdered ground nut shell, paddy husk improves these type of soils.

Sandy Soils:

- Sandy soils are weakly developed because of slow chemical weathering in dry and hot climate.
- The coarse texture of sandy soils causes a low water holding capacity and high infiltration rate which represents the main production constraint.
- Nutrient content and nutrient retention are normally low, thus causing a low inherent fertility status of the soil.
- The poor soil structure makes the soil very susceptible to wind erosion. The agricultural potential of sandy soils depends on the availability of sufficient water for crop cultivation and the provision of nutrients.
- If appropriately managed sandy soils can be highly productive.

Chemical nature of the problem

Salt affected soils:

- Some amounts of the salts are always present in soil. When concentration of these salts are low, they are not harmful but with the increase in the salt content the plant growth is adversely affected which in turn decrease the productivity.
- In India, salt affected soils are estimated to cover 7 m ha area. These types of soils are mainly confined to the arid and semi- arid regions.
- Salt affected soils have been classified in to three categories viz. Saline soils, Saline alkali soils and alkali or sodic soils.

Saline soils:

- Soils containing excess of neutral soluble salts dominated by chlorides and sulphates so as to affect plant growth. High osmotic pressure of soil solution hinders the water uptake by roots of plants.
- These soils are characterized by EC more than 4.0 dS m^{-1} , pH less than 8.5 and exchangeable sodium percentage (ESP) less than 15.0 .
- These soils are characterized by saline efflorescence or white encrustation of salts at the surface. In India, these soils are known as 'reh' and in others as 'thur'.

Management:

- Removal of excess salt to a desired level in the rooting zone is the basic principle in the reclamation of saline soils.
- Leaching with water of good quality and adequate drainage are the two essential components.
- The addition of organic matter improves physical conditions of the soil and increase the water holding capacity, hence keeps the salt in diluted form.
- Rice is considered a satisfactory crop during initial year of reclamation. After rice, growing of legume is suitable for the production. Cultivation of salt tolerant crops (Table-1) is the other management practices.

$$\text{Soil} - \text{Na2} + \text{CaSO4} \rightleftarrows \text{Ca} - \text{Soil} + \text{Na}_2\text{SO4}$$

- The above reaction is reversible therefore sodium sulphate formed needs to be removed by leaching.
- The fertilizers which have acidic residual effect should be used. The preferential order is NH_3 >NH_4Cl > $(NH_4)_2SO_4$ > Urea.
- The addition of organic matter is always good in improving soil physical conditions viz. aeration, water holding capacity, infiltration, pulverization.
- It is advisable to grow tolerant and medium tolerant crops.
    - Tolerant crops: Rice, Sugarbeet, Dhanicha
    - Medium tolerant crops: Wheat, Barely, Oats, Millets
    - Sensitive crops: Legume, Maize, Ground nut

Saline – alkali soils:

- These soils are characterized by EC more than 4.0 dSm-1, pH more than 8.5, ESP more than 15.0.
- Such soils have characteristics of both saline and alkali soils. Therefore, soils showing high salinity and ESP should be reclaimed for both but first for salinity and later for excessive exchangeable Na.

Acid Soils:

- The leaching of bases is the main cause of the formation of acid soils though parent acidic rock is also contributing factor.
- These soils are high in exchangeable Al3+ and H+ with a pH value less than 5.5 and respond to lime application.
- The adverse effect of acid soils on plant growth is mainly related to presence of aluminum, manganese and iron in toxic concentration, deficiency of calcium and magnesium, nutrient imbalance and microbial imbalance.
- The aluminium toxicity has multiple effects, of which the inhibition of root growth is perhaps the most important.
- The manganese (below pH 5.0) toxicity interferes with plant metabolism.
- The acid soils are generally low in available phosphorus and have high P fixation capacity. The status of available micronutrient elements, except molybdenum, is generally adequate in these soils.
- The population of bacteria and actinomycetes are lower, and those of fungi are higher.
- The acid soils cover a large area of about 47 mha in the states of Assam, Tripura, Mnipur, W.Bengal, Bihar, Orissa, Karnataka, Tamil Nadu, Himachal Pradesh and Kerala.

Management:

- Acid soils can be managed in two ways viz. either by growing crops suitable for a particular soil pH or by ameliorating the soils through the application of amendments which will conteract soil acidity.
- The acid soils are made more suitable for agriculture use by liming which raises the pH.
- The common practice of liming is to apply ground limestone to soil. When liming materials (Table-2) are added to the soil they get hydrolysed and release hydroxyl ions which neutralize hydrogen ions (cause of acidity). This process can be represented by the following equations:

$$CaCO_3 + H_2O \text{ --------> } Ca^{++} + HCO_3^{-} + OH^{-}$$
$$H^{+} \text{ (soil solution) } + OH^{-} \text{ -----> } H2O$$

Table2: Liming material and their neutralizing value

Liming material	Chemical formula	Neutralizing value
Burnt lime	CaO	179
Slacked lime	$Ca(OH)_2$	136
Dolomite	$Ca\,Mg(CO_3)_2$	109

- The crop species which are more tolerant to soil acidity and problems associated with it should be grown.
- Sensitive Crops: Arhar, soybean, cotton, oats
- Semi-tolerant crops: Gram, maize, sorghum, peas, wheat, barley
- Tolerant crops: Paddy, potato, tea, millets.

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Lecture 15 Soil Environmental Quality

Introduction

- The agricultural activities involve addition of nutrients, pesticides and sediment to soil.
- On the other hand, industry and urbanization pollute the soil with solid wastes, heavy metals, solvent and several other organic and inorganic substances.
- As the world population grows, increasing amounts of wastes are produced and most often soil is the medium for disposal of wastes.
- Dispersal of wastes from its source can be through the atmosphere, via the water bodies or directly in to the soil.
- Once in the soil it enters in to food chain thereby affecting plants, animals and human but in some cases, alters the composition of the soils and its ability to form perform its many functions. For example, some forms of pollutants can diminish the population of soil organisms such as earth worms and microbes, which decrease the biotic capabilities of the soil.
- The pollutant can be transported from the soil to water bodies where they contribute to further damage of environment.
- The soil acts as a physical filter by its sieving action , a chemical filter by absorption , precipitation and transformations of chemical substances, and a biological filter by decomposing organic materials, it does not have infinite capacity to perform these functions.
- The addition of any substance to soil which exert adverse effects on its functioning can be defined as soil contamination.

Types of environmental pollution activities :

- Two types of environmental pollution activities are associated with the soil.
- The pollution of soil itself making it unfit either as a medium for plant growth or for growing crops plants that do not contain enough toxic substances so as to suitable for human/ animal consumption. The indiscriminate application of nitrogen and some micronutrients can pollute the soil. An indiscriminate land application of wastes may often lead to pollution problems.
- Management of soil may contribute to the pollution of water such as leaching of nitrate to ground water.

Types of pollutant

There are six general kind of pollutant which receive attention in the soil environment.
Pesticides:

- The use of pesticides (insecticide, fungicides, herbicides) in India is increasing at the rate of 2-5 % per annum.
- A large portion of the pesticides applied to control pests and weeds find its way in to the soil which acts as residues.
- Inappropriate application of pesticide can lead to off- target contamination due to spray drift and run-off from plants, causing contamination of the soil.

- Soil flora and fauna may be adversely affected due to contamination. Organisms responsible for nitrification and nitrogen fixation are seriously affected by pesticides.

Inorganic pollutants:

- The group of inorganic pollutants such as mercury, cadmium, lead, arsenic, nickel, copper, zinc, molybdenum, manganese, fluorine and boron which have been found in toxic quantities as they move along the food chain.
- The burning of fossil fuels, smelting and other processing techniques release in to the atmosphere, tons of these elements which can adversely affect surrounding vegetation. These 'aerosol' dust particles may be carried for miles and later deposited on the vegetation and soil.
- The domestic and industrial sewage and sludges are major source of potentially toxic chemicals.
- A continuous application of sewage waste over several years may result in enrichment of heavy metals that can have harmful environmental effects.
- The inorganic chemical compounds can be prevented and eliminated by eliminating or drastically reducing the soil application of toxins and by reducing recycling of inorganic chemicals through soil and crop management.

Organic wastes:

- Soil have long been used as disposal sinks for organic wastes.
- The pollution potential of organic wastes, urban and rural, has become a national and even international problem.
- The primary disadvantages of disposing of organic wastes in soils include heavy metal contamination and excess nitrate leaching in to ground water.
- Toxicity of heavy metals and nutrients growth of grass or other plants used for ground cover. This in turn lead to a reduced infiltration rate at the site, limiting the soil usefulness for further waste absorption.

Salts

- Contamination of soils with salts is one form of soil pollution primarily agricultural origin.
- Salt accumulation has been a perpetual problem of civilization in arid and semiarid regions.
- Salt accumulate in the soils because more of them move in to the plant rooting zone than move out. This may be due to application of salt-laden irrigation water in poorly drained soils.
- Salts move up from the lower horizons and concentrate in the surface soil layers.
- The salts are found in heavily populated and industrialized areas where water is returned to streams following its domestic or industrial use.
- Some sevage sludge have sufficiently high levels of salts to cause crop plant damage when the sludge is applied.
- The control of salinity depends almost entirely on water, its quality and management.

Since soils are being used as burial sites for low –level radioactive waste, care should be exerted to be certain the soil properties are such as to discourage leaching or significant plant uptake of the chemicals.

Radionuclides:

- Radioactive elements emit radiations which could be gamma rays, beta rays, alpha particles or neutron. There are several sources from which radioactive contamination might be occurring.
- The fallout from testing of nuclear weapons has resulted in worldwide contamination, while waste products and effluents from nuclear reactors have been the principle source of localized contamination.
- The serious nuclear accident at the Chernobyl power plant in 1986 demonstrated the vulnerability of agricultural soils to radioactive contamination from atmospheric fallout plant.

Acid rain :

- Acid precipitation , popularly called acid rain, is apparently due to the oxidation of nitrogen and sulphur containing gases that dissolve in water vapor of the atmosphere to form nitric acid and sulphuric acid.

$$2NO + O_2 \_\_\_\_\_\_\_\_\_ 2NO_2 \overset{H_2O}{\_\_\_\_\_\_\_\_\_} 2HNO_3 + HNO_2$$

Nitric	Nitrogen	Nitric	Nitrous
Oxide	dioxide	acid	acid

$$2SO_2 + O_2 \_\_\_\_\_\_\_\_\_\_\_ 2SO_3 \overset{2H_2O}{\_\_\_\_\_\_\_\_\_\_\_} 2H_2SO_4$$

Sulphur	Sulphur	Sulphuric
dioxide	trioxide	acid

- These nitrogen and sulphur oxides move into the atmosphere, be converted to inorganic acids, and return to the soil in rain and snow.
- The continued inputs of acid rain at pH 4.0-4.5 would have significant effects on pH of soils, especially those that are weakly buffered.

Strategies for minimizing soil pollution

- The genetical characteristics, plant species and even verities differ in their susceptibility and tolerance. The leafy vegetables and root crops accumulate larger amounts of heavy metals than grain crops. For example spinach can absorb large amounts of Pb and Cd, whereas, wheat grains accumulate very less amount of toxic heavy metals.
- It will be safe to apply wastes containing toxic constituents less than 1/15th of the amount of nitrogen that will become available.
- There must be judicious reduction in the intended application to the soil of the wastes containing toxic compounds
- Growing of crop plants that have tendency to accumulate the pesticide or following soil management practices leading to increased leaching of the pesticides
- For the minimization of pollution due to N can be achieved by
    - Optimum use of the ability of crop plant to compete with processes that lead to losses of nitrogen from soil plant system

- Direct reduction in the rate, duration and extent of losses of N to the environment by loss processes themselves
- Use of high analysis fertilize.
- The application of easily decomposable organic matter can help to reduce pesticide level in the soil.
- The prevention of soil contamination by inorganic toxic compounds particularly heavy metals can be achieved by
    - Reducing the application of toxins to the soil.
    - By managing the soil-crop system in a manner that leads to the prevention of further cycling of toxins
- Heavy phosphate application to soil can also lead to reduced availability of toxic cations
- The removal of Se through phytoremediation if harvests are not fed to human beings or domestic animals.
- The adverse effect of acid rains in the soil can be reduced or alleviated by drastically reducing the emission of sulphur and nitrogen oxides. Second, the effect of acid rain on soil pH can be overcome by adding lime.

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Lecture 16 Quality of Irrigation Water

Introduction

- Knowledge of irrigation water quality is critical to understanding management for long-term productivity.
- Irrigation water quality is evaluated based upon total salt content, sodium and specific ion toxicities.
- In many areas, irrigation water quality can influence crop productivity more than soil fertility, hybrid, weed control and other factors.
- The concentration and composition of dissolved constituents in a water determines its quality. Quality of irrigation water is one of the main factor that affect the physical and chemical properties of the soil and ultimately, the crop growth.
- The irrigation water must be free from excess soluble salts and chemical substances that may create soil quality problems such as salinity, sodicity, permeability and specfic ion toxicity.
- The underground water remains in contact with various types of rocks and minerals which may be the source of its contamination.
- There is a universal fact that as we increase the area under irrigation, means we are increasing the area under salinity problem. Thus, there are two problems.
    - Irrigation problem
    - Salt problem
- The soluble salts contained in irrigation water has two problems or adverse effects
    - On the physico-chemical properties
    - On the metabolic activities of the crop plants.

Characteristics that determine quality:

- The characteristics of an irrigation water that appears to be t important in detemining its quality are:

Total concentration of soluble salts

- It is expressed in terms of electrical conductivity (EC). The soluble salts are SO_4^- and Cl^- of Ca^{++}, Mg^{++}, Na^+ and K^+.
- In general, irrigation water with EC values less than 750 micro-mhos/cm is safe for plant growth.
- Under good drainage conditions, the crops can be grown successfully even at higher EC values. Thus both the drainage condition of the soil and salt tolerance of the crops is important in this case.

Sodium adsorption ratio (SAR)

- This determines the alkali hazard of the irrigation water. As we know that alkali soils are formed by the accumulation of the exchangeable Na+.
- Thus a poor quality irrigation water rich in Na + is responsible for alkalinity in the soil. The equation of SAR is given below:

-
- Thus higher the SAR of irrigation water, more harmful it is for the crops. Thus, low SAR is better (<10).

Boron content

- The concentration of boron is safe in water when it is < 0.04 ppm. However, it is an important plant nutrient but very toxic when present in high concentration.

Bicarbonate content

- Irrigation water containing high concentrations of bicarbonate ion (HCO_3^-), there is tendency for calcium and magnesium to precipitate as carbonates.
- This reaction does not go to under ordinary circumstances. Thus, the concentration of calcium and magnesium are reduced and relative proportion of sodium is increased which is harmful for plant growth.
- The effect of its concentration on the quality of water is determined by the "residual sodium carbonate" or ' RSC'. The water containing RSC less than 1.25 meq L -1 is safe for plant growth.
    - $RSC = (CO_3^{--} + HCO_3^-) – (Ca^{++} + Mg^{++})$

Specific ions

- Chloride is a common ion in irrigation waters. Although chloride is essential to plants in very low amounts, it can cause toxicity to sensitive crops at high concentrations.
- Like sodium, high chloride concentrations cause more problems when applied with sprinkler irrigation. Leaf burn under sprinkler from both sodium and chloride can be reduced by night time irrigation or application on cool, cloudy days.
- Drop nozzles and drag hoses are also recommended when applying any saline irrigation water through a sprinkler system to avoid direct contact with leaf surfaces.
- As with boron, sulfate in irrigation water has fertility benefits, and irrigation water often has enough sulfate for maximum production for most crops. Exceptions are sandy fields with <1 percent organic matter and <10 ppm SO_4^- S in irrigation water.
- The nitrate ion often occurs at higher concentrations than ammonium in irrigation water.
- Waters high in N can cause quality problems in crops such as barley and sugar beets and excessive vegetative growth in some vegetables. However, these problems can usually be overcome by good fertilizer and irrigation management.
- Regardless of the crop, nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 ppm NO_3^- N (45 ppm $NO3^-$).
- Some important and widely acceptable ratings are given below. These should be taken as general guideline and necessary correction may be made depending upon the soil-crop situation.

Parameter	**Permissible/ safe**	**Moderately safe**	**Moderately unsafe**	**Unsafe**
RSC (meL^{-1})	< 1.25	-	1.25-2.50	>2.50
SAR	< 10	10-18	18-26	>26
B ($mg L^{-1}$)	< 2.0	2.0-2.5	2.5-3.0	>3.0
Cl ($mg L^{-1}$)	< 140	140-350	-	>350

Management of poor quality irrigation water

- The poor quality irrigation water should be mixed with good quality water, if possible to dilute bad effect.
- To remove the soluble salts, they may be removed by leaching through heavy irrigation.
- Organic matter, if applied binds boron and make organo- metallic complex. Thus, toxic effect of boron will be reduced.
- Application of gypsum will neutralize the bad effect of Na^+.

* * *

Lecture 17 Soils of India

Introduction

The major soil groups of India and their properties

- India situated between the latitude of 08^{0}4′ and 37^{0} 06′ N and longitudes of 68^{0} 07′ to 97^{0} 25′ E, has a geographical area of 329 Mha.
- India with a variety of landforms,geological formations and climatic conditions, exhibits a large variety of soils. The variety is so diverse that except few soil orders, India represents all the major soils of the world.
- The major soil group of India , according to the Genetic approach can be classified in to following soil groups:

Alluvial Soils:

- The name of Alluvial Soils is given to soils which have developed on parent materials transported by differnt agencies viz. water, ice, gravity and wind.
- They are by far the largest and the most important group of soils for crop production.
- They are extensively distributed in the states of Punjab, Haryana, Uttar Pradesh, Uttrakhand, Bihar,West Bengal, Assam and coastal regions of India and occupy an estimated area of 75 Mha in the Indo-Gangetic Plains and Brahmaputra valley alone.
- These soils are variable in texture, depending on the source of parent material and their place of deposition.
- They are coarser near the source and become finer near to sea.
- They are stratified and irregular distribution of organic matter with depth.
- They are either alkaline or acdic
- The profle development varies from undeveloped (A-C)to very developed(A-B-C) profiles.
- They are inherently rich in plant nutrients.In general, they are fairly sufficient in phosphorus and well supplied with potassium, but are deficient in nitrogen and organic matter.
- These are the best agricultural soils used for growing most agricultural crops. Because of unjudicious use of irrigation water some soils have been rendered waterlogged and pose problem of soil salinity and/ or sodicity.

Black(Cotton) Soils:

- The name black is given to soils that are very dark in colour and turn extremely hard on drying and sticky and plastic on wetting, and hence are very difficult to cultivate and manage.
- These soils are dominantly distributed in the central, western and southern states of India.
- They occupy an estimated area of 74 Mha.
- The soils developed on gneisses and schist are moderately shallow(50 - 80 cm) to moderately deep(80-120 cm), while those developed on basalt are very deep (>150cm)
- They are highly clayey (30-80 %)
- The pH ranges from 7.8 to 8.7, which may go up to 9.5 under sodic conditions.
- They have high exchange capacity because of smectite clay minerals.
- These have high water and nutrient holding capacity.

- These soils do not exhibit eluviation and illuviation process, because of churning.
- These have high bulk density because of the swelling and shrinking nature of the soil.
- The dark colour of the soil is due to clay-humus complex and presence of titaniferous magnetite minerals.
- They are highly sticky and plastic and pose problems in both agriculture and non-agricultural crops.
- These soils are poor in some available plant nutrients especially N,P,S and micronutrients.
- The main constraints to crop production are due to low workability, low infilteration, poor drainage and occassional moisture stress.
- These soils are used for growing cotton, millet, sorghum in Madhya Pradesh,Andhra Pradesh, Gujrat and Maharashtra states of India.
- Under irrigated conditions they can be used for a variety of other crops like sugarcane, wheat and citrus plantations.

Red Soils:

- These soils are generally red or reddish brown and derived from granites, gneiss and other metamorphic rocks.
- These soils are formed under well drained conditions.
- Eluviation and illuviation of clay, iron, aluminium and bases are the main soil forming processes.
- These soils are predominantely observed in the southern parts of the Indian Peninsula, comprising the states of Andhra Pradesh,Tamil Nadu, Karnataka, Maharashtra, Orissa and Goa and in North Eastern States.
- These soils are highly variable in texture, ranging from loamy sand to clay loam.
- They are shallow and poor gravelly in the uplands to very deep, fertile in the plains and valley.
- They are, in general, neutral to acidic in nature.
- The CEC and base saturation of these soils are relatively lower than those of black and alluvial soils.
- These soils are generally deficient in N,P and K.They are also poor in organic matter and lime contents.
- These soils show common presence of kaolinite clay minerals.
- The soils pose limitations of soil depth, poor water and nutrient holding capacity, surface crusting and hardening, excessive drainage and runoff.
- Under good management practices, these soils can be profitabily used for variety of agricultural, horticultural and plantation crops, such as millets, rice, groundnut, maize, soybean, pigeonpea, greengram, jute, tea, cashew, cocoa, grapes, banana, papaya, mango etc.

Laterite and Lateritic Soils:

- The lateritic soils are those in which laterization is the dominant soil forming process.
- It is a compact to vesicular rock like material composed of a mixture of hydrated oxides of iron and aluminium with small amounts of manganese oxides and titania.
- They are generally observed on hill tops and Plateau landforms of Orissa, Kerala, Tamil Nadu etc.
- These are deeply weathered soils with high clay content.
- The lateritic soils are more widely distributed and occupy about 25 Mha of the total geographical area of India
- Kaolinite is the dominant clay mineral of these soils

- These soils lose bases and silica due to pronounced leaching with accumulation of sesquioxides and the soils are rendered acidic .
- These are low in CEC and base saturation.
- The major limitations posed by these soils are deficiency of P,K,Ca, Zn,B, etc and high acidity and toxicity of aluminium and manganese
- The laterites of lower topographic positions are used for growing rice, banana, coconut, arecanut and higher topographic positions for cocoa, cashew, tea, coffe, rubber etc.

Desert (Arid) Soils:

- A large part of the arid region belonging to western Rajasthan, southern Haryana and south west Punjab, lying between the Indus river and Aravalli hills, covering an area of 29 Mha.
- The soils of hot arid belts are comparable with those of Alluvial soils, but have an aridic moisture regime.
- The sandy material, under arid conditions , results in poor profile development.
- These are sandy to loamy fine sand in texture with clay content varying from 3.5% to less than 10%.
- Pale brown to yellowish brown in colour and have weak subangular blocky structure.
- Poor in nutrient(N,P,K,S and Zn) and water holding capacity.These are slightly to moderately alkaline in reaction(pH 7.8-9.2) because of calcareous nature.
- These soils may form gypsic horizon. Such gypsiferrous soils need special attention to avoid formation of sink holes, if irrigated.
- The built up of organic matter is very low
- The major constraints of these soils are less water which restricts their use for raising agricultural crops. However, some areas are used for growing millet and pulses.
- If irrigated, they can be profitabily used for growing two crops in a year.

Forest and Hill Soils:

- These soils developed under forest cover.
- In India , the total area under forest is estimated to be 75 Mha and is observed dominantly in the states of Himachal Pradesh, Jammu and Kashmir, Uttar Pradesh, Uttrakhand, Bihar, Madhya Pradesh, Maharashtra, Kerala and North-East region.
- The climatic conditions and and altitude control the kind of forest species, the kind of forest and topography control the kind of soils and their degree of profile development.The major soils observed in different areas are
    - **Brown forest and Podsolic:** In Northern Himalayas, developed on sand lime stone, conglomerate, granite, gneisses and schists under cool/cold humid climate (acidic enviornment)
    - **Red and Lateritic:** In Deccan Plateau, developed on igneous and metamorphic rocks(basalt, granite, gneisses) under tropical climatic conditions(slightly acidic, neutral or basic environments)

Podsolic Soils:

- The soils found under coniferous vegetation in the presence of acid humus and low base status.
- These soils are moderately to strongly acidic in reaction (pH 4.5-6.0)
- These soils are high in organic matter content(3.0-3.5%) and, in general, low(<50%) in base status.

- These soils are variable in exchange capacity [10-15 cmol (p+) kg^{-1}]. The clay content varies from 20-30%
- These soils are deficient in P.
- These soils face a major problem of erosion by water.
- They are used for growing a variety of crops – rice, maize, soybean etc. on terraces and tea and other fruit crops on slopes.

Brown Forest Soils:

- These soils developed on sedimentary rocks/ or alluvium under subhumid to humid climate and mixed vegetation are Non Calcic Brown or Brown Forest soils.
- They are neutral to slightly acidic in reaction (pH 6.0-7.0).
- The calcareous members under sub-humid conditions may have a pH around 8.2.
- These are moderate to high in organic matter content (2-3%) which decreases with depth
- These are moderate in cation exchange capacity [15-20 cmol(p+) kg^{-1}] and exchange complex is almost saturated with bases (70-90%).
- The soils have great potential for growing agricultural crops such as rice, maize and fruit plants such as apple, almond, pear, apricot etc.

Salt Affected Soils:

- The soils occuring in the arid and semi arid regions and occupy about 10 Mha area of which 7Mha is sodic.These soils occurs in the Indo-Gangetic planes followed by the Deccan (Peninsula)
- Plateau supporting black soils, the rest in the arid and coastal regions are saline.
- The sodic soils of the Indo-Gangetic plain, occupy relatively lower topographic positions where products of weathering accumulate during the monsoon rains by surface runoff.
- The saline soils of coastal region result from the rise of brackish ground water due to capillary action under excessive evaporation.
- The sodic soils pose serious problem of high sodium on the exchange complex, poor physical conditions, especially soil structure and drainage, nutrient and water availability and micronutrient deficiency.
- Another problem is of receding ground water in the central sectors and the south-west sectors of Punjab, Haryana and some parts of Rajasthan. The rise in ground water causes salinization of soils.
- The sodic soils once ameliorated by applying gypsum, are used for growing rice followed by wheat.

Soil Orders (as per Soil Taxonomy) representing different soil groups:

S.No.	Genetic System	Soil Taxonomy	
		Mainly	**Occasionally**
1	Alluvial Soils	Entisol,Inceptisol	Alfisol, Aridisol
2	Black(Cotton) Soils	Vertisols,	Inceptisols, Entisols
3	Red Soils	Alfisol, Ultisols	Inceptisols, Entisols
4	Laterite and Lateritic Soils	Ultisols	------
5	Desert soils	Aridisol	Entisols
6	Forest and Hill Soils	Alfisols, Ultisols	Inceptisols

	Podsolic Soils *Brown Forest Soils*	Inceptisols, Mollisols, Alfisols	Entisols
7	Salt Affected Soils	Aridisols, Inceptisols,	Alfisols and Vertisols

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PRACTICALS

Exercise: 1

Aim: Collection and preparation of Soil Samples

Importance:

- Soil sampling is the most vital step for analysis. As a very small fraction of the huge soil mass in the field is used for analysis.
- One of the most important aspects in soil testing is the matter of obtaining a soil sample that is representative of the area. If the samples do not represent the field, it is impossible to make the good recommendations.
- It is said that sample is filth or dirt, if it has been not drawn properly by adopting standard methods.
- Soil sampling is done in order to find out the quantity of essential nutrients available to plants and other relevant physico-chemical properties which influence plant growth such as water retention, acidity, alkalinity etc.

Time and depth of Soil Sampling :

- The soil sampling is done when there is no crop in the field i.e., before the growing the next crop and also prior to application of manures and fertilizers. Rainy season should be avoided for sampling work.
- The root penetration is important for crop growth, therefore, for cearls, vegetables and another seasonal crops the sample should be drawn from 0-15cm i,e., plough layer.
- For deep rooted crops like sugarcane, cotton or under dry farming conditions, obtain samples from different depths. For plantation crops or fruit trees samples should be collected from 0-30, 30-60, and 60-100 cm depth.
- In case of saline alkali soils, salt crust if visible on the soil surface should be sampled separately and record the depth of sampling. Generally, the sample may be drawn up to 15 cm depth from surface for testing.
- Ten-fifteen soil samples collected from homogeneous sampling units are mixed and smaller sample is drawn which represents the entire sampling unit is known as composite sample. A field can be treated as a single unit if it is appreciably uniform and 0.5 ha is taken as one sampling unit.

Tools and Materials:

- Sampling tools: Soil auger/soil tube/spade/pick-axe/khurpi
- All sampling tools and storage bags (Fig-1.1) should be cleaned to avoid contamination.
- A bucket or tray for collecting and mixing the composite sample.
- Cloth bags or polythene bags , Paper tags, Information sheet, Ball point pen or copying pencil, Pestle and mortar and 2 mm sieve.

Procedure:

- Divide the field (Fig1.2) on the basis of variations in slope, colour, texture, crop growth and management practices.
- Scrap away the surface litter without much disturbing soil.

- Take 15 soil samples randomly distributed over each area using a soil auger/tube and place them in clean bucket(Fig.1.3A &B). A khurpi or spade can be also used if auger is not available. In this case, make a V shaped cut up to 15 cm thick slice of soil from top to bottom, moving in a zig-zag manner from each sampling unit and place the samples in a clean bucket.
- From fields having standing crops in rows draw samples in between rows(Fig.1.4)
- Mix thoroughly the soil sample taken from each area on a clean piece of cloth or polythene sheet by hand(Fig.1.5)
- Reduce the bulk of soil sample to about 500g by quartering process in which the entire soil is spread, divided in four equal parts; two opposite ones are discarded and remaining two are remixed. Repeat this procedure until about half kilogram of the soil is left. Put the soil in a clean cloth/ polythene bag free from any contamination of fertilizer, salt etc.
- Prepare two labels, one to be put inside the bag (Fig1.6)
- Fill out an information sheet for each composite sample. The information should be as complete and accurate as possible.
- Pack the soil sample bags along with information sheet in a clean and dry gunny bags.

Processing of Soil Samples for Analysis:

- Air dry the soil samples in shade.
- Crush the soil clods lightly and grind with the help of wooden pestle and mortar.
- Pass the entire quantity through 2 mm stainless steel sieve.
- Discard the plant residues, gravels and other material retained on the sieve.
- If the gravel content is substantial, record as per cent of the sample(w/w)
- For certain type of analysis (organic carbon), grind the soil further so as to pass it through 0.2 to 0.5 mm sieves.
- Remix the entire quantity of sieved soil thoroughly before analysis

Precautions:

1. Draw the soil samples from uniform piece of land. Sample should never be collected either from hills or depressions in the field as these do not represent the natural conditions of the field.
2. Do not draw any sample from extreme corners of the field, areas recently manured or fertilized, old bunds, marshy spots, manure piles and non-representative areas.
3. Avoid contact of samples with chemicals, fertilizers and manures.
4. Use steel augers instead of rusted iron khurpi or kassi for sampling of micro-nutrient analysis.
5. Do not take less than 0.5 kg of composite sample
6. Do not dry the soil directly under sunlight or by artificial heating. Air dry the sample under shade.
7. Store the samples preferably in a clean cloth or polythene bags.
8. Use glass, porcelain or polythene jar for long duration storage

Information sheet

The following information should be collected and send with the sample:

1. Date of sampling
2. Address of the farmer
3. Field number
4. Depth of sampling.

5. Purpose of sampling. (fertility appraisal, garden plantation, etc.)
6. Soil name
7. Slope
8. Irrigated/ Rain fed
9. Natural drainage
10. Water table
11. Land use and rotation followed
12. Details of manures or soil amendments applied

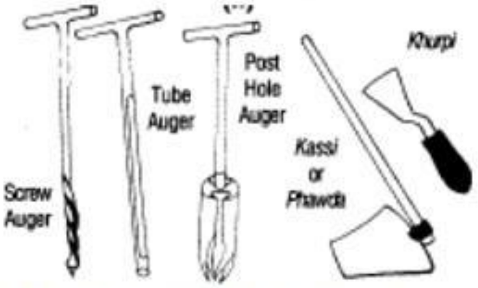


Fig. 1.1 : Tools for collecting soil samples. A khurpi or tube auger proves more convientent for sampling from plough layer.

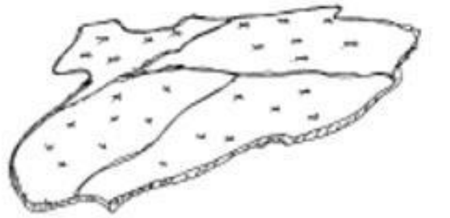


Fig. 1.2 : Draw a separte sample from each field. Areas or patches looking different in slope, colour, texture, crop perfomance should be sampled separately.

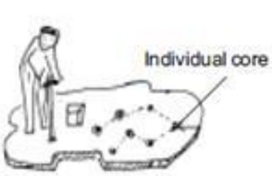


Fig. 1.3A : Collect a repersentative soil sample by mixing soil from individual core.

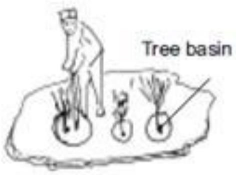


Fig. 1.3B : From the orchards, draws soil samples from the tree basin. (60 cm away from tree trunk in full grown fruit trees).

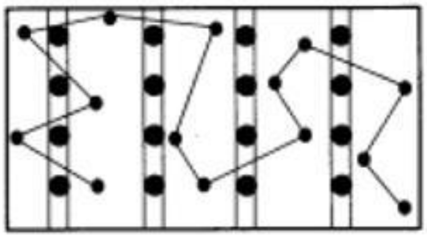


Fig. 1.4 : From the standing crops, draw soil samples in between the rows to prepare a composite sample

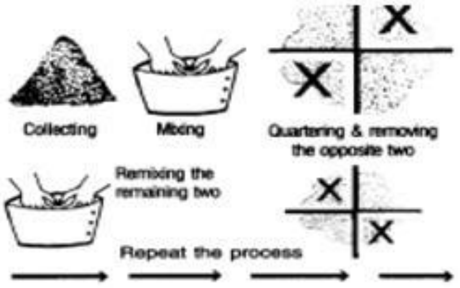


Fig. 1.5 : Keep the collected soil at a clean place, mix thoroughly by hand, spread and make foru quarters, discard the two opposite ones. Remix the remaing two quarters. Repeat the process to reduce the quantity to about 400-500 g.

Fig. 1.6 : Transfer the soil to clean bags. Place one lable inside the bag and another be pasted outside, indicating sample no., name of owner, depth of sampling, identification mark etc. before sending to soil testing laboratory.

Fig.1. Procedure for collecting a representative soil sample

Exercise : 2

Aim: Study of Soil Profile

- The vertical section of the soil from the surface extending in to the parent material is called soil profile.
- The various layers, composing the soil, are called horizons. A soil horizon may be defined as a layer (of varying thickness) approximately parallel to to the soil surface.The horizons in profile (Fig-1) can be designated as follows:
  - The organic horizon on the top is called 'O' horizon which is formed above the mineral soil. This results from the addition of any organic matter like litter derived from plants, roots, rootlets, dead bodies of insects, animals, etc. This layer ordinarily occurs in cool, humid temperate and subtropical climates.
  - The 'A' horizon (zone of eluviation)is the mineral horizon which lies below 'O' near the surface and is characterised usually as the zone of intensive leaching.
  - The 'B' horizon (zone of illuviation) occurs immediately below the 'A' horizon in which maximum accumulation of materials such as iron and aluminium oxides, salts and clays has taken place. These might have been washed down from upper horizons. The 'A' and 'B' horizons together are called 'solum'. These are further divided into A_1, A_2, A_3, B_1,B_2 and B_3 horizons depending upon identifying characters. The A_3 and B_3 are transition horizons between A and B, B and C horizon, respectively.
  - The 'C' horizon is the parent material underlying the solum. It is less weathered than solum and consequently has no horizon differentiation. However in certain cases like alluvial soils, black soil, the horizon differentiation may not be there. The 'R' layer is the underlying consolidated bed rock but in alluvial soils this is not likely to be present.

Significance:

- The study of soil profile and its characteristics determines the agricultural value(orchard, forest & crop) of land.
- It also gives an insight in to the problems, such as salinity and alkalinity, waterlogging, presence of hard pans etc of soil and explain its behaviour towards use and management.
- It is pre-requisite for classifying soils.

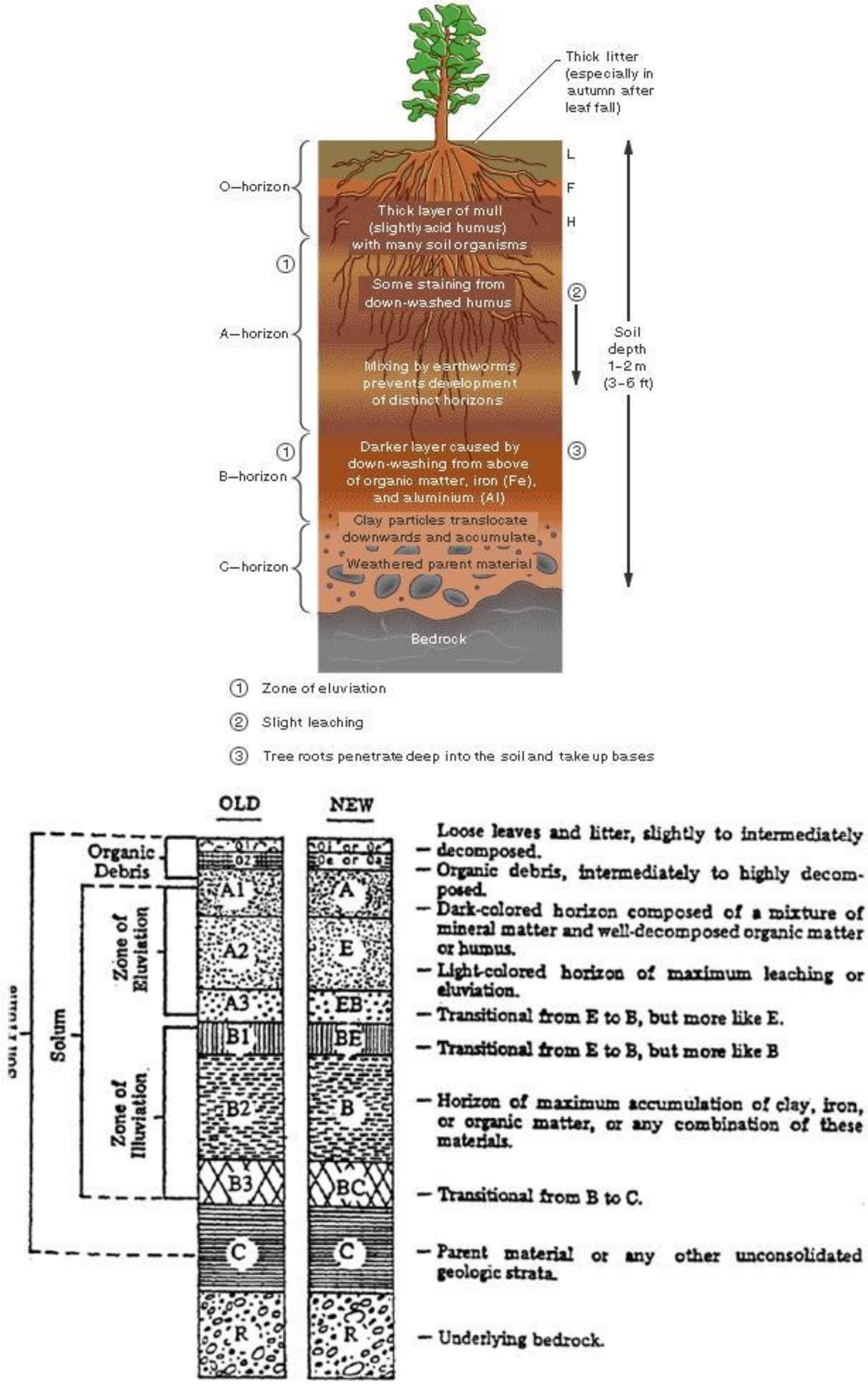


Fig1: Soil Profile with common horizon designation.

Materials required:

1. Digging tools - Spade, pickaxe, khurpi etc.
2. Cutting knife with a strong wooden handle.
3. Abney's level or inclinometer
4. Altimeter
5. Measuring scale / tape
6. Munsell's colour chart
7. Dilute hydrochloric acid (10%)
8. Wash bottle (with distilled water)
9. Magnifying lens
10. Indicator papers
11. Tray with shoulder
12. Profile description papers
13. Soil sample bags with polythene lining
14. Copying pencil/ ball pen

Procedure:

A. Selection of soil profile:

- **Select the profile such that**
    - It is representative of the normal conditions prevailing in the area.
    - It is away from tree an irrigation channel/ditch/rivers, roads,human inhabitation etc.
    - It shows minimum of human interference, if, possible virgin area should be selected.

B.Digging of a soil profile

- Dig out a pit of size 2m x 2m to a depth of 2m or upto the parent material. Provide steps, if necessary, on one side for getting into the pit.

C.Examination and Description of soil profile

- Identify the horizons of the profile on that side of the pit which receives maximum daylight.
- Demarcate the horizons on the basis of characteristics that can be seen or measured in the field such as colour, texture, structure, consistence, presence of carbonates etc.
- If the horizons are not properly differentiated as in case of alluvial and black soils, examination of soil should be done at a depth intervals of 15 cm down to 1 m depth and thereafter, at intervals of 15 cm up to 2m or up to the parent material, whichever occurs earlier.
- Describe each horizon for the following:
    - Horizon symbol
    - Depth of from the top to bottom of a particular horizon in centimeters
    - Nature of boundary with the horizon below
    - Colour : Moist and dry –Munsell colour chart
    - Colour of mottling (if any)
    - Texture: Feel method which will be explained in the field
    - Structure: Three feature of structure viz. grade, class and type.
    - Consistence : wet, moist and dry

- Cutans(ped coatings), pressure faces, slickensides etc.
- Roots traces : The quantity, size and location of roots in each horizon
- Nodule concretions and cementation (if any)
- Pores
- Lithorelics: The content of rock and mineral fragments in each horizon, note down their percentage.
- Hard pans
- Content of carbonates, soluble salts etc.
- Artefacts : The activity of man's activity
- Soil reaction

Complete the profile description in the given proforma, while studying the profile.

- Collect the soil samples in marked sample bags by making a vertically uniform slice of soil for further examination in the laboratory.

D.General description of profile site:
The general description of soil profile should include

1. Profile number e.g. P_1, P_2 etc.
2. Location of the profile: Give longitude and latitude with distance and direction from a nearby bench-mark reference site.
3. Date of examination
4. Climatic conditions e.g. monthly and annual rainfall and temperature data.
5. Vegetation and landuse e.g. grasses,shrubs, forest etc. and landuse i.e. wheat, paddy or fallow
6. Parent material e.g. alluvium, mica schist, granite etc.
7. Physiographic position of the site e.g. terrace, flood plain, depression, plateau, valley bottom etc.
8. Land form of surrounding area
9. Elevation (in meters above the mean sea level)
10. Hydrology. Drainage condition, depth of ground water, moisture condition in the profile and artificial drainage.
11. Biological activity, root development etc
12. Evidence of erosion and its intensity
13. Presence of salts or alkali
14. Human influence like tillage, levelling, use of amendments, heavy manuring etc.
15. Presence of surface stones or rock out crop

Precautions:

- Expose the profile at such a place that it is representative of the whole area.
- Do not expose it at elevated or depressed locations in field or in a direction directly facing the sun.
- Dig the profile at such a place that maximum visibility is obtained.
- Remove the plant cover if any before digging the pit in a manner so that the soil surface is not disturbed.
- Mark the soil sample bags properly indicating location, depth, horizon details, etc.
- Dig the profile pit in such a way that one side of it has steps for movement of the personnel.

Exercise: 3

Aim: Determination of Soil Colour

- Soil colour is one of the most widely known and most generally used property.
- Soil colour often form the basis of recgnition of soil groups, differentiation of soil horizon and other soil conditions such as the content of organic matter,drainage conditions etc.
- It can be releated to specific chemical, physical and biological properties of soils.
- Soil colours are measured by comparing them with **Munsell Soil Colour Chart**.
- The soil colour is measured by ***Hue, Value and Chroma*** , the three variables, that combine to give colours.
    - Hue is the dominant spectral colour and is related to the dominant wavelength of the light. It indicates its relation to red, yellow, green etc.(e.g. R-Red, Y-Yellow).Thus 5YR is the middle of the yellow and red hues which extends from 10 R to 10 YR.
    - Value:Refers to relative lightness of colour and is a function of total amount of light. It consists of numbers frm 0(absolute black) to 10 (absolute white).
    - Chroma:Refers to the relative purity or strength of the spectral colour.Purity/Strength increases with decreasing greyness or increasing chroma.It consists of numbers from o(neutral grey), increasing at equal intervals, to a maximum of 20(for strongest colour).The chroma of 20,however, never reaches in soils. The higher the chorma, the purer is the colour.
- In the soil colour chart, the various hues are arranged by pages, one hue to a page.
- The units of a value are arranged vertically and the units of chroma are arranged horizontally on a page.
- Opposite to each page of the colour chips is a colour notation, symbols and corresponding name.
- Elements of soil colour description are colour names, the Munsell notation, the water state (dry/moist) and the physical state(crushed/rubbed/broken).
- The colour names and their limit are given in a digram opposite to each chart.
- Vertically the colours become lighter and the value increases towards the top.
- Horizontally the colours become stronger and the chroma increases as we move to right.
- In writting the Munsell notation, the order is hue, value and chroma, with a space between the hue letter and the succeding value number and a virgule between the two numbers for value and chroma.
- Thus the notation for a colour of hue 10 YR, value 4 and chroma 2, is 10 YR 4/2 and the colour name will be dark greyish brown.

Procedure:

- Take a soil ped and select an appropriate hue chart by placing the clod/crushed soil mass under the chart and match through the holes meant for the purpose.
- Determine the colour chip by moving the clod vertically/horizontally with which soil colour closely matches.
- Record the hue, value and chroma and write Munsell notation.
- Note the colour name from the digram oppsite colour chart.
- Determine soil colour under dry and moist condition.

- It may be seen that moisture influences the soil colour.It seldom changes the hue. But it does changes the value(darkness) and chroma by 1 to 3 and1/2 to 2 steps, respectively.

Precautions:

- Colour should be seen that which one is the closest match.
- The main difficulties encountered in using the soil colour chart are selection of appropriate hue chart,determination of colours that are intermediate between the hues and distinction between value and chroma where chromas are strong.

Observations:

Sample No.	Moisture	Hue	Value	Chroma	Munsell Notation	Colour Name
1	Dry Moist					
2	Dry Moist					

Exercise: 4

Aim: Determination soil moisture content

- Soil water content is used to refer the water that may be evaporated from a soil by heating until there is no further loss of weight. Therefore, soil water content is either the ratio of the mass of water present in a soil sample to the mass of soil solid present in that soil or the volume of water present in unit volume of soil sample.
- Knowledge of soil water may be required to assess the extent of availability of soil water to plants.This determination provides a means for comparing the analytical values of samples with different moisture content.

Methods of determination

- There are numerous methods available for the determination of soil water which can be divided into two categories:
    - Direct methods by which the amount of water present in a given soil is determined directly i.e. gravimetric method.
    - Indirect methods by which a soil property related to the soil water content is measured.

The simplest and most widely used method for determining the soil moisture is gravimetric method.
Principle:

- Soil water content is determined by drying a known mass of moist soil sample in an oven at 105° C. The loss in weight of wet soil sample upon drying is equal to the water content retained by the soil.

Materials required:

- Soil sampling auger,moisture boxes, oven,desiccator and balance

Procedure:

- Weigh the empty moisture box with lid
- Take soil sample of about 100 g from the required depth with the help of auger.
- Put the soil sample immediately in the moisture box and close it to prevent loss of moisture by evaporation.
- Bring the boxes containing moist soil to the laboratory and weigh immediately.
- Remove the lids and place moisture boxes in an oven and dry to a constant weight at 105° C. This takes approximately 24-48 hours.
- Allow the sample to cool for some time in oven. Then close the boxes and put them in a desicator for further cooling. Now weigh the closed boxes with the oven dry soil.

Observations and calculations:

- Weight of empty moisture box with lid = X_g
- Weight of moisture box + lid + moist soil = Y_g
- Weight of moisture box + lid oven dry soil = Z_g
- Moisture content in soil(g) = (Y - Z)
- Weight of oven dry soil(g) = (Z - X)
- Per cent moisture in soil (w) = $(Y - Z) / (Z - X) \times 100$

Precautions:

- Sample drawn should be representative of the site of sampling
- Put the soil sample into moisture box immediately following its collection and cover it with lid to avoid any moisture loss due to evaporation.
- Dry the sample to a constant weight at 105^0C

Exercise: 5

Aim: Determination of Bulk Density of Soils

- The bulk density (also known as apparent density) is defined as the mass per unit volume which includes volume (space) occupied by solids as well as pore space and is expressed in g cm-3. It changes with tillage, manuring and cropping. It decreases with loosening and increases with compaction.
- Bulk density tends to increase with depth in the profile due to low organic content in the lower layers.Fine-texture soils tend to have lower bulk densities (and thus higher porosities) than coarse-textured soils due to loose packing of the clay particles.
- Bulk density of a soil is required to determine the degree of compactness, soil pore space, an indicator of aeration status, to convert soil water contents from the gravimetric to the volumetric basis, to provide information about the environment available to the many soil micro-organisms, which live within them.

Methods of determination

- There are different methods adopted for the determination of bulk density in the field and laboratories. The various methods used for determining bulk density are pycnometer, core - tube ,clod coating and gamma density methods.
- The most commonly used core - tube method have been described below:

Principle

- The method involves sampling a soil core, from a desired depth, in its most natural
- condition using core sampler (cylindrical metal sampler) and determining the mass of solids and the water content of the soil core by weighing the wet core, drying it to constant weight in an oven at l05° C, and reweighing after cooling (A core may take 24 hours or more to dry).
- Bulk density is, then, calculated from the measurement of the bulk volume, using the
- core length and the diameter of the cutting edge of the sampler.

Materials required :
(i) Core sampler (ii) Vernier calliper (iii) Moisture boxes (iv) Oven (v) Balance
(vi) Desiccator (vii) Knife (viii) Spatula.

Procedure

- Slice off vegetation, if any, from the site prior to inserting the core sampler into the soil.
- Drive the core sampler vertically into level ground, deep enough, to fill the sampler upto the brim.
- Dig out the sampler by means of a khurpi or spade without disturbing the soil in the core sampler.
- Trim off the protruding soil if any from both ends of the sampler with a sharp knife.
- Take out the soil in a tray and weigh it.

- Take a part of the moist soil (about 50-75 g) in a moisture box and find out water content by drying it in an oven at 105° C and determine the oven dry weight of the soil in whole core (Ms, g).
- Measure the dimensions of the core sampler for computing the core volume (Vt cm3).
    - Volume of soil = inside volume of the core sampler

Observations and Calculations:

- Dimensions of core sampler: Radius, r = cm; Length, l = cm
- Volume of core sampler/soil, Vt cm3 = ðr2l
- Weight of moist soil (whole core), g = X
- Weight of empty moisture box, g = A
- Weight of moisture box + moist soil, g = B
- Weight of moisture box + oven dry soil, g = C
- Moisture content in soil, g = (B - C)
- Weight of oven dry soil, g = (C - A)
- Per cent moisture in soil (w) = (B - C) /(C - A) × 100
- Weight of oven dry soil (whole core) Ms, g = X ×100 / w +100

- Bulk density (g cm^{-3}) =Weight of oven dry soil in the core (Ms, g)/Volume of the core/soil (Vt ,cm^3)

Precautions

- The volume of soil is not constant as some clays swell when wet and shrink when they are dried. Hence, bulk density should be measured at field/ natural conditions,preferably at field capacity.
- Always use dent free core.
- Core should be pushed straight into the soil.
- If sampling has to be done for different layers then handling of core is obstructed by the surface soil as the core is not to long. So for this, whole area of sampling is excavated layer wise.

Exercise: 6

Aim: Determination of Soil pH

- pH is a measure of the acidity or a alkalinity of the soil It is defined as the negative logrithm of hydrogen ion activity.

Mathematically pH = - log10aH^+.
Where; aH^+ is activity of hydrogen ions in g ions/litre.
Pure water is dissociated into H+ and OH- ions according to the following equations:
$H_2O = H^+ + OH^-$

- According to law of dissociation

$[H^+] \times [OH^-] / H_2O = K$
Where: H^+ etc are the concentrations and K is the dissociation constant. Since the concentration of undissociated water remains practically the same, because of very little ionization of H_2O molecule the above relationship becomes
$[H^+] \times [OH^-] = K_w = 10\text{-}14$ at 20^0C
Kw: ion product constant of water.

- At neutrality $H^+= OH^-$ and H^+ = 10-7 or pH 7.Pure water has a pH value of 7.
- As the hydrogen ion activity increases, the pH will decrease. On the other hand, if the hydrogen ion activity decreases, the pH value will increase.. The pH scale extends from 0 to 14 and mid point on this scale is neutral. The pH value above 7 denotes alkalinity and below 7 acidity.

Principle

- The principle underlying potentiometric determination of pH is based on the measurement of electrical potential developed by an electrode (whose potential depends on the hydrogen ion activity of the solution) in conjunction with a second electrode (reference electrode) dipping into the same solution.

Material Required:

- Beakers (100 ml)
- Glass rods
- Electrical or analytical balance
- Cylinder, graduated (50 ml)
- pH meter fitted with glass and reference electrodes
- Buffer solutions of pH 4 and 10 or tablets
- Ordinary filter paper
- Wasing bottle with distilled water.

Procedure:

- Weigh out 20 g of soil in a 100 ml beaker, add 40 ml of distilled water and stir at least four times within a period of half an hour. This time is required for the soil and water to attain equilibrium.
- After half an hour again stir the soil suspension and measure the pH on a pH-meter.
- In the meantime, switch on the pH meter and set the temperature compensation knob at buffer solution tempertaure and the range selector to zero.
- After 10 minutes warming up peroid, dip the electrode in to a buffer solution of known pH, and adjust the reading to the pH of the buffer solution.
- Rinse the electrodes with distilled water and carefully wipe the filter paper.
- Shake the soil solution and insert the electrode in to it.
- Read the pH on the instrument.
- Rinse the electrodes with the distilled water and than lower them back into a beaker containig distilled water.

Observations

- pH of the soil (1:2 ratio) = ------------------

Precautions in the use of pH meter

- The electrodes should not be allowed to remain in the test solution or suspension for a longer period than necessary.
- Immediately after testing, the electrodes should be washed off with a gentle stream of distilled water.
- For storage, after cleaning, the electrodes are suspended in distilled water and the system is protected from evaporation.
- Drying out of the electrode should be avoided.

Interpretation:

pH	Interpretation
< 6.5	Acidic- requires liming
6.5-7.5	Normal- No treatment; optimum for most crops.
>7.5	Alkaline

Exercise: 7

Aim: Determination of Electrical Conductivity of Soil

- The soils contains varying amounts of soluble salts in the soil. However, excessive accumulation of these soluble salts in the soil results in harmful effects on plant growth. The measurement of electrical conductivity of soil is important as it renders information about the concentration of soluble salts in the soil.
- Electrical conductivity (EC) is the reverse of resistance. Therefore, electrical conductivity is defined as the reciprocal of the resistance of a conductor 1 cm long and 1 cm^3 in cross sectional area. It is expressed as mhos cm-1. as the value of electrical conductance obtained for soil solution are very small, therfore, it is expressed in millimhos/cm($ECx10^3$) or dS/m.
- The salt content of the soil can be estimated roughly from an electrical conductivity measurement of a saturated soil paste or a more dilute suspension of soil in water.

Principle

- Solutions of electrolyte conduct an electric current by the migration of ions under the influence of an electric field. Like a metallic conductor, they obey Ohm's law. Thus for an electromotive force E (in volts) maintained constant, the current I (in amperes) flowing between the electrodes immersed in the electrolyte will vary inversely with the resistance R of that portion of the solution between the electrodes.
- The reciprocal of the resistance is called the conductance (C) and is expressed in reciprocal ohms or mhos. The electrical conductivity values of soil are now being expressed as dSm-1.

$$\text{Viz., } I = E/R$$
$$R = I/E = C$$

- Since, salt ions allow the electric current to pass through them, therefore, the electrical conductivity of the soil water suspension rises with increasing content of soluble salts in the soil. Thus, EC is a measure of the concentration of soluble salts in the soil at a particular temperature.

Materials required:
i) Analytical/ Electrical Balance ii) Cylinder graduate of 50 ml iii) Beakers (50 ml)
iv) Thermometer (Centigrade) v) Wash bottle vi) Conductivity Meter

Procedure

- Weight out 25 g soil in a 100 ml beaker and add 50 ml of distilled water.
- Stir it intermittently for 4-5 times and than leave it overnight for getting a clear supernatant solution. Alternatively, the clear extract after the pH measurement can also be used for EC measurements.
- Adjust the temperature compensation knob to the room temperature and connect the cellto the meter.
- Measure the EC of supernatant solution using conductivity meter.

Precautions

- Soil suspension should be allowed to stand for a sufficient time so as to obtain a clear supernatant solution.
- The instrument must be set at the temperature of the test solution.
- The electrodes should be completely immersed in the test solution to get an accurate reading.
- The electrodes must be washed with distilled water and cleaned with filter paper after measuring the conductance of every sample.
- When not in use, the electrodes should be kept dipping in distilled water, otherwise, deposition of salts on them will reduce their efficiency.

Interpretation

EC(1:2 Soil :Water) dS m-1 (mmhos/cm)	Approximate salt concentration(%)	Effect
<0.8	<0.05	Normal-suitable for all crops
0.8-1.6	0.05 – 0.15	Critical for salt-sensitive crops
1.6-2.5	0.15 – 0.20	Critical for salt tolerant crops
> 2.5	0.20 – 0.25	Injurious to all crops

Exercise: 8

Exercise: Particle Size Analysis of Soil.

- The process of determining the amount of individual soil separates below 2 mm in diameter i.e. sand, silt and clay is called mechanical analysis.
- The determination of various sized particles (sand, silt and clay) helps in understanding the weathering, profile development, water retention, plasticity, cation exchange capacity, soil workability, erodibility etc.
- The information about particle size analysis is also of utmost importance for judicious nutrient and water management.
- An essential step in the mechanical analysis of soil is to separate the particles so that they function as individuals. This is called dispersion or separation.
- The completely dispersed individual primary particles are usually referred to as textural or mechanical separates.

Methods of determination

- Generally, two methods are used in the laboratories viz. ***hydrometer and international pipette method.***
- There is however, another method called 'rapid feel method' generally used in the field. This method is rough but quick and if carried out carefully gives satisfactory results.
- *International Pipette method is described below.*

International pipette method

The International pipette method is a standard for particle size (given below) analysis of soils because of its accuracy, but it is time consuming method. This is based on Stoke's law, which states that the terminal velocity of a spherical particle settling under the influence of gravity in a fluid is proportional to the square of its radius and is expressed as:

$$V = \frac{2g(\rho - \rho_w)}{9\eta} r^2$$

Where,

V = *Velocity of falling particles*
g = *Acceleration due to gravity*
ρ_w = *Density of liquid*
ρ_s = *Density of soil particles*
η = *Viscosity of liquid*
r = *Radius of the particles*

Particle size classification:

S.No.	Separate	Particle Diameter (ISSS) (mm)
1	Coarse sand	2.0 - 0.2
2	Fine sand	0.2 - 0.02
3	Silt	0.02 - 0.002
4	Clay	< 0.002

Materials required:

Equipments

(i) Balance and weight box (ii) One litre cylinder (iii) One litre beaker (iv) Hot water bath (v) Cover glass (vi) Filtration apparatus (vii) 70 mesh sieve (viii) Dish (ix) Oven (x) Wash bottle (xi) Thermometer (xii) 25 ml pipette (xiii) Rubber pestle (xiv) Blue litmus paper (xv) Sedimentation cylinder (xvi) Burner (xvii) Stirrer (Plunger).

Reagents

Hydrogen peroxide(6%), Hydrochloric acid(2N), Sodium hydroxide(1N), Phenolphthalein(1%), AgNO3solution and Distilled water

Procedure

Treatment with hydrogen peroxide

- Take 20 g air dry soil, passed through 2 mm sieve, in 1000 ml beaker.
- Add 50-60 ml 6 per cent H_2O_2 to destroy organic matter.
- Mix well and allow the reaction to proceed in the cold, preferably for overnight keeping the beaker properly covered with a glass cover.
- Place it on a hot water bath for about 15 minutes with intermittent stirring to avoid frothing over.
- Remove it to add a further 25-40 ml H_2O_2 and after a minute or two, replace the beaker on the top of the water bath for 10-15 minutes.
- In each case, when the treatment with H_2O_2 on the water bath is finished, rinse the soil from the cover and sides of the beaker with water and dilute to about 150 ml.
- Bring it to boil on a heating source and keep boiling gently for 5 minutes avoiding frothing.
- Repeat the treatment with H_2O_2 till the entire organic matter is oxidized.

Treatment with acid

- When the contents of the beaker become cool, clean its sides with a rubber pestle.
- Add 25 ml of 2N HCl and shake to destroy $CaCO_3$ content. If the soil contains more than 2 per cent of $CaCO_3$, add an extra 2.5 ml of 2N acid for each per cent.
- Dilute the contents to approximately 250 ml and thoroughly rub the soil with a rubber pestle. Allow the acid and soil to react for one hour, rubbing well at intervals.
- After one hour, test the solution with a piece of blue litmus paper to ensure that an excess of acid is present.
- Filter through a Buchner funnel using Whatman No. 50 filter paper.
- Wash the soil with four successive washings, each of 100 ml disti1led water. Continue the leaching until the filtrate is nearly neutral (as tested by litmus paper) and is free from chlorides ($AgNO_3$ Test).

- In case soil contains more than 2-3 per cent gypsum, then, after the peroxide treatment transfer the soil and water to a shaking cylinder, dilute it to about 650 ml and add 115 ml of 2N HCl. If the soil contains more than 10 per cent $CaCO_3$, add an extra 2.5 ml HCl for each per cent present. After allowing any CO_2 evolved to escape, close the cylinder and shake for 8-16 hours in a shaker to dissolve all the gypsum present. After shaking, filter through a Buchner funnel and wash the soil with water as before, until the filtrate is nearly neutral (as tested by litmus paper) and is free from chlorides ($AgNO_3$ Test).

Separation of coarse sand

- After washing is complete spread out the fi1ter paper on large clock glass.
- Place a 70 mesh sieve in the mouth of a sedimentation cylinder.
- Pour the suspension on to the sieve and with a stream of water from the wash bottle, wash as much materials possible through the sieve, until no more clay and silt remain on the sieve and the cylinder is about one-half full.
- Transfer the coarse material thus left on the sieve to a weighed dish.
- Dry it at 105° C and weigh. Calculate the per cent of coarse sand as follows:

Weight of dish, g = W_1
Weight of dish + dry coarse sand, g = W_2
Weight of coarse sand, g = $W_2 - W_1$
Percentage of coarse sand in air dry soil = $\mathbf{W_2 - W_1 \times 100/20}$

Dispersion

- Add 10 ml 1 N NaOH in the cylinder having contents of previous step.
- Make the volume of the suspension in the sedimentation cylinder up to 1000 ml rendering it alkaline. Addition of 5-6 drops of phenolphthalein will show pink color
- Shake the contents for 15-20 minutes to complete dispersion.

Separation of silt and clay

- Stir the suspension with the plunger, using vertical strokes for two minutes.
- Stand the sedimentation cylinder on the bench and note the time of commencement of sedimentation.
- Record the temperature of the suspension and note the corresponding time of sedimentation for silt and clay from Table 1
- Then withdraw 25 ml of the suspension using a pipette, in such a way that the point of pipette is at required distance below the surface of the suspension (10 cm in this case). Care should be taken to ingress the liquid slowly to avoid the disturbance in the bulk of suspension. Begin this operation about 20 seconds before the stipulated time.
- Take this sample into a weighed dish.
- Dry at 105° C and weigh it as silt plus clay.

Weight of dish, g = W_1
Weight of dish +silt+clay (in 25 ml suspension), g = W_2
Weight of silt + clay (in 25 ml suspension), g = $(W_2 - W_1)$
Percentage of silt + clay in air dry soil = $\mathbf{(W2-W1) \times 1000 \times 100/25 \times 20}$

Separation of clay

- Stir the suspension again with the plunger for one minute.
- Draw the sample in the same way at a depth 10 cm after the settling time for clay (as noted from the Table 1) is reached.
- Dry it at 105° C and weigh as follows:

Weight of dish, g = W_1
Weight of dish + clay (in 25 ml suspension), g = W_2
Weight of clay, g = (W_2-W_1)
Percentage of clay in the soil = **$(W2-W1)\times1000\times100/25$ x 20**

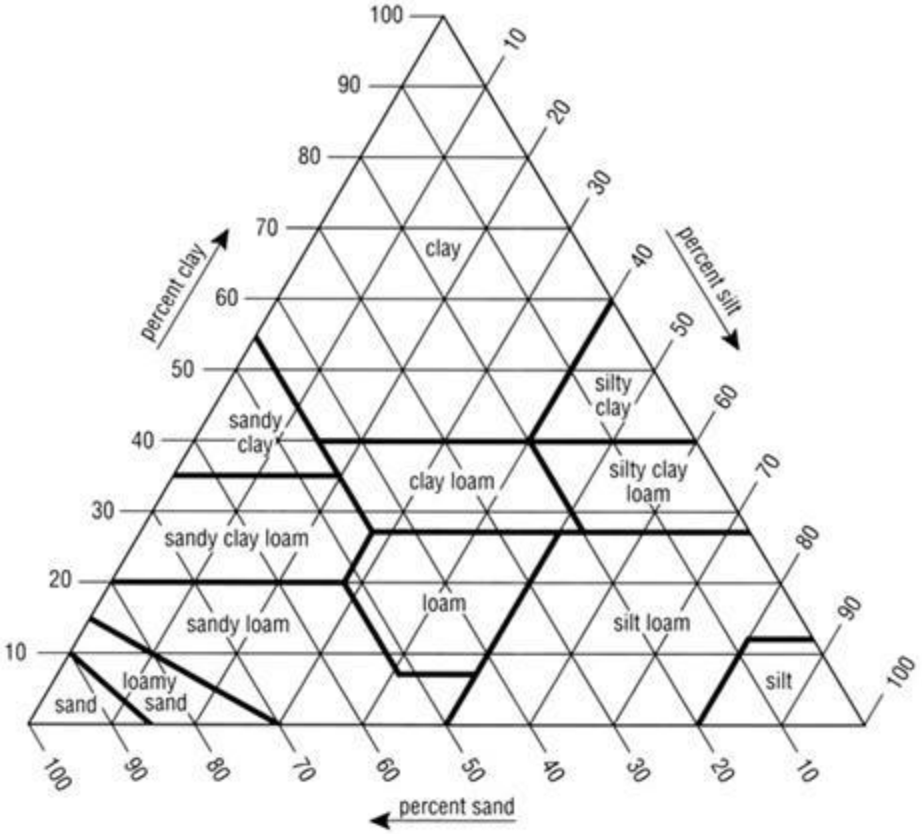
Separation of fine sand

- Decant the bulk of the supernatant liquid.
- Transfer the sediment to a 1000 ml beaker.
- Add water to a height of 10 cm above the base.
- Stir well and allow standing for some time and pour away the turbid suspension.
- Fill the beaker again to the mark with water and repeat this process until the liquid is no longer turbid at the end of the period.
- Collect the residue which is fine sand, dry it at 1050C and weigh. Calculate the percentage of fine sand as follows:

Weight of dish, g = W_1
Weight of dish + fine sand, g = W_2
Percentage of fine sand = **$(W2-W1) \times 100/ 20$**

Express the results of analysis on air dry /oven dry soil basis . Determine the textural class with the help of triangular diagram (Fig.1). If a soil contains more than 20 per cent gravel, the word gravelly is to be prefixed before the textural class.

Figure 1: Textural Triangle



Temp. °C	Clay		Silt + clay		Temp. °C	Clay		Silt + clay	
	Hr.	Min.	Min.	Sec.		Hr.	Min.	Min	Sec.
8	11	0	6	40	21	7	50	4	40
9	10	40	6	30	22	7	40	4	30
10	10	25	6	20	23	7	25	4	35
11	10	10	6	10	24	7	15	4	20
12	9	50	6	0	25	7	5	4	15
13	9	35	5	50	26	6	55	4	10
14	9	20	5	40	27	6	45	4	5
15	9	5	5	30	28	6	40	4	0
16	8	50	5	20	29	6	30	3	55
17	8	35	5	10	30	6	20	3	50
18	8	25	5	0	31	6	15	3	45
19	8	10	4	50	32	6	5	3	40
20	8	0	4	45	33	5	55	3	35

Exercise 9-13

Objective:

- To find the total mineral constituents of a soil it is digested with acids or fused with sodium cabonate. The method of digestion with acid such as hydrochloric, triple acids(nitric,sulphuric and perchloric) are quite common, but the most popular method is the extraction with hydrochloric acid.
- For the determination of of total phosphorus, potassium, calcium, magnesium and even for many micronutrients, this method is universaily adopted.

Exercise 9:

Exercise : Preperation of HCl extract

Material required
Equipment and glassware

- Conical fkask (500ml)
- Glass funnel
- Hot plate, Buchner funnel
- Volumetric flask (500ml)
- Whatman No. 50

Reagents:

- HCl

Procedure

- Place a 20 g of dry soil in a 500 ml conical flask. Add 200 ml of hydrochloric acid
- Place a funnel in the mouth of flask and boil gently for one hour on a sand bath or hot plate. Filter through Whatman No.50 filter paper fitted in a Buchner funnel.
- Wash the residue with hot water containing 50 ml of HCl per litre. The washing should be continued untill 500 ml of the extract is obtained .
- Transfer the filterate to a 500 measuring flask. Cool and make up the volume and call it solution A. Use a suitable aliquot for the determination of potash and other constituent.

Exercise 10

Exerise : Determination of sesquioxides(Fe_2O_3 and Al_2O_3)

Material required
Equipment and glassware

- Beaker (100ml)
- Whatman No. 40 filter paper

Reagents

- HCl
- Methyl red indicator
- Liquid Ammonia
- Ammonium nitrate (2% solution)

Procedure

- Take 50 ml of the solution A in a beaker. Add 10 ml of HCl and a few drops of methyal red indicator.
- Heat to gentle boiling and add ammonia until the precipitate is formed and the colour of the indicator just changes to distinct yellow. Boil not longer than 2 minutes and filter rapidly through a Whatman No. 40 filter paper.
- Wash the precipitate 6-8 times with hot 2% ammonium nitrate solution. Return the precipitate and filter to original beaker. Add 10 ml of HCl and macerate filter paper with a policeman. Dilute with water and heat to dissolve the precipitate. Dilute to about 20 ml and reprecipitate as directed above.
- Wash throughly with the hot ammonium nitrate solution as above until free of chlorides. Combined the first and second filterate and save them for Ca and Mg determinations.
- Ignite the precipitate gently, cool and weigh. Calculate the percentage of sesquioxide (Fe_2O_3, Al_2O_3, P_2O_5 and TiO_2)
- If the percentage of P_2O_5 is substracted from the total remainder will be sesquioxides.

Calculations
Tare of crucible = W_1
Crucible + residue = W_2
Residue = $W_2 - W_1$

$$= \frac{W_2 - W_1}{2} \times 100 = Y$$

Percentage of sesquioxide other than P_2O_5 = Y% P_2O_5

Exercise 11

Aim: Determination of calcium
Material required
Equipment and glassware

- Beaker
- Filter pater (Whatman No. 40)

Reagents

- Ammonium chloride
- Ammonium hydroxide
- Ammonium oxalate
- Methyl red indicator
- HCl
- Sulfuric acid
- Potassium per manganate

Procedure

- Concentrate the combined filterate and washing to about 50 ml.Add about 5g of ammonium chloride. Make it slightly alkaline with NH_4OH (1+1).
- While still hot , add saturard solution of ammonium oxlate as long as any precipitate is formed and then add excess of it to convert the calcium ions in to calcium oxlate.
- Add two drops of methyl red indicator and then add either HCl (0.1N) or NH_4OH (1+4) till the colours turns light pink. Heat to boiling and allow to stand for 3 hours or longer.
- Decant the clear solution through filter paper Whatman No. 40. Wash the precipitate on the filter paper with hot water.
- Dissolve any precipitate remaining on the filter paper washing with HCl(1+10) in to the original beaker in which it was precipitated. Wash the filter paper with hot water 5-6 times to ensure the complete transfer of the precipitate to the original beaker.
- Reprecipitate by adding ammonium hydroxide and ammonium oxlate solution.
- Allow to stand as before and filter through the same filter paper.Wash it free from chlorides with hot water.
- Reserve the filterate and washings for the estimation of Mg.
- The precipitate of calcium oxlate may be dissolved in dilute sulphuric acid and titrated with N/20 $KMnO_4$ solution.

1ml N/20 $KMnO_4$ = 0.001 g Ca

Determination of Magnesium
Material required
Equipment and glassware

- Beaker (500ml)
- Filter paper (Whatman No. 40)

- Gooch crucible

Reagent

- Citric acid
- Ammonia solution
- Absolute alcohol
- Ammonium phosphate
- Ammonium nitrate

Procedure

- To the combined Mg filterate and washing from Ca determination, add 2 ml of citric acid, 100ml of ammonia and 50ml of alcohol and then add with constant stirring 25 ml of 10% ammonium phosphate solution.Let it stand overnight.
- Filter the solution in to original beaker, make the volume to 100-150 ml.To this solution in to the original beaker, add 10-15 ml of ammonia and 2 drops of ammonium phosphate solution.
- Stir vigorously and alow to stand for 3 hours or longer, filter through a gooch crucible and wash with ammonia(1+9).
- Moisten filter paper with saturated ammonical solution of ammonum nitrate. Ignite the precipitate and weigh as $Mg_2P_2O_7$.
- Calculate the percentage of Mg as:

Weight of Mg = Weight of $Mg_2P_2O_7$ x 0.2162

Exercise 12

Aim:Determination of P_2O_5
Material required
Equipment and glassware

- Porcelain dish
- Water bath
- Beaker (500ml)
- Shaker
- Red litmus paper
- Whatman No. 44 filter paper

Reagent

- HCl
- H_2SO_4
- HNO_3
- Ammonia solution
- Molybdate solution
- Soodium nitrate
- NaOH
- Phenolphthalein indicator

Procedure
Preperation of extract

- Take 20-50 ml of HCl extract in a 50 ml porcelain glazed dish. Evaporate on a water bath and ignite at a dull read heat. Rub with a pestle and ignite again.
- Extract the well ignited mass with hot water and filter free from chlorides. Keep the residues on the filter paper for the estimation of P_2O_5 and the extract for potash.

Determination of P_2O_5

- Digest the residue from which the potassium is removed for half an hour on a water bath with 30 ml of 10% H2SO4 and filter free from acid.
- Transfer the filterate to a 400 ml beaker.
- Add 5-10 ml HNO_3 and then add ammonia until a precipitate that forms dissolve on shaking.
- Dilute to about 100 ml and warm to about 25 – 30^{o}C and put a piece of red litmus paper which should turn blue.
- Now add drop wise drop HNO_3(1+10) till it turns red again. Add sufficient amount (30 ml) of molybdate solution to ensure complete precipitation.
- Shake vigorously for five minutes, allow to stand for at least half an hour.
- Filter by decantation using Whatman No. 44 filter paper.
- Wash the precipitate with 2 % solution of sodium nitrate or ice cold water. The washing should be continued till the filterate is free from acid.

- It can be tested by adding a drop of standard alkali and a few drops of phenolphthalein.
- The filterate should have pink colour.
- Spread the filter paper on the sides of the beaker in which the precipitation was done.
- Wash it with a jet of distilled water. Dissolve in a known amount of N/10 NaOH.
- Titrate with N/10 H_2SO_4, using phenolphthalein indicator till the pink colour just disappears.
- Put the filter paper in the beaker and add more acid till the pinkish color which reappeared on the addition of filter paper disappears.

Calculate results assuming 1 ml N/10 NaOH = 0.000309 g P_2O_5

Determination of K_2O

Reagent

- HCl
- H_2SO_4
- Glacial acetic acid
- Sodium chloride
- Sodium nitrate
- Cobalt nitrate
- Alcohol
- $KMnO_4$
- Evaporate the water extract on the water bath after the addition of few drops of HCl
- When cold take up the residue in 1.5 ml glacial acetic acid and 10 ml of saturated sodium chloride solution.
- Stir well and after 3 to 4 minutes, add 5 ml of 35% $NaNO_2$ solution stirring again.
- When solution is complete say after 5-10 minutes, but not longer, add 5ml of 20% cobalt nitrate solution rapidly with constant stirring. It would not take more than 2-3 seconds.
- Stir for 40 to 60 seconds. Cover and allow it to settle overnight in a cool place free from fumes of ammonia.
- Filter through a gooch crucible charged with asbestos or use sintered glss crucible No. 4.
- Transfer the precipitate to the crucible and wash 4 times with 6-10 ml of 35% alcohol each time.
- Fially wash the sides of the crucible with 3 small lots of about 2 ml each of cold water to remove alcohol.
- Pipette out a suitable amount i.e. 50 ml of 0.05N $KMnO_4$ in a 400ml beaker.
- Dilute to about 150 ml with water and add 5 ml of H_2SO_4(1+10). Add the crucible and the precipitate in this mixture and keep it submerged in the solution warm gently.
- If the colour appears to be discharged add further known quantity of $KMnO_4$ solution to ensure an excess. Heat nearly to boiling.
- Remove from the flame and after few minutes add excess of 0.05N oxalic acid (50ml).
- Warm until all oxides of manganese have dissolved.
- Titrate excess of oxalic acid with 0.05N $KMnO_4$ used for the oxidation of the precipitate.

Calculations

Amount of 0.25% solution of potassium sulphate taken = 10ml
Amount of 0.05 N $KMnO_4$ solution added = 50ml
Amount of 0.05 N oxalic acid solution added = 50ml
Amount of 0.05 N $KMnO_4$ solution required for the excess of oxalic acid = y ml
Amount of 0.05 N $KMnO_4$ solution used for reacting with precipitate= x- y ml

$$\text{Percentage of } K_2O \text{ in the sample} = \frac{\text{ml of 0.05N } KMnO_4 \times \text{Total volume of solution}}{\text{Volume of solution taken}} \times \frac{100}{\text{Wt. of soil}}$$

Amount of K= Amount of K_2O x 72 / 94

Exercise 13 - Determination of total Sulphur

Principle: The organic sulphur of soils is oxidized to sulphate by sodium peroxide followed by fusion with sodium cabonats to break down the soil minerals. The sulphate is determined by precipitation as barium sulphate.

Reagents and appratus:

- Sodium peroxide
- Granular Sodium Cabonate
- Concentrated HCl
- Hydrochloric acid(1+10)
- Methyl red indicator
- Barium chloride (10%)
- Ethyl alcohol (95%)
- Sulphuric acid (1+2)
- 10% $BaCl_2$
- Nickel crucible

Procedure:

Fusion:

- Weigh 5 to 10 g of air-dry soil of 0.5 mm mesh in to a 50 ml nickel crucible. Add an equal weight of anhydrous sodium cabonate : mix, 2ml of water to the soil and stir well to a stiff paste.
- Immediately add 10 g in successive portion of sodium peroxide (about 1 g at a time) to avoid excessive frothing. Put it in the furnace for 30 minutes at 400 to 500^{0}C: then raise rapidly to to bright red heat (about 900^{0}C) and heat for about 10 minutes.
- Withdraw the crucible from muffle furance, and place the crucible sideways in a 600 ml beaker and cover with distilled water.
- Add about 5 ml of ethyl alcohol and place it on a cold hot plate and heat. Remove the crucible and rod from the beaker.
- If small glassy particles still cling to the inside of the crucible, disentegrate them by adding water and boiling over a hot plate or small flame and add it to the main portion.
- Filter by suction through a 9 cm Buchner funnel in to a litre beaker or jar.When no more liquid can be drawn through the filter, return the residue together with filter paper to the original beaker, add about 1 g of sodium carbonate, macerate with 75 to 100 ml of water and bring to a brisk boiling.
- Again filter through a Buchner funnel using suction and wash with 20 ml portions of hot water to a total of 500 ml portions of hot water to a total of 500 ml. Make up the volume to 1 litre.
- Determine the amount of sulphate in the extract gravimetrically.

Precipitation of $BaSO_4$:

- The solution is brought to boiling, and 10 ml of 10% barium chloride($BaCl_2$) is slowly added to precipitate the sulphate.

- The solution is allowed to stand untill cool, then is passed through a small fine porosity filter paper, and the precipitate is washed.

Ignition of $BaSO_4$:

- The paper is ignited at low temperature and the precipitate weighed.
- The ignited $BaSO_4$ is treated with a few drops of HF and H_2SO_4, cautiously ignited, and weighed again.
- The reagents used invariably contain some sulphur, blanks are carried along in the same manner as the determinations.

Calculations:

%S = gm $BaSO_4$ x 13.7/ Weight of sample

Exercise 14 - Determination of Total Nitrogen Content of Soils

Nitrogen is one of the major nutrients required for plant growth. Out of the total amount of nitrogen present in soils, nearly 95-99 % is in the organic form and 1- 5% in the inorganic form. Because of the importance of nitrogen in crop growth and for fertility evaluation, the determination of nitrogen in soils hold an important place.

Principle:

- The principle underlying determination of total nitrogen in soil by kjeldhal method involves three steps viz. digestion, distillation and titration. The chemistry involved in these steps is outlined below:

Digestion

- When H_2SO_4 is heated in the presence of organic matter, the sulphate is reduced to form SO_2 and the carbon is oxidized to CO_2, whereas H is oxidized to H_2O. The nitrogenous compounds are reduced to NH_4^+. Let us consider glucose, for the sake of explanation.

$C_6H_{12}O_6 + 12\ H_2SO_4 = 6\ CO_2 + 18\ H_2O + 12\ SO_2$

- In the organic matter some nitrates are also present which are accounted for by salicylic acid forming nitrosalicylic acid. The nitrosalicylic acid is then reduced to amino salicylic acid by $Na_2S_2O_3$, which on digestion with H_2SO_4 is converted to $(NH_4)_2SO_4$. The reactions occurring can be summarized as follows:

$C_6H_4(OH)COOH + HNO_3 = C_6H_3(OH)\ NO_2COOH + H_2O$
Salicylic acid Nitrosalicylic acid
$Na_2S_2O_3 + H_2SO_4 = Na_2SO_4 + H_2S_2O_3$
$C_6H_3(OH)\ NO_2COOH + 3H_2S_2O_3 + H_2O = C_6H_3(OH)NH_2COOH + 3H_2SO_4$.
Aminosalicylic acid
$C_6H_3(OH)NH_2\ OOH + 27H_2SO_4 = (NH_4)_2SO_4 + 14CO_2 + 26SO_2+30H_2O$
Ammonium sulphate

- In the digestion mixture K_2SO_4 is added to raise the temperature of digestion. In order to accelerate the speed of digestion, a digestion accelerator containing copper sulphate,mercuricoxide and selenium powder is added.

Distillation

- During distillation of ammonia, pumice stone pieces or glass beads are added to prevent bumping. Additions of zinc cause the liberation of nascent hydrogen in a fine stream and prevent overheating.

$Zn^{+2} + 2NaOH = 2H^+ + Na_2ZnO_2$ (Sodium zincate)

- Alkaline conditions by the additions of NaOH prevent escape of NH_3 gas.

Titration:

- During titration NH_3 reacts with H_3BO_3 in the following manner:

$NH_3 + HOH = NH_4OH$
$4H_3BO_3 + 2NH_4OH = (NH_4)_2 B_4O_7 + 7 H_2O$.
(Ammonium tetra borate)

- During back titration a replacement titration occurs in which an anion of a strongacid (H_2SO_4) replaces that of the very weak boric acid:

$(NH_4)2B_4O_7 + H_2SO_4 + 5 H_2O = 4H_3BO_3 + (NH_4)_2SO_4$

Reagents

- Concentrated H_2SO_4
- Digestion mixture: K_2SO_4 : $FeSO_47H_2O$: $CuSO_4$ (20:2:1) Or
- 20g $CuSO_4$ $5H_2O$,3g HgO ,1g Selenium Powder
- 40% NaOH
- Boric acid 4% : Approximately 40g of H_3BO_3 is dissolved in distilled water containing 5 ml. of mixed indicator. The boric acid stock solution is adjusted by dilute H_2SO_4 or HCl titration until the bluish colour of the indicator weakens towards pink.
- Mixed indicator solution : Dissolve 0.5g of bromocresol green and 0.1 g methyl red in 100 ml of 95% ethanol and adjust the solution with drops of dilute NaOH or HCl to bluish purple colour at pH 4.5
- 0.1 N H_2SO_4

Procedure

- The procedure for the determination of total nitrogen in soils also involves the three steps i.e. digestion ,distillation and titration

Digestion:

- Weigh 10g soil sample in a 500 ml Kjeldahl flask. Add 30 ml concentration H_2SO_4 containing 1 g salicylic acid.
- Keep it for few minutes after shaking and add 5g. $Na_2S_2O_3$. Heat the material for 5 minutes and cool Add 20 ml of water, 10g K_2SO_4 and 1 g of the digestion mixture and digest the contents till light blue colour appears.

Distillation:

- Cool the contents and add about 200 ml of water and swirl the flask for two minutes, and take the supernatant liquid into a distillation flask.
- Add about 50 ml of water to the digestion flask and take the water extract into the distillation flask. Repeat this process for at least 4 times.
- Add 10 ml of Na_2Solution to the distillation flask, and then and 135 ml of 40 per cent KOH slowly from the side of the flask. Add 2 pieces of zinc and distill NH_3 into a 25 ml boric acid indicator solution kept in a receiver flask. When no more NH_3 is received-test with blue litmus stop the distillation and proceed for titration.

Titration:

- The unreacted boric acid solution in the receiver flask is back titrated with standard H_2SO_4. The disappearance of blue colour indicates the end point. Run a blank without the soil sample.

Calculations:

1 ml. of 0.1N H_2SO_4 = 0.0014g of N

$$\% \text{ N in soil sample} = \frac{0.0014 \times T \times V}{S \times W} \times 100$$

Where:

T = ml of 0.1N H_2SO_4 used for titration
V = Total volume of aliquot prepared
S = ml.of aliquot taken
W = Weight of soil sample taken in gm.

Exercise 15 : Determination of Organic Carbon Content of Soils

Importance:

- All plant, animal and microbial residues, both decomposed and un-decomposed in the soil constitutes organic matter, most of which is of plant origin.
- Soil organic matter (SOM) is an index of productivity of soil since it is a store house of essential nutrients for plant growth. It is also a source of cation exchange capacity besides promoting desirable soil structure and influencing moisture retention and aeration of soils.
- The SOM is the seat of nitrogen in soil and its determination is often carried out as an index of nitrogen availability.
- Organic matter on an average contains 58 per cent carbon, the per cent organic matter can be obtained by multiplying per cent organic carbon with 100/58 or 1.724 which is also known as van Bemmlen factor.

Methods:

- Carbon is the chief constituent of soil organic matter that can be readily measured quantitatively. Hence estimates of organic matter are based on organic carbon which can be determined mainly by two methods:
- Dry combustion method
- Wet digestion method
- Rapid titration method (Walkley and Black, 1934)
- Colorimetric method.

Principle:

Dry combustion method:

- The dry combustion method gives absolute values and is useful for very accurate estimations. However, this method is tedious and time consuming. In this method, a known weight of soil, pre-treated with excess of 0.5 per cent sulphurous acid (H_2SO_3) to destroy $CaCO_3$, is ignited in silica tubes packed with copper oxide.
- The CO_2 evolved is then absorbed in weighed quantity of soda lime and the amount of CO_2 produced is found by the difference in the initial and final weight of the soda lime. From the amount of soil taken and CO_2 evolved, content of organic carbon and hence organic matter is calculated.

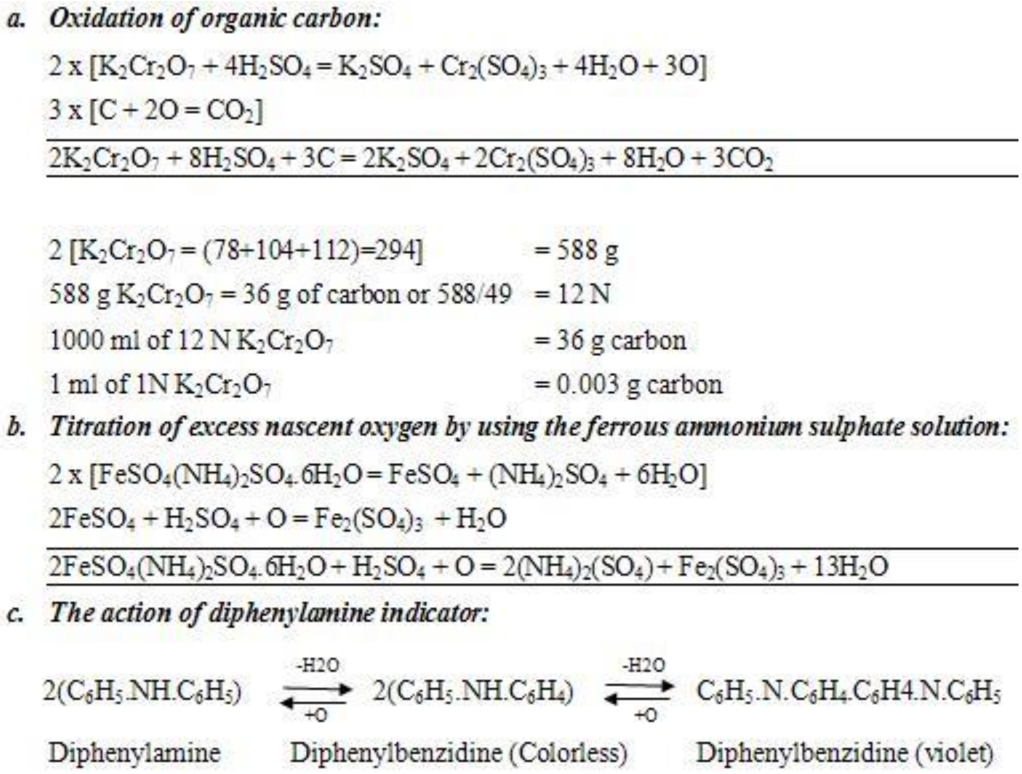
Wet Digestion method:

- For ordinary routine work, wet digestion method is generally used.
- In this method, organic matter is oxidized with chromic and sulphuric acid making use of the heat of dilution of strong sulphuric acid so as to oxidize the humus.
- In this method the excess of chromic acid not reduced by SOM is determined by titration with standard ferrous ammonium sulfate solution in the presence of phosphoric acid, sodium fluoride and diphenylamine solution as indicator.
- Phosphoric acid and sodium fluoride make the colour change distinct because of their suppression of Fe^{+++} (Ferric) ion activity (flocculating effect) which is generated during the titration with ferrous salt.

- At the end point, colour of the suspension changes from violet through blue to bright green. High chloride content (in case of saline soils), which interferes in the estimation of organic carbon, can be prevented by adding 1.25 per cent Ag_2SO_4 to concentrated sulphuric acid.
- The recovery of organic carbon by this method varies with the nature of the soil. The values obtained using this method are only approximation because all the carbon which is oxidized is 60-90 per cent with a mean value between 75-80 per cent.
- In the colorimetric method the intensity of green colour of chromic acid obtained due to its reduction is measured colorimetrically. The intensity of green colour is directly proportional to the amount of organic carbon present in the soil.

The details of most widely used method (**Walkley and Black)** in soil testing laboratories are given here.

Reactions:



a. Oxidation of organic carbon:

$2 \times [K_2Cr_2O_7 + 4H_2SO_4 = K_2SO_4 + Cr_2(SO_4)_3 + 4H_2O + 3O]$

$3 \times [C + 2O = CO_2]$

$2K_2Cr_2O_7 + 8H_2SO_4 + 3C = 2K_2SO_4 + 2Cr_2(SO_4)_3 + 8H_2O + 3CO_2$

$2 [K_2Cr_2O_7 = (78+104+112)=294]$ $= 588$ g

588 g $K_2Cr_2O_7$ = 36 g of carbon or 588/49 = 12 N

1000 ml of 12 N $K_2Cr_2O_7$ = 36 g carbon

1 ml of 1N $K_2Cr_2O_7$ = 0.003 g carbon

b. Titration of excess nascent oxygen by using the ferrous ammonium sulphate solution:

$2 \times [FeSO_4(NH_4)_2SO_4.6H_2O = FeSO_4 + (NH_4)_2SO_4 + 6H_2O]$

$2FeSO_4 + H_2SO_4 + O = Fe_2(SO_4)_3 + H_2O$

$2FeSO_4(NH_4)_2SO_4.6H_2O + H_2SO_4 + O = 2(NH_4)_2(SO_4) + Fe_2(SO_4)_3 + 13H_2O$

c. The action of diphenylamine indicator:

$$2(C_6H_5.NH.C_6H_5) \underset{+O}{\overset{-H2O}{\rightleftarrows}} 2(C_6H_5.NH.C_6H_4) \underset{+O}{\overset{-H2O}{\rightleftarrows}} C_6H_5.N.C_6H_4.C_6H4.N.C_6H_5$$

Diphenylamine   Diphenylbenzidine (Colorless)   Diphenylbenzidine (violet)

Apparatus and Reagents required:

- 500 ml conical flask
- Pipette (10 and 20 ml)
- Burette (50 ml)
- Sieve (0.5 mm)
- 1N Potassium dichromate ($K_2Cr_2O_7$): Dissolve 49.04 g of AR grade $K_2Cr_2O_7$ in about 500 ml of distilled water and make the volume to one litre.
- 0.5N Ferrous ammonium sulphate [$FeSO_4(NH_4)_2SO_4.6H_2O$ (Mohr's salt)]: Dissolve 196 g of $FeSO_4$ $(NH_4)_2SO_4.6H_2O$ in distilled water and add 20 ml of concentrated sulphuric acid before making final volume to one liter.
- Diphenylamine indicator: Dissolve 0.5 g of diphenylamine in 20 ml of distilled water and 100 ml of concentrated sulphuric acid.
- Concentrated sulphuric acid.
- Orthophosphoric acid (86%) or Sodium fluoride (NaF)

Procedure:

- Weigh 1g of soil sample (passed through 0.5 mm sieve) into 500 ml dry conical flask.
- Add 10 ml of 1N $K_2Cr_2O_7$ solution and shake gently to disperse soil in the solution.
- Add 20 ml of concentrated sulphuric acid carefully from the side of flask, swirl the flask during the addition.
- Keep the flask on a dry tile or asbestos sheet for 30 minutes at room temperature.
- Add a pinch of NaF/10 ml of orthophosphoric acid and 100 ml of distilled water
- Add about 10 drops of diphenylamine indicator and shake vigorously to mix the contents.
- Take 0.5 N Ferrous ammonium sulphate solution in 50 ml burette and titrate the contents of flask till the colour changes from violet to bright green.
- Note the volume of ferrous ammonium sulphate solution used.
- Carry out a blank titration in similar manner, using all the reagents except soil.

Precautions:

- Add potassium dichromate very carefully without touching the neck of the flask.
- Handle the string sulphuric acid with caution as it can injure the skin and spoil clothes.
- Read upper meniscus of ferrous ammonium sulphate solution.
- In case the contents of flask turns green with the addition of indicator before titration, repeat the sample either with double amount of potassium dichromate or with lesser amount of soil.

Observation and calculations:

- Weight of soil taken = S g
- Volume of N/2 ferrous ammonium sulphate = X ml
- used for blank titration
- Volume of N/2 ferrous ammonium sulphate = Y ml
- used to titrate excess nascent oxygen (from 1N $K_2Cr_2O_7$)
- Volume of 1N $K_2Cr_2O_7$ used for oxidation of carbon = (X – Y) / 2 ml
- 1 ml of 1N $K_2Cr_2O_7$ = 3 mg or 0.003 g of carbon
- Per cent of organic carbon (A) = ((X – Y) x 0.003 x 100)/(2 x S)
- Per cent organic matter = A x 1.724

Note:
To obtain actual percentage of organic carbon by Walkley and Black method, organic carbon should be multiplied by a factor 100/77 i.e. 1.3 (77 % being the average recovery factor)

Interpretation:

Organic carbon (%)	Rating
< 0.25	Very low
0.25 – 0.50	Low
0.51-1.00	Medium
1.00 – 1.50	High
> 1.50	Very high

Exercise 16: Determination of Cation Exchange Capacity of Soils

- The cation exchange phemenon is the second most important reaction in nature, surpassed only by the photosynthetic process of green plants. The sum total of exchangeable cations that a soil can adsorb is called cation exchange capacity (CEC) and is expressed as cmol (p+) kg^{-1} here p+ refers to protons.
- The determination of CEC is one of the most fundamental properties, used to characterize the soils. The cation exchange material in soils is clay and organic matter. Depending upon the nature and amount of clay minerals and organic matter, the cation exchange capacity of soils varies widely.
- The soils dominated by Kaolinite, have low exchange capacity and those having predominance of illite and montmorillonite have a much higher adsorptive capacity.
- Soils high in humus will have still more cation exchange capacity.

Principle:

- The principle underlying determination of CEC involves 4 steps; (i) saturating the exchange complex with a buffered solution of the desired cation, (ii) washing out the excess salt, (iii) displacing the saturating cation from the exchange with a concentrated solution of another cation, and (iv) determining the amount of the saturation cation displayed.
- A pretreatment with an acidified sodium acetate solution is sometimes used to dissolve any free carbonates, and to disperse aggregates.
- A number of cations may be used for determining the cation exchange capacity of a soil. In the commonly used procedure all the adsorbed cations in a soil are replaced by a common ion such as barium, potassium, or ammonium. The commonly used salts for these ions are barium chloride, potassium acetate and ammonium acetate. Ammonium acetate is often used, primarily because it gives no interference, with most methods of determination used.

Materials required:

- 1 N Ammonium acetate: Dissolve 77.089 g solid ammonium acetate salt in sufficent amount of water. Check the pH of the resulting solution and adjust the same to 7.0. The pH adjustment can be done by adding ammonia solution drop wise.After pH adjustment, make the volume to one litre.
- Methyl or ethyl alcohol(60%)
- Magnesium oxide powder
- NH_4Cl solution: Prepare 1.0 N NH_4Cl solution using AR grade reagent. From
- this ,prepare 0.25 N NH_4Cl solution
- $AgNO_3$ solution(0.1 M) : Dissolve 8.5 g $AgNO_3$ in 500ml of water, add 2mlconcentrated nitric acid and mix well.
- N/10 NaOH
- N/10 H_2SO_4
- Methyl Red Indicator

Procedure:

- Weigh 20 gm. of air dry 2 mm sieved soil into a 250 ml Erlenmeyer flask and add 35 to 50 ml of ammonium acetate solution. Shake the flask for several minutes and allow it to stand overnight.
- Transfer the contents of the flask to a funnel using Whatman No. 44 filter paper and leach with 200 ml of ammonium acetate adding small amounts at a time so that leaching requires not less than 1 hour. Collect the leachate and make the volume to 250 ml. Retain the leachate for analysis of ammonium acetate extractable cations..
- After the solution has leached down, add a drop of NH_4Cl solution and 60 per cent alcohol to the ammonium-saturated soil remaining on the funnel until the leachate is chloride free as checked with $AgNO_3$ solution taken in a tube.
- When the filtrate does not show the test for chloride, transfer the soil along with filter paper to Kjeldahl flask. Add some glass beads and a spoonful of MgO powder and about 250 ml of distilled water and connect the flask with distillation apparatus.
- Take exactly 25 ml of N/10 H_2SO_4 in a conical flask, add about 2-3 drops of methyl red indicator and place it under the delivery end of the distillation apparatus.
- Make sure that the connections are air tight. Switch on the heating source and distil over 125 ml of solution into the receiver.
- Titrate the excess of acid using N/10 NaOH until the pink colour changes to yellow. Note the volume of N/10 NaOH used.

Calculations :

$$\text{C.E.C. (meq.100 g)} = \frac{\text{ml of acid}}{\text{g sample}} \times \text{N of acid} \times 100$$

Note that [cmol (p^+) kg^{-1}] = meq.100 g.Report the results on dry weight basis.