A Practical Manual

Fundamentals of Soil Science

Dr. Anil Kumar Saxena

DEPARTMENT OF SOIL SCIENCE
School of Agricultural Sciences
Shri Guru Ram Rai University, Pathribagh
Dehradun 248 001 (Uttarakhand)

FOREWORD

A particularly relevant and current initiative to enhance the practical abilities of undergraduate students is the practical manual "Fundamentals of Horticulture," which is created in accordance with the curriculum of the ICAR 5th Dean's Committee. I have no doubt that the student's practical knowledge will be valuable to them in their future careers.

Soil science involves the study of the formation and distribution of soil, the biological, chemical and physical properties and processes of soil and how these processes interact with wider systems to help inform environmental management, industry and sustainable development.

Soil science provides an understanding of how soil properties relate to and can be managed for optimal agricultural production, forest, range, and wetland management, urban land use, waste disposal and management, and reclamation of drastically disturbed sites.

I am very happy to go through the A Practical Manual entitled "Fundamentals of Soil Science" prepared by Dr. Anil Kumar Saxena, Department of Soil Science, School of Agricultural Sciences, SGRR University, Pathribagh, Dehradun, Uttarakhand. The manual covers the practical syllabus of undergraduate course.

The manual written by the authors is a good attempt which is based on their experience of teaching undergraduate courses. The language used in the manual is simple and lucid. The outline and description of practical exercises covering objectives, materials required, procedures and observations to be taken have been nicely presented which would be helpful in conduction practical more.

I hope this manual will make its own place in the libraries of Agricultural Universities in near future.

I congratulate the author for the efforts put in bringing out his practical manual.

Dean

(School of Agricultural Science)

ACKNOWLEDGEMENT

Ever since the introduction of new course for professional B.Sc. (Hons.) Agriculture degree, there was a need to have a present practical manual which covers the practical syllabus of 'Fundamentals of Soil Science' of undergraduate B.Sc. (Hons.) Agriculture. This manual is designed according to the syllabus offered in undergraduate degree of Agriculture as per fifth Dean Committee for the student which covers the practical with objectives, material required, procedure and steps to follow precautions to be taken, observations to be recorded and exercise to be done by the students. The main objective of this manual is to acquaint students about the brief knowledge of practicals. I hope that users will find the manual immensely useful.

I am looking forward to receiving the valuable suggestions of readers for improvement of this manual.

Dr. Anil Kumar Saxena
(Associate Professor, Department of Soil Science)

Contents

EXERCISE NO. - 1

OBJECTIVE: STUDY OF SOIL PROFILE AND ITS CHARACTERISTICS

Soil Profile

For a complete appraisal of soil, which can be considered to be a three dimensional unit, the surface features and characteristics as well as characteristics in depth need to be studied. Such a study can be made of the soil formed in depth, as can be seen in a soil profile. The vertical section of soil from surface down to hard rock from which the soil is formed is called soil profile. Each soil profile has a sequence of different layers is called horizon. A soil horizon can be defined as layer of soil approximately parallel to the soil surface with characteristics produced by soil forming processes.

Designations for horizons and layers

Capital letter symbols are used in designating soil horizons include A, 3, C and R. They indicate dominant kinds of departures from the parent material. The sub-divisions are indicated by placing an arabic number after the capital letter. Thus, symbols A1, A2, A3, B1, B2 are obtained. The layers in the profile are grouped as under:

- The "O" group is a organic horizon which is formed above mineral soil. This results from litter derived from plant and animal residue.
- The "A" group (zone of eluviation) is mineral horizon which lies at or near the surface. This is characterized as a zone of maximum leaching.
- The "B" group (zone of illuviation) occur immediately below the "A" horizon in which maximum accumulation of material such as Fe and Al oxide and the silicate clay occur. These may have washed down from upper horizon or they may have formed in B horizon.
- The "A" and "B" horizon together are called "solum". This portion of profile is developed by soil forming processes and is distinguished from the parent material.
- The "C" horizon is the unconsolidated materials underlying the solum. It is less weather than solum and consequently has not been subject to horizon differentiation.
- The "R" layer the parent rock laying below the parent material is termedas bed rock or R horizon.

Regolith: Solum plus parent material (A + B + C) is referred to as regolith.

Characteristics of different horizons

'O' Horizon

The "0" group is an organic horizons which is found above the mineral soil. It formed of the plant and animal residues. It is separated in two divisions: O1: In this horizon, plant and animal residues can be recognized by the neckedeyes.

O2: It is also organic horizon in which original plant and animal forms can not berecognized by necked eyes.

A_1 horizon

It is a topmost mineral horizon. Organic matter is fully decomposed and mixed with mineral matter to give colour darker than lower one.

A_2 Horizon

It is a horizon of maximum eluviation of clay, Fe and AI oxides and O.M. Quartz and other resistant minerals are more. It is lighter in colour than the horizons above or below it.

A_3 Horizon

It is a transitional layer between A and B horizon with properties more nearly like those of A. Some time it is absent.

B_1 Horizon

It is also a transitional layer between A and B horizon with properties more like B than A. Some time it is absent.

B_2 Horizon

It is a zone of maximum accumulation of clays and Fe and AI oxides. Colour is darker than that of A2. Maximum development of blocky or prismatic structure or both. It is also known as illuvial horizon.

B_3 Horizon

It is a transitional horizon between B and C with properties more like B2 horizon.

'C' Horizon

It is a horizon below A and B relatively less affected by the soil forming processes. It is outside the zone of major biological activity.

'R' Horizon

It is underlying consolidated bed rocks.

Lowercase letter symbols to designates subordinate distinctions withinmaster horizons

Letter	Distinction
A	Organic matter, highly decomposed
G	Gleying (mottling)
H	Illuvial accumulation of organic matter
I	Organic matter slightly decomposed
K	Accumulation of carbonates
N	Accumulation of sodium
O	Accumulation of Fe and Al oxides
P	Ploughing or other disturbance
Q	Accumulation of silica

r	Weathered or soft bed rock
s	Illuvial accumulation of organic matter and Fe and Al oxides
t	Accumulation of silicate clays
w	Distinctive colour or structure
x	Fragipan (high bulk density, brittle)
y	Accumulation of gypsum
z	Accumulation of soluble salts

another.

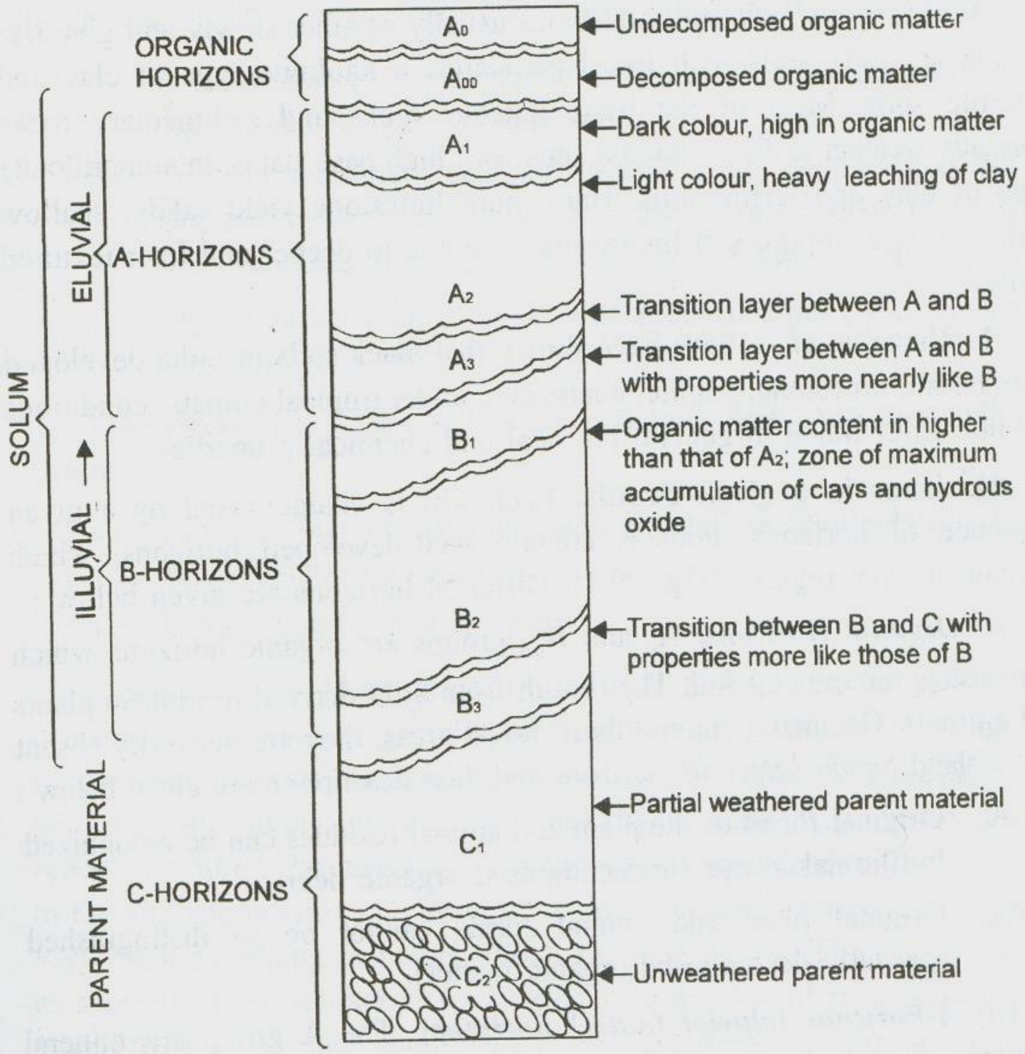


Fig. 20.1. A well-developed imaginary soil profile.

EXERCISE NO.-2

OBJECTIVE: COLLECTION OF SOIL SAMPLE FROM A GIVEN PIECE OF AGRICULTURAL LAND, ITS PROCESSING AND STORAGE

This exercise commonly referred to as soil testing and is used to arrive at optimum fertilizer application ratio. The need for estimation of available nutrient arises because only a small fraction of what the soil contains is the total nutrient content of the soil. Soil test are calibrated by correlating them with crop response and the result from the basis for making fertilizer recommendations.

Estimation of nutrient contents and forms in materials that are involved in nutrient supply and dynamics is a conical step towards planning scientific nutrient management. In this content, both soil and plant testing information comes out of the interpretation of analysis assumes a greater value when their concentrations and amounts can relate to soil fertility, nutrient availability, plant growth, yield and quality of the crop produce.

Objectives

- To evaluate soil fertility and its productivity by the estimation of level of nutrient (Low, Medium, High).
- Grouping of soil for their classification
- To determine the specific soil problem such as an acidity, alkalinity and sodicity if exist. Subsequently giving recommendation for their correction (Lime/Gypsum requirement etc.)
- To predict the probability of getting maximum response of crops to fertilizers.

Procedure for soil testing

The procedure for testing the soil to meet these objectives is divided into the following phases:

- Collection of soil samples and its preparation
- Extraction and determination of nutrients and physico-chemical properties of the soil.
- Interpretation of analytical results.
- Recommendation and follow up of results and evaluation of recommendations.

Soil testing is a chemical method for estimation of nutrient supplying power of a soil/ soil fertility evaluation.

Soil fertility may be defined as the capacity of soil to furnish available plant nutrients to the plants in proper amount and appropriate balance, under ideal condition of plant growth. Whereas, Soil productivity is the capacity of soil to produce under specific condition of crop production.

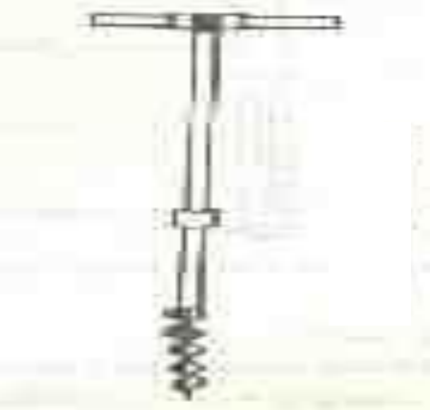
Advantages of soil testing :

- More rapid method as compare to biological or deficiency symptoms/ plant analysis.
- One may determine the need of the soil before the planting of crop.
- To determine the suitability of the soil for laying gardens.
- Assessment of problem soils.
- Soil survey.

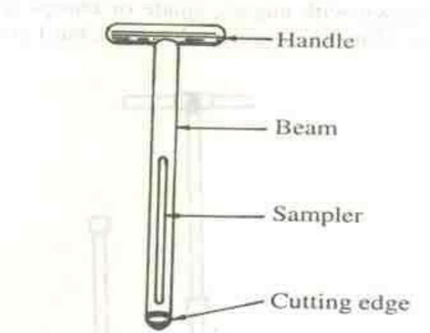
The error in soil sampling in a field is generally greater than the error in laboratory analysis. The most recommendation call for soil testing of each field is about every three years with more frequent testing on lighter soils. Therefore, it is necessary that the soil sample should be representative of the area. Further, the subsequent handling operation in the laboratory should be carefully performed because a minute quantity (1 – 10g) of the large soil mass of the field is actually used for the analysis in the laboratory. Unless one is sure of representative and proper sampling, the results obtained in the laboratory analysis will be of no use under the field conditions.

Apparatus and materials :

Khurpi, Spade, Augers, Plastic bowl, Scale, Rack, Wooden roller, Mortar and pestle, Sieve, Polythene/paper/cloth bags, Labels, Card board cartons, Aluminum boxes



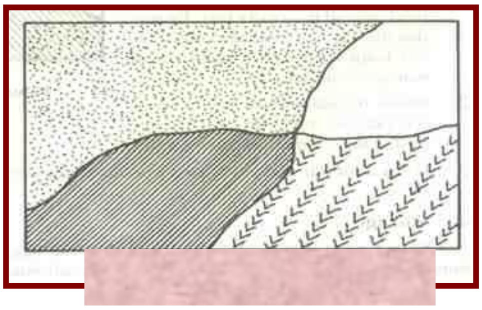
Screw Auger



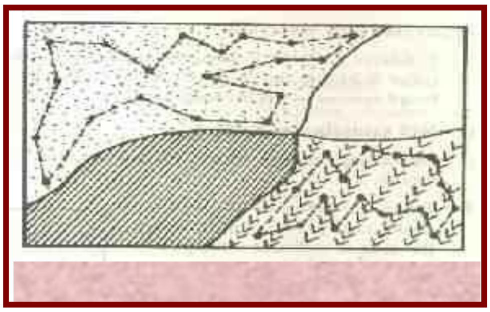
Parts of an Auger

Collection of representative soil sample:

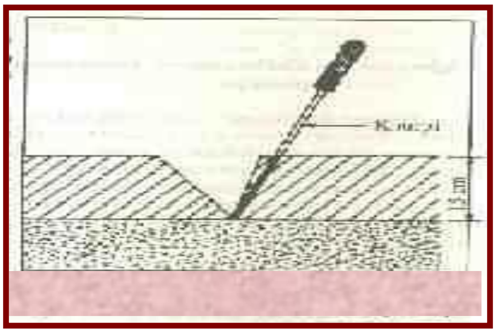
- Depending on field conditions and the objective of sampling, select proper sampling tool (s).
- Based on difference in soil type, colour, crop growth or slope, divide the area in different homogenous units.



- In the uniform field, demarket the sampling points in a zig zag fashion or randomly in such a way that the whole field should be covered i.e. about 30-35 sample per ha.



- At the sampling site, remove the surface litter with *Khurpi* or spade. With the help of the sampling tool (Auger) collect a sample in a plastic bowl.
- If the soils is hard, make a 'V' shape cut upto 15 cm depth. Remove the soil of the pit. Now scrap or remove 1 cm / 1" soil from the surface upto 15 cm depth from both the side with the help of khurpi. This scraped soil is collected in a plastic bowl. This sample is known as 'primary' sample. Such primary samples should be approximately the same weight.



- After collecting at least 30 – 35 primary samples, mix all the samples in plastic bowl thoroughly and draw about ½ to 1 kg composite sample by quartering method. Label the sample in the bowl and divide the sample approximately 4 equal part. Discard the 2 opposite portions of the samples and remaining 2 portions are again thoroughly mixed and again divided in to 4 equal parts and 2 opposite parts again discarded. This procedure is continue until ½ to 1 kg sample remain in the bowl. This is known as composite sample which is true representative of the area.
- The most suitable containers for soil samples are polythene bags 6x9’’ made of film about 0.13 mm thick, which may be sealed by twisting or tying the neck or by mean of rubber bands or adhesive tape.
- If the soil is to be kept in moist condition for moisture determination, bacterial count and nitrate estimation etc. air tight containers are preferred.

If the soil to be used for the estimation of micronutrients like Zn, Cu, Fe, Mn. Use of metallic tools should be avoided. Use sharp stick or stainless steel. Brass sieve should be avoided. Nylon net or aluminum sieve should be used.

In majority of cases, large stones and pieces of gravel (7.6 – 2mm) can be discarded. Soil is broken up and spread out in a thin layer on strong paper or polythene film, preferably on a rack of wire mesh to allow air to circulate. The drying area protected from direct sun and wind.

Soil samples should be labelled/ numbered by field staff with water proof ink or paint. These bag numbers being entered in the sampler’s record books, as each sample is taken together with other information. He needs to identify and describe the samples.

If labels are used, they should either printed numbers on them already or water proof ink should be used to write information on them (this excludes pencil, washable ink pens and ball point pens). Duplicate labels should be placed between the two bags, never in the bag with the soil. The information on a label should be kept to a minimum preferably a number which may be either a ‘bag number’ or ‘sample number’. Depth may be given usefully for soil profile samples.

When labels are hand written special care should be taken to prevent ambiguity. For arabic numbers “6” and “9” and combination like “69” and “96” should be under line, and ‘1’ and ‘7’ should be clearly distinguished. Where letters & numbers are used ‘5’ may be easily confused with ‘S’. This is why printed labels are always better.

Field samplers have their own numbering system and may have record book containing printed forms for entry of information serially numbered. These ‘sample number’ are main identification of soil for most purposes but the relevant form should also have a record of the ‘bag number’ and subsequent ‘laboratory number’.

When a box of samples is dispatched to the laboratory, it should contain a packing note giving the total number of sample, ‘sample number’ of each sample and its corresponding ‘bag number’, the depth of soil sample from profile pit and other information needed by the laboratory staff for registration purposes, particularly on the analysis required. A duplicate packing note should be sent separately so that missing boxes can be investigated.

On arrival of the soil samples at the laboratory, the content of a box should be checked against the packing note if any discrepancies should be reported to the sampler. The samples are register in laboratory giving each sample a ‘laboratory number’ for particular analysis.

Small laboratory simply the numbered serially as they arrive. Larger laboratory may have 2 or more numbering system, using a prefixed letter (group of letter) to distinguish them. This procedure helping to channel samples into various analytical stream. Larger laboratory may need to 'punched card system' or other means of storing complete information on all samples. So that can be recovered quickly.

It is essential to keep a record of the date of arrival and the source of all samples. A table can be drawn up for each month.

Information sheet: The soil sample thus collected must be furnished important information like –

1. Sample number
2. Name and address of the farmers.
3. Details of the field and site. Local name of field, Khasra no etc.
4. Date of sampling
5. Name of crop and variety to be sown
6. Source of irrigation
7. Whether the crop in the subsequent season will be irrigated or un-irrigated.
8. Name of crops and fertilizer used in previous years.
9. Date of harvest of the previous crop.
10. Any other problem observed in the field.

Preparation of soil sample for testing

1. Spread sample for drying on clean cloth, plastic or brown paper sheet.
2. Remove the stone pieces, roots, leaves & other un-decomposed organic residues from the samples.
3. Large lumps of moist soils should be broken.
4. After air drying the samples should be crushed gently and sieved through a 2 mm sieve.
5. About 250 g of sieved sample should be kept in properly labeled sample bag for testing.

Appropriate time for soil sampling

An ideal time for soil sampling is just after harvest of the Rabi crops,

Precautions to be taken during collection of soil sampling

1. Remove all debris from surface before collection of soil sample.
2. Avoid taking sample from upland and low land areas in the same field.
3. Take separate sample from the areas of different appearances.
4. In row crop take sample in between rows.
5. Keep the sample in a clean bag.
6. A sample should not be taken from large area (more than 1-2 ha).
7. Sample for micronutrient analysis must be collected by steel or rust free khurpi/auger and kept in clean polythene bag.
8. Avoid sampling from low – lying spots, manure dumping sites, near trees and from fertilizer placed zones.
9. Use clean bags for sample collection. Do not use bags which had earlier contained fertilizer, manure or plant protection chemicals etc.

STORAGE :-

- The registered and labelled samples in laboratory are finally placed in a cardboard carton. Label the carton properly with the details of soil sample and store in a separate room. The room should be away from direct sunlight/wind or dampness.

- The room exposed to heat or cold or dampness in not advisable.

EXERCISE NO.- 3

OBJECTIVE: STUDY OF SOIL FORMING ROCKS

Rock is a consolidated mass of one or more minerals. It is a mixture of minerals and therefore their physical and chemical composition vary with the characteristics of minerals present in them.

Classification

Rocks are divided into three natural groups based on mode of origin of formation.

(i) Igneous (ii) Sedimentary and (iii) Metamorphic.

Igneous rocks are the oldest rocks, formed from the molten magma. Sedimentary rocks are formed from weathered igneous rocks. Both igneous and sedimentary rocks can be modified in to metamorphic rocks. All the three are weathered into soil parent materials.

1. Igneous rocks

The igneous rocks are formed by solidification of molten magma. These rocks are the primary rocks and make up about 95 % of the earth's solid' crust and on an average approximately 88 % of the mass of these rocks consists of feldspar, free quartz and amphibole Igneous rocks are further classified on the basis of (i) the depth of formation and (ii) the percentage of silica content.

(I) Classification on the basis of depth of formation

a. Plutonic

These rocks are formed when the magma solidified at greater depth about 2 to 3 miles deep under the surface of the earth. These are crystalline rocks as the size of crystals is bigger. e.g. granite, syenite, gabbro, norite etc.

b. Intrusive or dike

These rocks are formed when the magma solidified at moderate depth The crystals are smaller in size. e.g. dolerite, pegmatite etc.

c. Extrusive or volcanic or effusive

These rocks are formed when the solidification of magma takes place on the surface of the earth as a result of volcanic activity. e.g. Rhyolite, pumis, basalt, trap etc.

(II) Classification of Igneous rocks on the basis of percentage silica contenta.

Acidic

SiO_2 content is more than 65 % e.g. granite, pegmatite, rhyolite

b. Intermediate

SiO_2 content is between 55 to 65 % e.g. syenite, diorite, andesite.

c. Basic

SiO_2 content is between 44 % and 55 -%. e.g. basalt, gabbro, dolerite etc.

d. Ultra basic

SiO_2 content is less than 44 % e.g. peridotite, picrite.

The characteristics of some important rocks are given in the table.

2. Sedimentary rocks

The weathering products of igneous and metamorphic rocks when transported by water or glaciers form new deposits, which in time become cemented and solidified into new form of rocks called the sedimentary rock. The water plays an important role in the formation of these rocks so they are also known as **aqueous rocks**. The different layers are formed by sediment deposition, which are cemented together with silica, lime, iron oxide etc. so they are also known as **stratified rocks**.

Classification

The classification of sedimentary rocks is based on the mode and mechanism of accumulation, consolidation and grain size.

(i) Transported mechanically and deposited

These rocks are formed due to accumulation of residues left during the operation of process of weathering and transportation or transported mechanically through water and then cemented to form rock. Depending upon their grain size, they are further grouped as:

a. Rudaceous

If the individual grains forming rocks are of the size of boulders and pebbles called Rudaceous. e.g. Grit and shingle are loose fragmented rocks of varying size and shapes. Grit is composed of sharp and angular sand. Single is composed of large rounded pebbles generally mixed with sand. Breccias are coarse-grained rocks, composed of angular fragments cemented in a matrix of fine sand.

b. Arenaceous

The rocks which have individual grain of sand size are classified in these group.
e.g. Sand stone is, sand cemented by any cement like silica, lime, iron oxide, organic matters and clay. e.g. siliceous sand stone, calcareous sand stone, ferruginous sand stone, carbonaceous sand stone, argillaceous sand stone.

c. Argillaceous

The individual grains are of clay size the formation of these racks. They are also loose and consolidated. Various clays are loose sediments. Kaolin is China clay formed from the decomposition of feldspar. Pipe clay is iron free clay while fire clay is clay free from lime and alkalies. Shales are compacted clay rocks. They are porous, soft and of variegated colour white, red, yellow etc. Laterite rocks are composed of clay mixed withhydroxides of iron and aluminum.

(ii) Transported in solution and precipitateda.

Chemical precipitates

These rocks are formed due to precipitation and consequent accumulation of the soluble constituents traveling with the surface run-off. The precipitation may take place under suitable chemical environment or due to microbial activity. Calcareous rocks consist chiefly of calcium carbonate and are usually called lime stones. Quite a large variety of lime stones occur are of widely differing in purity, texture, hardness and colour. Rock salt and gypsum are precipitated due to drying up of inland lakes and seas.

b. Organic precipitates

These are the products of accumulation of organic matter and are preserved under suitable conditions. Coal, peat, lignite are the carbonaceous (carbon containing) sediments whereas the silicious (silica containing) rocks are composed of SiO_2 derived from plants and animals like diatoms etc.

3. Metamorphic rocks

The metamorphic rocks are formed from igneous and sedimentary rocks through the action of heat, pressure and chemically active liquids and gases. Metamorphism may result in changes mainly physical, chemical or both.

a. Thermometamorphic rocks

Very hot molten magma present beneath the earth crust, when moves from its place, comes in contact with other rocks. Due to enormous temperature of highly heated lava, the composition of rock which comes in contact is completely changed. Many times new rocks are formed.

e.g. Lime stone → Marble and calcite (Recrystalized)
Sand stone → Quartzite

b. Dynamometamorphic rocks

The weight of overlying rocks and their movement produces a great pressure and heat. Therefore, folding of rocks takes place. Because of pressure, the crystals of rocks become flat and stratas are formed. Many times new rocks are formed. This is called **dynamo metamorphic rocks**. When the layers can not be separated, the rocks are called gneiss. eg. Granite gneiss, diorite gneiss etc. When the folias are thinner (quite flat) and can easily be separated, the rocks are called **schist**. e.g. quartz schist, chlorite schist, talc schist, mica schist etc. Many a time the effect of high pressure is such that the original form of rock is completely changed, the folias are thin and in parallel flakes.

e.g. shale to slate.

c. Hydrometamorphic rocks

The water is the most abundance of all the liquids. Circulating hot water may lead to variation in mineral-solution and redeposit them in the inter space of rocks as in quartzite or it may dissolve and recrystalize the minerals of rock.

e.g. Feldspar + Water $\longrightarrow$ Muscovite mica + K - silicate + SiO_2

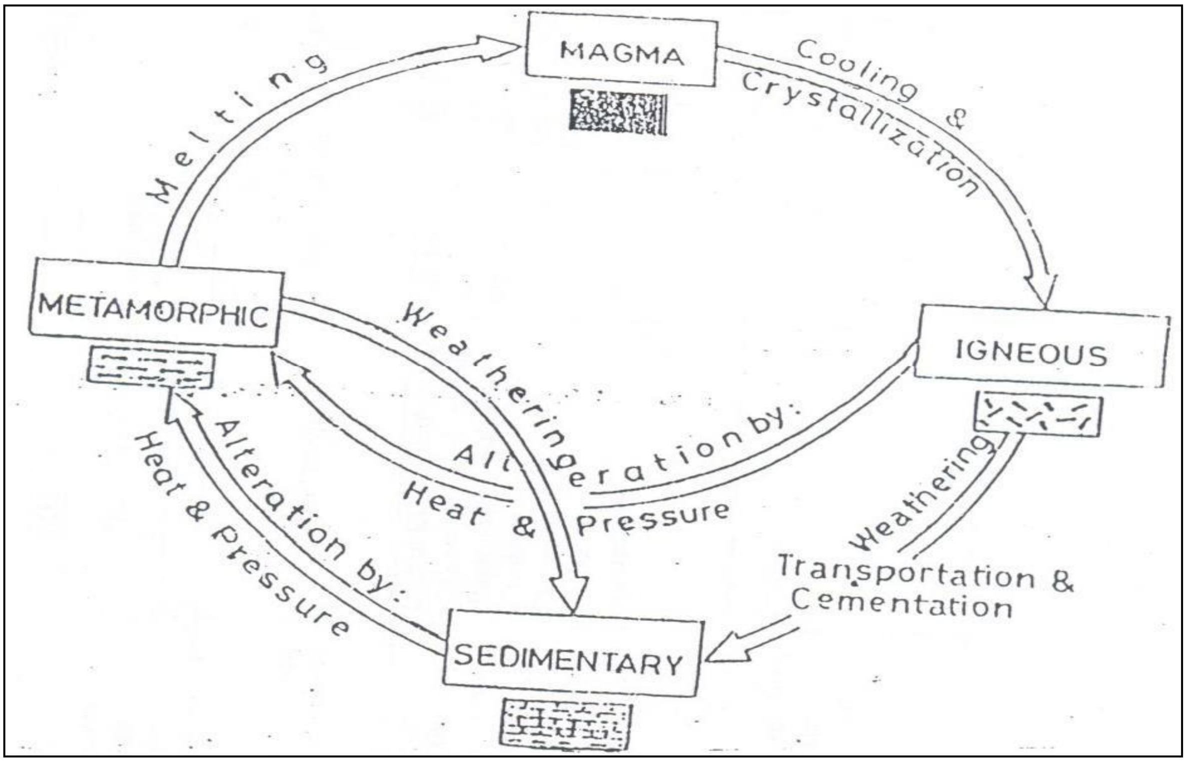


Fig.: A schematic diagram of rock cycle. The cycle, if uninterrupted, will continue from magma, through igneous rocks, sediments, sedimentary rocks, metamorphic rocks, and again to magma. It may be interrupted at various stages along its coarse to follow the altered path shown by arrows through the middle of the diagram.

CLASSIFICATION OF ROCKS

IGNEOUS		SEDIMENTARY						METAMORPHIC
On the basis of depth of formation	**On the basis of silica content**	**Transported mechanically and deposited**		**Transported in solution and precipitated**				
a. Plutonic (2-3 mile deep) -Granite -Syenite -Gabbro	a. Acidic (SiO_2>65%) -Granite -Rhyolite -Norite	Arenaceous or sandy	ArgiIlaceous orclayey	Chemical precipitates		Organic precipitates		a. Thermo metamorphic(non-foliated) e.g. Limestone to Marble-Sandstone to Quartzite
b. Instrusive or Dyke (moderate depth) –Dolorite -Pegmatite	intermédiate ($SiO_2$55-65%) -Syenite -Diorite	(i) Loose - Shingle - Grit	(i) Loose -Chinaclay -Pipeclay -Fire clay	Loss of CO_2 -Calcareous -Lime stone -Chalk -Dolomite -Stalactitie -Stalagmites	Evaporation -Rock salt -Gypsum	Siliceous-Diatoma ceous	Carbona-ceous -Peat -Lignite -Coal	b. Dynamo metamo rphic (foliated) -Bended folia-gneiss e.g. Granite gneiss Diorite gneiss - Thinner folia-schist e.g. Quartz schist Chlorite schist -Parallel folia-flakesShale to Slate
d. Extrusive or volcanic (on the surface) -Rhyolite -Basalt -Trap -Pumis	c. Basic ($SiO_2$44-55%) -Basalt -Gabbro -Dolorite	(ii)Consolidated -Rudaceous -Conglomerate -Breccia -Sandstone -Stalac	(ii)Consolidated -Shales -Laterite					C. Hydro metamorphic Recrystalization of minerals in rock Feldspar---Muscovite mica
	d. Ultrabasic (SiO_2<44%)-Peridotite-Picrite							

IMPORTANCE OF ROCKS: THEIR CHARACTRISTC AND MINEROLOGICAL COMPOSITION

Sr. No.	Name of Rocks	General Appearance	Mineralogical composition	Classification	Locality	Remarks
IGNEOUS ROCKS						
1	Granite	Light coloured, mixture of pink and white or black and white with shining medium granied hard rocks	Orthoclase feldspar, quartz and mica with or without hornblende	Igneous plutonic, acid rock	A.P., Belgam, -Khanpur, Vanakbori, -Dantiwada, Panchmahal, Sabarkantha.	High silica content. sp.gr. -2.64g.cc
2	Syenite	Light coloured pale grey to pink, medium grained hard rocks	Little or absence of quartz, orthoclase feldspar, hornblende, sometimes little plagioclase feldspar.	Igneous plutonic sub acidic rock	--do--	Intermediate silica sp. gr. is 2.80.
3	Diorite	Greenish black, medium grained hard rocks	Plagioclase feldspar, hornblende, biotite and auite.	Igneous plutonic sub basic rocks	Dacan trap Junagadh.	, Sp. gr. is 2.80.
4	Basalt	Dark coloured very compact and fine grained rocks with micro crystalline structure	Plagioclase feldspar, Augite, Magnetite.	Igneous volcanic basic rocks	Trap area of South Gujarat and Saurashtra.	Av. sp. gr. is3.0, high content of basic ions and smooth surface
5.	Trap (Amygdaloidal)	Medium coloured fine grained compact rocks with cavities filled with zeolite.	Plagioclase feldspar, Augite and magnetite	Igneous volcanic basic rocks	Trap area, Dhari, Amreli,Rajkot, Gondal, Morbi, Botad.	-
6.	Trap (vesicular)	Medium coloured rock with greenish spots, grained with long vesicles.	Plagioclase feldspar, fine Augite andmgnetite.	Igneous volcanic basic rocks	--do--	-
7.	Trap (concretionary)	Medium coloured, fine grained, concretionary soft rock.	Plagioclase feldspar Augite, Magnetite	Igneous volcanic basic rocks	Trap area, Dhari, Amreli,Rajkot, Gondal, Morbi, Botad.	Irregular rounded mass
8.	Trap (Buff or red)	Buff coloured, fine grained, fairly compact rock, with unfilled cavities.	Plagioclase feldspar, Hornblende,Magnetite	Igneous volcanic basic rocks	Trap area Dhari, Amreli, Rajkot,Gondal, Morbi,Botad, Rajula etc.	-

SEDIMENTARY OR AQUEOUS ROCKS

8.	Shingle	Light red coloured loose mass composed of large rounded pebbles.	Mainly quartz	Loose, arenaceous sedimenttary rock	Gokak	Layers are compressed.
9.	Grit	Composed of sharp & angular sand with grey colour.	Mainly quartz	Loose, arenaceous, sedimenttary rocks	Gokak	Layer can not be distinguished
10.	Conglomerate	Variously coloured consists of large rounded pebbles with elastic texture. present	Mainly quartz but pebble of other minerals are also	Consolidated arenaceous sedimentary rock	Gokak and Panchmahal	Hardly any layers are seen.
*	Breccia	Variously coloured coarse-grainedl rock composed of angular fragments fixed in the matrix of fine sand.	Mainly Quartz with other minerals	Consolidate darenaceous sedimentary	Gokak side near Varoli in Bombay	Layer can not be seen
11.	Sand stone (white)	Dirty white colour) granular mass made up of consolidated sand. Not so hard &compact.	Mainly quartz	--do--	Gokak, Morbi, Himatnagar, Bharuch, Panchmahal. Surendranagar districts	Rough to feel no layers
12.	Sandstone (Badami)	Slightly reddish colour, granular & rough to feel, medium hard rock	Mainly quartz	--do--	Gokak side near Varoli in Bombay	No Layers
13.	Sand Stone with Layers	Slightly red or red and layers grey coloured layers fine grain medium hard layered rock	Mainly quartz	--do--	Gokak and Belgam	Distinct layers
*	Sand stone black	Grey black some times with metallic iron luster. L coarse grained medium hard rock	Quartz with hydrated oxide of iron and aluminum as cementing material	--do--	Gokak	Very few layer to be seen
14.	Laterite	Brown red with yellow spots, vesicular medium hard rock, rough to feel hills	Mixture of hydrated oxids of iron and alumina	Consolidated argillaceous loose sedimentary	Belgam, Ratnagiri, Dharwar, Thana, Satara &Dang	It becomes hard when opened.

15.	Shale(White),	White coloured soft rock easily crumbling in hand extremely fine grained with definite layers	Mainly clay	Consolidated argillaceous Sedimentary rocks,	Dharwar	-
16.	Shale (Red) or (Pink)	Scarlet red coloured fine grain porous soft rocks with definite layers	Mainly clay	--do--	--do--	-
17.	Shale (Yellow)	Porous light yellow coloured soft rocks with layers	Mainly clay	--do--	--do--	-
18.	Lime stone, (Shahabad)	Light yellowish green colour with layer quite visible quickeffervescence with acid	Mainly $CaCO_3$	Consolidated calcareous, Sedimentary rocks	Shahabad and Nizamudin	Layers are quite distinct
19.	Lime stone (Cuddapah)	Black colour with layers gives effervescence with acid	--do--	--do--	Madras near kaladgi in Bombay	Distinguished from black marble by layer
20.	Lime stone (Porbandar)	White granular mass with rough surface and gives effervescence with acid.	--do--	--do--	Saurashtra and Baroda	No layers
*	Lime stone (Sindh)	Dirty white granular porous, some times cellular fairlysoft	--do--	--do--	Punjaband Sindh .	-
*	Limestone (Bagalkot)	Red coloured hard, gives effervescence with acid	--do--	--do--	Bagalkot	No layer
21.	Coal	Black shining colour with layers	Carbon	carbonaceous sedimentary rock	Kutch and some part of Saurashtra, Raniganj, Bengal	-

METAMORPHIC ROCKS						
22.	Quartzite	Fine granular mass rather rough to feel dull whitish grey colour without layer	Entirely quartz	Hydro metamorphic rocks	Gokak and Kandala	
*	Hematite quartzite	Alternate layer of hematite and quartzite, yellowish brown coloured hard rock	Hematite and quartz	--do--	Gokak and Bagalkok	
23.	Granite gneiss	White and pink colour with layers arranged in a parallel manner but are compact	Quartz, orthoclase feldspar hornblende and mica	Dynamo metamorphic rock (foliated)	Gokak, Khanpur, Mysore, Baroda, Sabarkantha, Banaskantha	Layers are not distinct, can not be separated
24.	Granite Schist	Light coloured & white orpink with layers	--do--	--do--	--do--	Layers can be easily separated
25.	Mica schist	Various colour like light green, pink, white or black, shining foliated soft rocks	Mica and few crystals of quartz	--do--	Gokak,Mysore, Nellore, Panchmahal	--do--
*	Quartz mica schist	Light coloured rocks with mica forming thin layer	Quartz is abundant mica is also an imp.constituent	--do--	Gokak	-
26.	Chlorite schist.	Green coloured foliated rocks	Mainly chlorite with quartz, feldspar, mica	--do--	Khambhat and granite area	--do--
*	Hornblende schist	Dark green coloured fairly soft rocks with elongated crystals	Mainly hornblende	--do--	Gokak	-
*	Talc schist	Greenish white mass soft and soapy to feel layers are seen	Chiefly talc	--do--	Near Mewad and Ajmer in Rajasthan	Very soft rocks
27.	Slate	Grey to black colour compacted and uniform texture, foliated structure	Mainly clays (formed from shale)	--do--	Kaladgi, Champaner (Baroda)	--do--

28.	Marble(white)	White shining and crystalline appearance readily gives effervescence with acid, Hard rock	$CaCO_3$ (Recrystalize)	Thermo metamorphic rocks	Jabalpur,Ambaji (Palanpur), Jesalmer, Indore	No layer
29.	Marble(green)	Green coloured shining & crystalline appearance, readily gives effervescence with acid, hard rock	--do--	--do--	--do--	--do--

EXERCISE NO.-4

OBJECTIVE: STUDY OF SOIL FORMING MINERALS

The minerals are the naturally occurring inorganic, homogeneous substances having definite chemical composition, physical properties and specific geometric forms (crystal) such as quartz, orthoclase etc.) From agricultural stand point, soil minerals are important because they provide.

(i) plant nutrients (ii) space for water and (iii) physical supports to plants.

Characteristics of minerals

The minerals have definite chemical composition. Mostly they exist as salt or oxides. Besides having definite chemical composition, the minerals have more or less definite physical properties viz. colour, luster, transparency, crystallinity, streak, hardness, cleavage and specific gravity by means of which they can often be identified right in the field and laboratory.

Physical characteristics

1. Colour

Each mineral has got its characteristic colour, which give some indication for its classification. But in nature, colour of mineral is greatly variable and is dependant on its chemical composition. e.g.

1. Colourless	Quartz
2. White to pale	Feldspar, dolomite, gypsum muscovite mica, kaolin
3. Yellow	Iron pyrite, sulphur
4. Greenish	Olivine, serpentine
5. Reddish brown	Garnet
6. Black	Biotite mica, haematite, magnetite, graphite, augite

2. Luster

It is reflection of light from the surface of the mineral. There are several types of mineral lusters. viz.

(i) Metallic : The luster of metals
e.g. copper pyrite, iron pyrite, graphite

(ii) Vitreous : The luster of glass
e.g. rock crystal, rock salt

(iii) Resineous : The luster of yellow resin
e.g. peach stone

(iv) Pearly : The luster of pearl
e.g. Mica

(v) Silky : The luster of silk
e.g. asbestos

(vi) Adamantine : The luster of diamonds
e.g. Diamond

(vii) Waxy : The luster of wax
e.g. Flints (greasy like oil)

3. Structure

The structure refers to the typical shape or forms of crystal fragment or mineral aggregate. There are 6 basic systems of crystalline forms.

(i) Monometric or cubical: The three axes are of equal length and at rightangles to one another as in cube. egogalena, halite, garnet.

(ii) Dimetric or tetragonal: Two axes ate equal and one unequal. Allthese axes are at right angles to one another. e.g. zircon.

(iii) Trimetric or orthorhombic: There are 3 axes, all at right angles butof different lengths. e.g. sulphur, olivine.

(iv) Monoclinic: There are 3 unequal axes, two of which are not at right angles, while the third makes a right angle with the plane of other two. e.g. orthoclase,gypsum, mica, horn-blende.

(v) Triclinic: This has 3 unequal axes but none form right angle with any other pyramide like. e.g. plagioclase.

(vi) Hexagonal: This has 3 equal axes at 120° arranged in one plane and one more forth axis of a different length at right angle to the other three. e.g. quartz, calcite.

The arrangement of crystals gives rise to several kinds of structures:

1. Granular 2. Lameller (like plates) 3. Columnar
4. Reticulated 5. Stelleted and 6. Drusy

4. Transparency

It is the degree of the penetration of light through a mineral. viz.

Transparent – e.g. Mica
Translucent – e.g. Quartz
Opaque - e.g. pyrite

5. Streak

It is the colour of finely divided powder obtained when the mineral is rubbed on a piece of unglazed porcelain plate. If the mineral is harder than the porcelain plate the streak can be obtained by scratching the surface of the specimen with a piece of corundum. Some times the colour of the streak differ from the colour of the mineral. e.g.

Minéral	**Colour**	**Streak**
Heamatite	Reddish black	Red
Magnetite	Black	Black
Limonite	Black	Yellowish
Iron pyritie	Brass yellow	Greenish black
Apatite	Pink to yellow	White

6. Hardness

Hardness of mineral is defined as the resistance offered to scratching or abrasion. The hardness of mineral is determined by scratching the smooth surface of one mineral with the edge of another. The diamond is the hardest as it can scratch all the substance in this universe. Hardness is referred to by number from one to ten. Mho has arranged the minerals in order of increasing hardness which is known as **Mho's scale of hardness**. This is as under:

Mineral	Relative hardness
Talc	1 - softest
Gypsum	2
Calcite	3
Fluorite	4
Apatite	5
Feldspar	6
Quartz	7
Topaz	8
Corundum	9
Diamond	10- hardest

With the use of this scale, hardness of other mineral can be determined.

e.g. If a given mineral scratch gypsum but not to calcite, its hardness is between 2 and 3. As a rough and ready method the following scale is useful.

Finger nail - 2.5, Copper - 3.0, Glass - 5.5 and Iron (sharpknife) - 6.5

7. Cleavage

It is the property of certain minerals to split along planes to one or more faces when they are struck with a hard object. e.g.

Cubical Cleavage : Cleavage in three direction at right angle. e.g. galena.
Rhombohedral : In three direction but not in right angle – rhombic e.g. calcite.
Basal : In one direction e.g. Mica.
Fracture : Irregular e.g. glass and quartz.

8. Specific gravity

It is the ratio the weight of mineral and weight of an equal volume of water. It is more or less constant and hence the substance can be easily recognized from its sp. gr. e.g. gypsum 2.3, quartz 2.65 and hematite 5.3. If specific gravity is more than 2.85 is called heavy Minerals and less than 2.85 light minerals.

Classification of minerals

The minerals are classified by two ways on the basis of their (i) origin and (ii) chemical composition.

(I) On the basis of origin

On the basis of origin and mode of formation, the minerals can be classified as (1) Primary minerals and (2) Secondary minerals.

I. Primary minerals

When a mineral arises trom the cooling and solidification ofa molten megma, it is called primary minerals. e.g. given in table

2. Secondary minerals

When a mineral arises through the metamorphism or weathering of primary or other pre - existing minerals, it is called secondary minerals. e.g. givenin table.

(II) On the basis of chemical composition

The minerals have definite chemical composition and they are found in compound form in the rocks except few are found in elemental form. According to their chemical composition, minerals are divided into eight groups as under:

(1) Silicate
(2) Elements
(3) Oxides
(4) Sulphates
(5) Carbonates
(6) Sulphjdes
(7) Phosphates
(8) Halides

Examples are given in table.

Classification of minerals

According to origin and mode of formation		**According to chemical composition**	
I. PRIMARY		**I. SILICATE**	**5. CARBONATES**
Orthoclase Feldspar-$KAISi_3O_8$		Muscovite, Biotite	Calcite-$CaCO_3$
Albite Feldspar	-$NaAISi_3O_8$	Feldspar, Olivine	Magnesite-$MgCO_3$
Anorthite Feldspar	-$CaAI_2 Si_3O_8$	Epidote:$Ca_3(AIFe)_3OH(SiO_4)_3$	Dolomite-$CaMg(CO_3)_2$
Quartz	-SiO_2	Zeolite-$CaAISi_7O_4.7H_2O$	
Hornblende	-$Ca_2AI_2Mg_2Fe_3Si_6O_{22} (OH)_2$	Amphibole	**6. SULPHIDE**
Muscovite mica	-$KH_2AI_3 (SiO_4)_3$	**2. ELEMENTS**	Copper pyrite - CuS_2
Biotite mica	-$KH_2(Mg, Fe)_3 AI (SiO_4)_3$	Graphite-(C)	Iron pyrite - FeS_2
Augite	-$Ca_2 (AI, Fe)_4 (Mg, Fe)_4 Si_6O_{24}$	Diamond-(C)	Galena - PbS
II. SECONDARY		SuIphur-(S)	
Calcite	-$CaCO_3$	**3. Oxides**	**7. PHOSPHATES**
Magnesite	-$MgCO_3$	Quartz- SiO_2	Apatite
Dolomite	-$CaMg (CO_3)_2$.	Hematite-Fe_2O_3	$Ca_5(Fe,CI. OH)(PO_4)_3$
Sederite	-$FeCO_3$	Goethite- $FeO(OH)-Fe_2O, H_20$	
Gypsum	-$CaSO_4 2H_2O$	Limonite-$Fe_2O_3.3H_20$	**8. HALIDES**
Apatite	- $Ca_5 (Fe, CI, OH) (PO_4)_3$	Magnetite-Fe_3O_4	Fluorite-CaF_2(Fluorspar)
Limonite	- $FeO(OH)nH_2O$ or $Fe_2O_3.3H_2O$	Pyrolusite-MnO_2	Rock salt- NaCI (Halite)
Hematite	- Fe_2O_3	Rutile- TiO_2	
Gibbsite	- $Al_2O_3.3H_2O$	**4. SULPHATES**	
Clay minerals:		Gypsum-$CaSO_4.2H_2O$	
Kaolinite	- $AI_2 (OH)_4 Si_2O_5$	Baryte- $BaSO_4$	
Montmorillonite	- $AI_2 (OH)_2 Si_4O_{10}$	Anhydrite-$CaSO_4$	
Hydrous mica	- $KAI_2 (OH)_2 (AI. Si)_3 O_{10}$		

Chemical composition and physical characteristics of important minerals

Sr. No.	**Mineral**	**Chemical composition**	**Colour**	**Streak**	**Luster**	**Opacity**	**Hardness**	**Sp. gr.**
I. Elemets								
1.	Graphite	C	Steel grey	Dark shining	Metallic	Opaque	1	2.2
2.	Sulphur	S	Yellow	Yellow or white	Resineous	Translucent	1-2	2.07
II. Oxides								
3.	Rock crystal (Quartz)	SiO_2	Various	White	Vitreous	Transparent	7	2.6-2.7
4.	Amethyst	SiO_2	Purple	White	Vitreous	Translucent	7	2.65
*****	Rutile	TiO_2	Brown	Pale brown	Adamantine	Transparent	6-6.5	4.25
5.	Milkquartz	SiO_2	Milk white	White	Vitreous	Translucent	7	2.65
6.	Chalcedony	SiO_2	Variously coloured	White	Resineous	Opaque	7	2.6
*****	Brucite	$Mg(OH)_2$	Greenish white	White	Pearly to vitreous	Translucent	2.5	2.39
7.	Carnelian	SiO_2	Yellow red	White	Resinous waxy	Translucent	7	2.6
*****	Gibbsite	$AI(OH)_3$	Greenish grey	White	Pearly to vitreous	Transparent	2.5	2.39
8.	Agate	SiO_2	Variegated colours	White	Resineous waxy	Translucent	7	2.6
*****	Goethite	$FO_3.H_2O$ or FeO (OH)	Blackish brown yellow	Brownish	Adamantine	Transparent	5.5-5	3.3-4.3
9.	Flint	SiO_2	Smoky brown bluish	White	Resineous waxy	Translucent	7	2.6

10.	Jaspar	SiO_2	Dull red, brown yellow	White	Dull (earthy)	Opaque	7	3.6
11.	Opal	SiO_2	All coloured white, yellow, brown, grey etc.	White	Sub vitreous	Translucent	5.5-6.5	1.9-2.3
12.	Haematite	Fe_2O_3	Steel grey	Rcd	Earthy to metallic	Opaque	5-6.5	4.9-5.2
*****	Iimenite	$FeTiO_3$	Black	Black	Metallic	Opaque	5-6	4.72
13.	Limonite	$2(Fe_2O_3).3H_2O$ $FeO(OH)_2nH_2O$	Yellowish	Brownish	Earthy	Opaque	5-5.5	3.6-4.0
14.	Magnetite	Fe_3O_4	Black	Black	Dull metallic	Opaque	5.5-6.5	4.9-5.2
*****	Pyrolusite	MnO_2	Dark grey to black	Black	Metallic	Opaque	6-6.5	5.06
15.	Corundum	AI_2O_3	Red, brown, black	White	Vitreous	Opaque	9	4
III. Silicates								
16.	Plagioclase feldspar	$Na(AlSi_3O_8)+Ca(Al_2Si_2O_8)$	White greenish & reddish	White	Pearly	Translucent	6-6.5	2.6-2.76
*****	Albite	$NaAl Si_3O_8$	Greyish white	White	Sub vitreous	Translucent	6	2.6-2.76
*****	Anorthite.	$CaAl_2Si_3O_8$	Greyish white	White	Sub vitreous	Translucent	6	2.6-2.76
*****	Oligoclase	$Na_2CaAl_2Si_6O_{17}$	Greyish white	White	Sub vitreous	Translucent	6	2.6-2.76

17.	Orthoclase Feldspar	$KAISi_3O_8$	Colourless to pinkish white	White	Vitreous to pearly	Translucent	6	2.56
*	Microcline	$KalSi_3O_8$	Creamy to pinkish white	White	Vitreous to pearly	Translucent	6	2.56
18.	Zeolite	Ca.K.Na.Al. silicates	White	White	Vitreous to pearly	Translucent	6	2.8
*	Stilbite	$CaAl_2Si_7O_{18}7H_2O$	Creamy to pinkish white	White	Vitreous to pearly	Opaque	4	2.1-2.2
*	Kaolinite	$Al_4Si_4O_{10}(OH)_8$	Whitish grey	White	Pearly	Opaque	1	2.6
*	Montmorillonite	$Al_2Si_4O_{10}(OH)_2\ xH_2O$	Greyishyellow	White	Dull	Opaque	2-2.5	2.6
*	Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$	Yellowish white	White	Pearly	Opaque	1-1.5	2.84
*	Serpentine	$Mg_6Si_4O_{10}(OH)_8$	Greenish yellow to greyish brown	White	Waxy to silky	Opaque	4-6	2.5-2.6
19.	Muscovitemica	$KAI_2(AlSi_3O_{10})(OH)_2$	Colourless to white	White	Pearly to vitreous	Translucent	2.5	2.8-2.31
20.	Biotitemica	$K(Mg,Fe,Mn)_3(AISi_3O_{10})(0H)_2$	Brown to dark green	Grey	Vitreous to pearly	Translucent	2.5-3.0	2.8-3.4
*	Galuconite	$K(Fe,Mg,AI)_2(Si_4O_{1O})(OH)_2$	Green to brown	Greenish grey	Earthy	Opaque	2-3	2.5-2.8
*	Apophyllite	$KCa_4(Si_4O_{IO})_2F.8H_2O$	Pinkish white	White	Pearly to vitreous	Translucent	5	2.35
*	Chorite	$Mg_{1O}Al_2(Si_6Al_2)O_{22}(OH)_{16}$	Brownish green	Greenish white	Earthy to pearly	Translucent	1.5-2.5	2.6-3.3

21.	Hornblende	$NaCa(Mg,Fe,Al)_5 (Si,Al)_8 O_{22} (OH)_2$	Dark green to brown or black	Greyish	Vitreous	Opaque	5.5-6.0	3.0-3.4
*	Augite	$Ca(Mg, Fe, Al)(Al,Si)_2O_3$	Dark green	Whitish grey	Vitreous	Opaque	6	3.2-3.5
*	Enstatite	$MgSiO_3$	Light green	White	Vitreous	Opaque	6	3.2-3.9
*	Epidote	$Ca_2(Al, Fe)_3Si_3O_{12}(OH)$	Brownish	Greyish white	Vitreous	Opaque	7	3.3-3.6
22.	Talc	$Mg_3Si_4O_{10}(OH)_2$	Greyish white	White	Pearly	Translucent	1	2.82
*	Vermiculite	$Mg_3Si_4O_{16}(OH)_2xH_2O$	Yellow	White	Pearly	Opaque	1.5	2.4
23.	Actinolite	$Ca_2(Mg,Fe)_5Si_3O_{22}(OH)_2$	Green	Greenish white	Vitreous	Opaque	5.5	3.35
24.	Olivine	$MgFeSiO_4$	Olive green to dark green	Whitish grey	Vitreous	Opaque	6.5	3.2-4.3
*	Zircon	$ZrSiO_4$	Variouscolour	white	Vitreous	Opaque	7.5	-
25.	Tourmaline	$Na(Mg,Fe)_3AI_6(BO_3)_3 (Si_6O_{18})(OH)_4$	Blackish brown to dark blue	White	Vitreous	Opaque	7.5	3.0-3.2
IV. Carbonates								
26.	Calcite	$CaCO_3$	ColourIess to white	White	Vitreous	Translucent	3	2.71
*	Magnesite	$MgCO_3$	Brownish	Brown	Dull meallic	Opaque	5.5	-
*	Dolomite	$CaCO_3 MgCO_3$	White	White	Vitreous to pearly	Translucent	3.5-4.0	2.85

V. Sulphates								
*****	Anhydrite	$CaSO_4$	White	Greyish white	Vitreous	Translucent to Translucent	3.5	2.96
*****	Baryte	$BaSO_4$	White	White	Vitreous	Translucent	3-3.5	4.48
*****	Gypsum	$CaSO_4.2H_2O$	Colourless or white	White	Vitreous to pearly	Translucent to Translucent	2	2.32
VI. Sulphide								
27.	Iron pyrite	FeS_2	Brass yllow	Greenish black	Metallic	Opaque	6-6.5	5.01
*****	Copper pyrite	CUS_2	Brass yellow	Greenish black	Vitreous	Opaque	3.4	3.1
28.	Galena	Pbs	Grey	Grey black	Metallic	Opaque	4-5	3.2
VII. Phosphates								
*****	Apatite	$Ca_3(P0_4)_2$(F,CI, OH)	Pink to yellow	White	Vitreous	Transparent to Opaque	5	3.1-3.2
VIII. Halides								
29.	Fluorite(Fluorspar)	CaF_2	Violet blue	Colourless	Vitreous	Opaque	4.0	3.1
30.	Halite(rocksalt)	NaCI	Bluish white	Colourless	Vitreous	Opaque	2.5	2.1

EXERCISE NO.-5

OBJECTIVE: DETERMINATION OF DENSITIES OF SOIL

(A) Measurement of particle density (Dp) of soil

The Particle density of a soil is referred to the mass of a unit volume of soil particles (Soil solids). It determined by measuring the mass and volume of soil solids.

Principle

When a known mass of dry soil is immersed in water and air is expelled out, the amount of displaced water equals to the volume of soil particles.

Equipments

1. Pycnometer (R.D. bottle) and 2. Balance.

Procedure

1. Weigh empty pycnometer.
2. Fill the dry pycnometer with water completely.
3. Wipe outer side of the pycnometer with a piece of filter paper andweigh it.
4. Pour out water and dry it from outside with a piece of filter paper.
5. Put 10 g of oven-dry soil into the pycnometer.
6. Fill the pycnometer up to top with water using the pipette and wash with a jet of water any particles sticking to the inner side of the neck.
7. Expel the entrapped air by gently boiling the contents.
8. Allow the contents to cool to room temperature and fill the pycnometerto the brim/ mark with boiled and cooled water.
9. Fix the stopper well.
10. Clean the outer side of the pycnometer with a filter paper and weigh it.

B. Measurement of bulk density (Db) of soil

(Laboratory method for disturbed soil)

Bulk density is defined as the ratio of mass of oven dry soil to its bulk volume and is expressed as g cm^{-3} or Mgm^{-3}. The bulk volume is the volume of soil particles plus pore space.

Relationship between porosity and densities of soil:

$$\%\ \text{solid space} = \frac{\text{Bulk density}}{\text{Particle density}} 100$$

Since, % pore space + % solid space = 100

Or % pore space = 100 -% solid space

$$\text{or} \quad \%\ \text{pore space} = 100 - \frac{\text{Bulk density}}{\text{Particle density}} 100$$

$$\%\ \text{pore space} = 100 \times \left[1 - \frac{\text{Bulk density}}{\text{Particle density}} \right]$$

(D) Weight of a hectare soil

Wt. of a hectare soil (t/ha) to 15cm depth = Db x 1000x 10000x Depth (m) up

=___________________________

=________________________kg/ha

=________________________t/ha

Principle

The mass of the oven-dry soil which fills the container of a known volume is determined by weighing. The volume of the packed soil will be equal to the capacity of the container. Bulk density is then calculated as the ratio of mass of soil to its volume.

Equipments and materials

1. Plastic bottle of 100 ml capacity 2. Balance.

Procedure

1. Weigh an empty large weighing bottle of about 50 ml capacity or specific gravity bottle without stopper.
2. Fill the bottle with soil up to the brim and tap it 15-20 times by letting it fall gently on the table from a height of approximately 2.5 cm each time. (This tapping is assumed to produce the same. state of packing as occurring naturally in the field. However, this assumption is not strictly correct.)
3. Empty the bottle and find its volume by filling it completely with water from a burette.

(C) Measurement of porosity of soil

Porosity of a soil sample is its that volume which is occupied by air and water or porosity of a soil is the fraction of soil volume not occupied by soil particles.

Procedure

1. Determine the soil bulk density (Db) and particle density (Dp)
2. Calculate the total porosity.

(D) Calculate the wt of a hectare soil Result

1. Use bulk density of soil

Sample	Dp Mg m^{-1}	Db Mg m^{-1}	% porosity	Wt. of soil (t ha^{-1})
Soil				

EXERCISE NO.-6

OBJECTIVE: DETERMINATION OF SOIL MOISTURE CONTENT

Soil moisture influences crop growth not only by affecting nutrient availability, but also nutrient transformations and soil biological behavior. Therefore soil moisture is routinely measured in most field trials. The gravimetric approach is more flexible, as samples can be readily taken from any soil situation. All analyses in the laboratory are related to an air- or oven-dry basis, and therefore must consider the actual soil moisture content.

Apparatus

Electric oven with thermostat, Desiccator, moisture box

Procedure

1. Weigh 10 g air-dry soil (< 2-mm) into a previously dried (105°C) and weighed metal can with lid.
2. Dry in an oven, with the lid unfitted, at 105°C overnight.
3. Next day, remove from oven; fit the lid, cool in a desiccator for at least 30 minutes and re-weigh.

CALCULATIONS

$$\%\ \text{Moisture in Soil} = \frac{\text{Wet soil (g)} - \text{Dry soil (g)}}{\text{Dry soil (g)}} \times \text{IOO}$$

EXERCISE NO.-7

OBJECTIVE: ESTIMATION OF ORGANIC CARBON CONTENT IN SOIL

Principle

A suitable quantity of the soil is digested with chromic and sulphuric acids, making use of the heat of dilution of sulphuric acid. The excess of chromic acid left over unreduced by the organic matter of the soil is determined by a titration with standard ferrous sulphate or ferrous ammonium solution using diphenylamine as an internal indicator.

Apparatus

(1) 500 ml beaker (2) Pipette (3) Burette (4) Analytical balance (5) Glass rod.

Reagents

1. **1 N Potassium dichromate ($K_2Cr_2O_7$) solution:** Dissolve 49.04 g pure crystals of potassium dichromate in water and dilute to 1 litre.
2. **0.5 N Ferrous ammonium sulphate solution:** Dissolve 785 g of Ferrous ammonium sulphate ($Fe(NH_4SO_4)_2$ $6H_2O$) in 4 litres of distilled water containing 100 ml conc. H_2SO_4. **OR** 139 g of $FeSO_4$ $7H_2O$ can also be used and that of dissolved in distilled water and add 15 ml conc.H_2SO_4 and dilute to1 litre.
3. **Ortho-Phosphoric acid (95%)**
4. **Diphenylamine indicator:** Dissolve 0.5 g diphenylamine in a mixture of 100ml conc. H_2SO_4 and 20 ml water.
5. **Sulphuric acid:** Not less than 96%.

Procedure

1. Weigh 1.0 g soil sample in a 500 ml beaker.
2. Add 10 ml 1N $K_2Cr_2O_7$ by means of a pipette and 20 ml concentrated $H_2SO_4$by measuring cylinder.
3. Mix thoroughly and allow the reaction to proceed for 30 minutes on asbestossheet.
4. Dilute the reaction mixture with 200 ml of water and 10 ml H_3PO_4 by measuring cylinder and add 7-8 drops of diphenylamine indicator.
5. Titrate the solution with std. 0.5 N $Fe(NH_4)_2(SO_4)_2$ to a brilliant green colour.
6. A blank without soil should be run simultaneously.
7. Calculate the organic carbon content of a given soil sample.

On the basis of organic carbon content, soil be classified as follows:

Low	< 0.5%
Medium	0.5-0.75%
High	> 0.75%

Results

Soil Sample No.	**% O.C.**	**% O.M.**	**% N**

EXERCISE NO.-8

OBJECTIVE: MEASUREMENT OF SOIL TEMPERATURE AND CALCULATION OF SOIL HEAT FLUX

Soil temperature is influences rate of seed germination, seedling emergence and growth, root development, and most microbial processes. Plants and microorganisms survive in certain range of temperatures. Too low and too high temperature are lethal to microorganism. The microclimate for a seed, plant, or microorganism can be impacted by different soil management practices. Ridging or ploughing a soil increases the soil surface area and can expose the soil to more radiation, resulting in warmer temperatures. Mulches and other crop residues insulate the soil, keeping soil surfaces cooler during hot weather and warmer during cold periods. Understanding how soil and land characteristics influence soil temperature enables us to make better decisions in growing crops, planting trees, or managing compost.

There are different kinds of instruments used to measure soil temperature. Some require manual readings whereas soil temperature sensors can be connected to a data logger.

Apparatus

Screw auger and soil thermometer

Procedure

1. Make holes of different depth in soil with the help of screw auger.
2. Insert the thermometers designed for different depths in an oblique position and fill the holes with soil. Pour some water so that soil is set properly adjacent to bulb of the thermometers.
3. After about a day record the soil temperatures.
4. Note down the temperature in this way during the day at specific intervals.

EXERCISE NO.-9

OBJECTIVE: DETERMINATION OF CATION EXCHANGE CAPACITY (CEC) OF SOIL

Cation exchange in soils is a reversible chemical reaction. The cation held on the surface of soil mineral and within the crystal framework of some mineral species plus those are a part of certain organic compounds can by reversibly replaced by those of salt solutions and acids. The CEC (usually expressed as me/100 g of soil) is defined as the sum of the exchangeable cations of a soil. Some exchangeable ions are more easily replaced then others and completeness of replacement of some cations will depend upon the method, it is especially important to specify the method used when reporting figures for CECof the soils.

In the method most commonly used a suitable quantity of the soil is leached with neutral normal Ammonium acetate solution to displace the exchangeable cations by NH_4 ions. The excess of ammonium acetate (NH_4OAC) being washed with achlcohol. The NH_4^+ adsorbed by the soil is than determine bydistillation with MgO.

The use of netural N-NH_4OAC has the following three advantages.

1. It is highly buffer, as a result while saturating the soil. Complex with NH_4^+, the last part of the solution leached through the soil emerges with the same pH as the solution added .
2. NH_4^+ can be easily determined.
3. NH_4^+ is more effective in the displacement of the cations from the soils used.

Apparatus:

1. Erlenmeyer flask 500ml.
2. Beaker 500ml
3. Distillation apparatus
4. Hot plate
5. Porcelain dish
6. Burette 50ml
7. Funnel
8. Filter paper No.44
9. Electronic balance

REAGENTS:

1. Neutral N NH_4OAC

   Dilute 114 ml of glacial aecetic acid (99.5%) with distilled water to a volume of approximately 1 liter. Add 138 ml of conc.NH_4OH and add water a volume of about 1980 ml. Check the pH of the resulting solution, add NH_4OH as needed to attain pH 7.0, and dilute the solution to a volume of 2 liter with water OR 154 gr of NH_4OAC to 2 liter of water.

2. Methyl or Ethyl alcohol (60%):

Dilute 250 ml of alcohol to 1000 ml using distilled water.

3. NH_4Cl crystal
4. MgO
5. 0.1 N H_2SO_4: Dilute 3ml of 36 N acid into 1000ml H_2O
6. 0.1 $NAgNO_3$ solution: Dissolve 17 gm $AgNO_3$ in water and make it 1000 ml
7. Mixed indicator:

   Bromocresol green (0.5%) and methyl red (0.1%) mixed indicator is prepared by dissolving (0.5 gm)of bromocresol green and 0.1 gm methyl red in 100 ml of 95% ethanol and adjusting the solution to the bluish purple mid color at pH 4.5 with dilute NaOH or HCl .This indicator is pink at pH 4.2 and bluish green at the pH rises to pH 4.9 and above.

8. 2% boric acid solution :

   Weigh 2 g of boric acid in 100ml of distilled water.

PROCEDURE:

1. Weigh 5 gm soil in Erlenmeyer flask.
2. Add 100 ml of NH_4OAC solution and shake it for 30 min. and keep it overnight.
3. Filter the content into 1000 ml beaker using Whatman No. 44 filter paper.

   Transfer the soil completely on the filter paper.

4. Continue to leach the soil with NH_4OAC solution, using 20-25 ml solution at a time using in all 100 ml (6 -7 washing are required) keep the filtrate for the determination of total and individual exchangeable bases.
5. To the soil on the filter paper add a little amount of NH_4Cl crystal and leach with alcohol-continue washing (8-10 washing)f the residual till the filter runs free of chloride (Test it with $AgNO_3$).
6. Transfer the residue and filter paper to a 600 ml distillation flask. Add 3-5 gm of MgO and 200-300 ml of distill water.
7. Connect the flask to the distillation apparatus place a 250ml beaker containing of 25 ml 2% boric acid solution alongwith 2 drops of mixed indicator under the condenser of the distillation apparatus to received Ammonia.
8. Start distillation by heating the distillation flask. Continue heating till no ammonia is evolved through the end of the condenser, test it with litmus paper.
9. Back titrate the contents of the beaker with 0.1 H_2SO_4 Solution.

EXERCISE NO.-10

OBJECTIVE: DETERMINATION OF SOIL TEXTURE IN A GIVEN SOIL SAMPLE

Individual soil particles vary widely in any soil type. Similarly, as these particles are cemented together, a variety of aggregate shapes and sizes occur. For standard particle size measurement, the soil fraction that passes a 2-mm sieve is considered. Laboratory procedures normally estimate percentage of sand (0.05 - 2.0 mm), silt (0.002 - 0.05 mm), and clay (<0.002 mm) fractions in soils. Particle size distribu- tion is an important parameter in soil classification and has implications on soil water, aeration, and nutrient availability to plants.

As primary soil particles are usually cemented together by organic matter, this has to be removed by H_2O_2 treatment. However, if substantial amounts of $CaCO_3$ are present, actual percentages of sand, silt or clay can only be determined by prior dissolution of the $CaCO_3$. The two common procedures used for particle size analysis or mechanical analysis are the hydrometer method (Bouyoucos, 1962; Day, 1965; FAO, 1974) or the pipette-gravimetric method.

The hydrometer method of silt and clay measurement relies on the effect of particle size on the differential settling velocities within a water column. Theoretically, the particles are assumed to be spherical having a specific gravity of 2.65 g/cm^3. If all other factors are constant, then the settling velocity is propor- tional to the square of the radius of the particle (Stoke's Law). The settling veloc- ity is also a function of liquid temperature, viscosity and specific gravity of the falling particle. In practice, therefore, we must know and make corrections for the temperature of the liquid. Greater temperatures result in reduced viscosity, due to liquid expansion and a more rapid descent of falling particles.

Apparatus

Soil dispersing stirrer: A high-speed electric stirrer with a cup receptacle. Hydrometer with Bouyoucos scale in g/L (ASTM 152H).

Reagents

A. Dispersing Solution

Dissolve 40 g sodium hexametaphosphate [$(NaPO_3)_{13}$], and 10 g sodium carbonate (Na_2CO_3) in DI water, and bring to 1-L volume with DI water. This solution deteriorates with time and should not be kept for more than 1 to 2 weeks.

B. Amyl Alcohol

Procedure

1. Weigh 40 g air-dry soil (2-mm) into a 600-mL beaker.
2. Add 60-mL dispersing solution.
3. Cover the beaker with a watch-glass, and leave overnight.
4. Quantitatively transfer contents of the beaker to a soil-stirring cup, and fill the cup to about three-quarters with water.
5. Stir suspension at high speed for 3 minutes using the special stirrer. Shake the suspension overnight if no stirrer is available.
6. Rinse stirring paddle into a cup, and allow to stand for 1 minute.
7. Transfer suspension quantitatively into a 1-L calibrated cylinder (hydrometer jar), and bring to volume with water.

A. Determination of Blank

- Dilute 60 mL dispersing solution to 1-L hydrometer jar with water.
- Mix well, and insert hydrometer, and take hydrometer reading, R_b.
- The blank reading must be re-determined for temperature changes of more than 2°C from 20°C.

B. Determination of Silt plus Clay

- Mix suspension in the hydrometer jar, using a special paddle carefully, withdraw the paddle, and immediately insert the hydrometer.
- Disperse any froth, if needed, with one drop of amyl alcohol, and take hydrometer reading 40 seconds after withdrawing the paddle. This gives reading, R_{sc}.

CALCULATIONS

Percentage Silt plus Clay in soil

$$\%\,[\text{Silt} + \text{Clay}]\,(\text{w/w}) = (R_{sc} - R_b) \times \frac{\text{IOO}}{\text{Oven-dry soil (g)}} \quad \text{..................} \quad (5)$$

C. Determination of Clay

- Mix suspension in the hydrometer jar with paddle, withdraw the paddle, with great care, leaving the suspension undisturbed.
- After 4 hours, insert the hydrometer, and take hydrometer reading, R_C.

Percentage Clay in soil:

$$\% \text{ Clay (w/w)} = (R_c - R_b) \times \frac{\mathrm{lOO}}{\text{Oven-dry soil (g)}}$$

Percentage Silt in soil:

$$\% \text{ Silt (w/w)} = [\% \text{ Silt + Clay (w/w)}] - [\% \text{ Clay (w/w)}]$$

D. Determination of Sand

- After taking readings required for clay and silt, pour suspension quantitatively through a 50-□m sieve.
- Wash sieve until water passing the sieve is clear.
- Transfer the sand quantitatively from sieve to a 50 mL beaker of known weight.
- Allow the sand in the beaker to settle, and decant excess water.
- Dry beaker with sand overnight at 105°C.
- Cool in a desiccator, and re-weigh beaker with sand.

Percentage Sand in soil:

$$\% \text{ Sand (w/w)} = \text{Sand weight} \times \frac{\mathrm{lOO}}{\text{Oven-dry soil (g)}}$$

Where: Weight of sand follows from:

$$\text{Sand weight(g)} = [\text{Beaker} + \text{Sand (g)}] - [\text{Beaker (g)}]$$

Note

1. If possible, all hydrometer jars should be placed in a water bath at constant temperature (20°C); in that case, temperature corrections are not needed.
2. For temperature correction, use a value of 0.4 for each degree temperature difference from 20°C. Add or subtract this factor if the temperature is more or less than 20°C, respectively.
3. All results of mechanical analysis should be expressed on the basis of oven- dry soil (24 hours drying at 105°C).
4. In the above procedure, carbonates and organic matter are not removed from the soil.
5. The Hydrometer method, as described in this section, cannot be applied to soils that contain free gypsum (gypsiferous soils). For gypsiferous soils, see Hesse (1971).
6. Sum of % silt and clay + % sand should be 100 %. The magnitude of deviation from 100 is an indication for the degree in accuracy.

Soil Texture

Once the percentage of sand, silt, and clay is measured, the soil may be assigned a textural class using the USDA textural triangle. Within the textural triangle are various soil textures which depend on the relative proportions of the soil fractions.

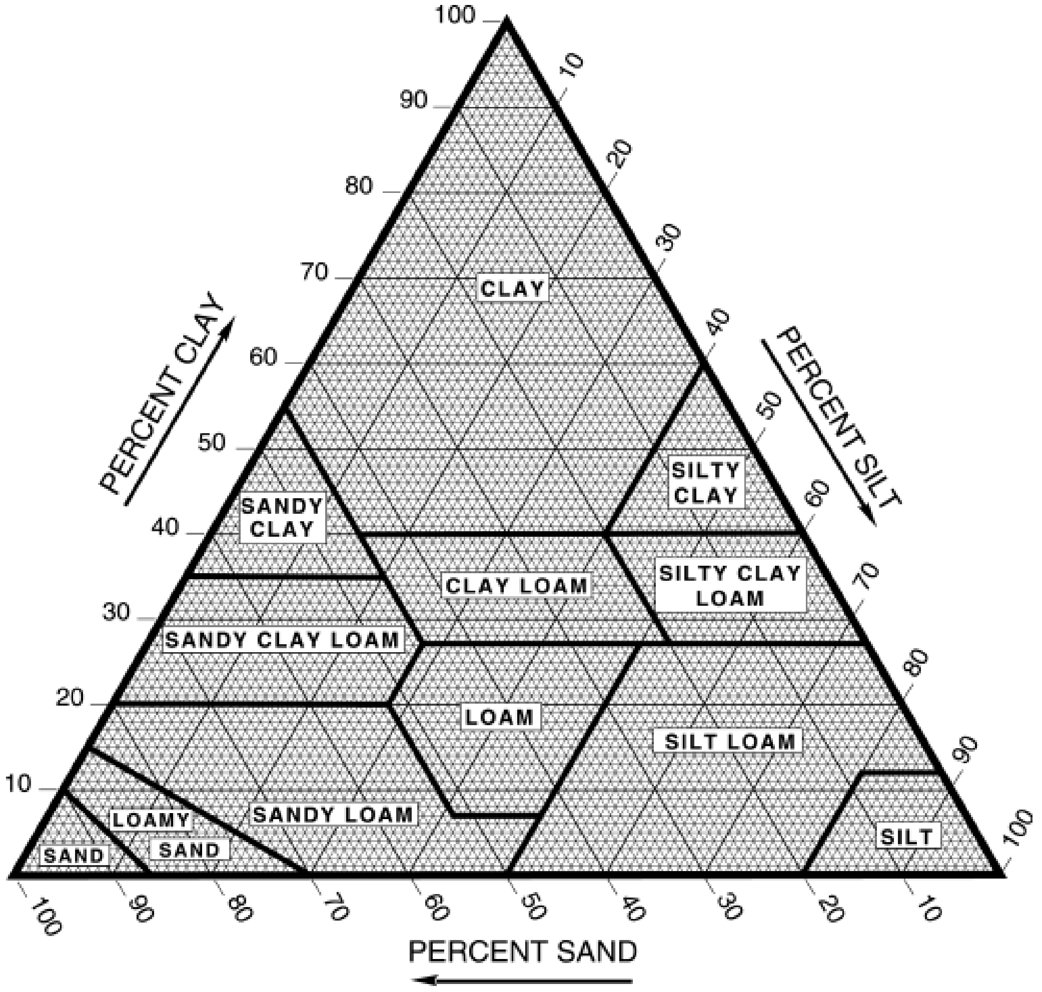


Fig. The USDA Soil Textural Triangle.

EXERCISE NO.-11

OBJECTIVE: DETERMINATION OF SOIL pH IN A GIVEN SOIL SAMPLE.

Determination of pH is actually a measurement of hydrogen ions activity in soil – water system. It is defined as negative logarithm of the hydrogen ion activity. Mathematically, it is expressed as:

$pH = - \log a H^+$

The pH value of a soil is an indication of soil reaction i.e. acidic, neutral or alkaline. The nutrient availability is governed by soil reaction. It is maximum at neutral pH and decreases with increase in acidity or alkalinity. Thus, pH value gives an idea about the availability of nutrients to plants.

Principle:

The pH is usually measured by pH meter, in which the potential of hydrogen ion indicating electrode (glass electrode) is measured potentiometrically against calomel saturated reference electrode which also serves as salt bridge. Now a days, most of the pH meters have single combined electrode. Before measuring the pH of the soil, the instrument has to be calibrated with standard buffer solution of known pH. Since, the pH is also affected by the temperature, hence, the pH meter should be adjusted to the temperature of the solution by temperature correction knob.

Reagents :

Standard buffer solutions: These may be of pH 4.0, 7.0 or 9.2 and are prepared by dissolving one standard buffer tablet in 100 ml distilled water, It is necessary to prepare fresh buffer solution after few days. In absence of buffer tablet, a 0.05 M potassium hydrogen phthalate solution can be used which gives a pH of 4.0 (Dissolve 10.21 g. of A.R. grade potassium hydrogen phthalate in distilled water and dilute to 1 litre. Add 1 ml of chloroform or a crystal of thymol per litre as a preservative).

Calibration of pH meter

- Switch on the instrument and allow it to warm for 10 minutes
- Keep the pH selector switch on zero position
- Set the temperature compensation control to the solution temperature
- Adjust the zero adjustment knob so that the pointer in the meter reads exactly zero, when the electrodes are immersed in distilled water.
- Lift the electrodes from distilled water and wipe it dry using filter paper and dip them in standard buffer solution of known pH (4.0, 7.0 and 9.2)
- Change the function switch to particular pH ranges (0-7 or 7-14) and adjusts the standardization knob till the pointer reads the correct pH value of the buffer solutions. Do not disturb the zero knob adjustment.

pH measurement

- Weigh 10 g of air dried soil passed through 2 mm sieve and transfer to a clean 50 ml beaker
- Add 20 ml of distilled water (1: 2 ratio)
- Using glass rod, stir the content intermittently and allow it to stand for half an hour.
- Wash the electrodes carefully with a jet of distilled water and wipe it dry with a piece of filter paper.
- Stir the soil suspension again just before taking the reading.
- Immerse the electrodes into the beaker containing soil water suspension and change the function switch to the particular pH range.
- Record the meter reading.

Result

The soil pH of the given soil sample is = ---------

EXERCISE NO.-12

OBJECTIVE: Determination of electrical conductivity (EC) in a given soil sample.

Electrical conductivity (EC)

The electrical conductivity (EC) measurement gives the total amount of soluble salts present in the soil and is expressed as millimhos/cm or dSm^{-1}
Amount of soluble salts in a sample is expressed in terms of the electrical conductivity (EC) and measured by a conductivity meter. The instrument consists of an AC solubridge or electrical resistance bridge and conductivity cell having electrodes coated with platinum black. The Instrument is also available as an already calibrated assembly (Solubridge) for representing the conductivity of solutions in dSm^{-1} (deci Siemen per meter) at 25^0C.

As the amount of the soluble salts in a solution increases the electrical conductivity also increases. This electrical conductivity is measured in terms of the resistance offered to the flow of current using a conductivity bridge.

It is known that solutions offer some resistance to the passage of electric current through them, depending upon the concentration of salts present. Hence EC is measured in terms of electrical resistance between parallel electrodes immersed in the soil suspension of water. In such a system, the solution between the electrodes becomes the electrical conductor to which the physical laws relating to resistance are applicable. The electrical resistance “R” is directly proportional to the distance “L” between the electrodes and inversely proportional to the cross sectional area “A” of the conductor.

Hence $R = L/ A$ or $R= r \times L/ A$

Where r = proportionality constant known as electrical resistivity If $L = 1$ cm and $A = 1$ cm^2 then $R = r$.

Where ‘r’ is called specific resistivity. Hence specific resistance is the resistance of a conductor of 1 cm in length and 1 cm^2 in area.

Higher the salt content, higher the passage of current and lesser the resistance to the flow of the current. Hence the reciprocal of specific resistivity is called as specific conductivity. Therefore specific conductivity is defined as the conductivity of a solution enclosed in a cell whose electrodes are exactly 1 cm and possess a surface area of 1 cm^2. The resistance is expressed as ohms/cm and the conductivity is expressed in reciprocal ohms or mhos per cm. It is not possible to make a conductivity bridge having electrodes 1sq.cm in area and place exactly 1 cm apart. Hence, the factor called the cell constant is determined for the given cell. Modern conductivity meters are calibrated to read directly the electrical conductance with given cell.

Reagents :

Potassium chloride: Dissolve 0.7456g dry potassium chloride (AR) in distilled water and make up the volume to one litre.

Procedure :

- Take 10 g of soil in 50 ml beaker, add 20 ml of distilled water and shake intermittently for 30 minutes.
- Determine the conductivity of the supernatant liquid with the help of conductivity meter.
- The electrical conductivity of saturation extract (E.C.e) is also determined for salinity ratings.

EC ($dS\ m^{-1}$)	**Effect**
<1	- No deleterious effect on crop
1-2	- Critical for salt sensitive crops
2-3	- Critical for salt tolerant crops
>3	- Injurious to most crops

Result

The EC of the given soil sample is = --------- $dS\ m^{-1}$

Appendix 1. Conversion Factors for SI and Non-SI Units.

To convert Column 1 into Column 2, multiply by:	Column 1 SI Unit	Column 2 non-SI Unit	To convert Colum 2 into Column 1, multiply by:
		Length	
0.621	kilometer, km (10^{3} m)	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
3.28	meter, m	foot, ft	0.304
1.0	micrometer, μm (10^{-6} m)	micron	1.0
3.94 × 10^{-2}	millimeter, mm (10^{-3} m)	inch, in	25.4
10	nanometer, nm (10^{-9} m)	Angstrom, Å	0.1
		Area	
2.47	hectare, ha	acre	0.405
247	square kilometer, km^{2} (10^{3} m)^{2}	acre	4.05 × 10^{-3}
0.386	square kilometer, km^{2} (10^{3} m)^{2}	square mile, mi^{2}	2.590
2.47 × 10^{-4}	square meter, m^{2}	acre	4.05×10^{3}
10.76	square meter, m^{2}	square foot, ft^{2}	9.29 × 10^{-2}
1.55 ×10^{-3}	square millimeter, mm^{2} (10^{-3} m^{2})	square inch, in^{2}	645
		Volume	
9.73 × 10^{-3}	cubic meter, m^{3}	acre-inch	102.8
35.3	cubic meter, m^{3}	cubic foot, ft^{3}	2.83 × 10^{-2}
6.10 × 10^{4}	cubic meter, m^{3}	cubic inch, in^{3}	1.64 × 10^{-5}
3.53 × 10^{-2}	liter, L (10^{-3} m^{3})	cubic foot, ft^{3}	28.3
0.265	liter, L (10^{-3} m^{3})	gallon	3.78
33.78	liter, L (10^{-3} m^{3})	ounce (fluid), oz	2.96 × 10^{-2}
2.11	liter, L (10^{-3} m^{3})	pint (fluid), pt	0.473
		Mass	
2.20 × 10^{-3}	gram, g (10^{-3} kg)	pound, lb	454
3.52 × 10^{-2}	gram, g (10^{-3} kg)	ounce (avdp), oz	28.4
2.205	kilogram, kg	pound, lb	0.454
0.01	kilogram, kg	quintal (metric), q	100
1.10 × 10^{-3}	kilogram, kg	ton (2000 lb), ton	907
1.102	megagram, Mg (tonne)	ton (U.S.), ton	0.907
1.102	tonne, t	ton (U.S.), ton	0.907
		Yield and Rate	
0.893	kilogram per hectare, kg ha^{-1}	pound per acre, lb acre^{-1}	1.12

0.107	liter per hectare, L ha^{-1}	gallon per acre	9.35
893	tonnes per hectare, t ha^{-1}	pound per acre, lb acre^{-1}	1.12 × 10^{-3}
893	megagram per hectare, Mg ha-1	pound per acre, lb acre^{-1}	1.12 × 10^{-3}
0.446	megagram per hectare, Mg ha^{-1}	ton (2000 lb) per acre, ton acre^{-1}	2.24

Appendix 1
(Contd...)

To convert Column 1 into Column 2, multiply by:	Column 1 SI Unit	Column 2 non-SI Unit	To convert Colum 2 into Column 1, multiply by:
	Pressure		
9.90	megapascal, MPa (10^6 Pa)	atmosphere	0.101
10	megapascal, MPa (10^6 Pa)	bar	0.1
1.00	megagram per cubic meter, Mg m^{-3}	gram per cubic centimeter, g cm^{-3}	1.00
2.09×10^{-2}	Pascal, Pa	pound per square foot, lb ft^{-2}	47.9
1.45×10^{-4}	Pascal. Pa	pound per square inch, lb in^{-2}	6.90×10^3
	Temperature		
1.00 (H-273)	Helvin, H	Celsius, °C	1.00 (°C+273)
(9/5 °C) + 32	Celsius, °C	Fahrenheit, °F	5/9 (°F - 32)
	Electrical Conductivity, Electricity, and Magnetism		
10	siemen per meter, S m^{-1}	millimho per centimeter, mmho cm^{-1}	0.1
10^4	tesla, T	Gauss, G	10^{-4}
	Water Measurement		
9.73×10^{-3}	cubic meter, m^3	acre-inches, acre-in	102.8
9.81×10^{-3}	cubic meter per hour, m^3 h^{-1}	cubic feet per second, ft^3 s^{-1}	101.9
4.40	cubic meter per hour, m^3 h^{-1}	U.S. gallons per minute, gal min^{-1}	0.227
8.11	hectare-meter, ha-m	acre-feet, acre-ft	0.123
97.28	hectare-meters, ha-m	acre-inches, acre-in	1.03×10^{-2}
8.1×10^{-2}	hectare-centimeters, ha-cm	acre-feet, acre-ft	12.33
	Concentrations		
1	centimole per kilogram, cmol kg^{-1} (ion exchange capacity)	milliequivalents per 100 grams, meq 100 g^{-1}	1
0.1	gram per kilogram, g kg^{-1}	percent, %	10

1	milligram per kilogram, mg kg^{-1}	parts per million, ppm	1
	Plant Nutrient Conversion		
2.29	P	P_2O_5	0.437
1.20	H	H_2O	0.830
1.39	Ca	CaO	0.715
1.66	Mg	MgO	0.602

Appendix 2. Symbols, Atomic Number, and Atomic Weights of Elements.

Element	Symbol	Atomic No.	Atomic Weight	Element	Symbol	Atomic No.	Atomic Weight
Actinium	Ac	89	227	Iodine	I	53	126.904
Aluminum	Al	13	26.9815	Iridium	Ir	77	192.2
Americium	Am	95	243	Iron	Fe	26	55.847
Antimony	Sb	51	121.75	Krypton	Hr	36	83.8
Argon	Ar	18	39.948	Lanthanum	La	57	138.91
Arsenic	As	33	74.9216	Lawrencium	Lr	103	257
Astatine	At	85	210	Lead	Pb	82	207.19
Barium	Ba	56	137.34	Lithium	Li	3	6.94
Berkeliom	Bk	97	249	Lutetium	Lu	71	174.97
Beryllium	Be	4	9.0122	Magnesium	Mg	12	24.312
Bismuth	BI	83	208.98	Manganese	Mn	25	54.938
Boron	B	5	10.81	Mendelevium	Md	101	258
Bromine	Br	35	79.909	Mercury	Hg	80	200.59
Cadmium	Cd	48	112.4	Molybdenum	Mo	42	95.94
Calcium	Ca	20	40.08	Neodymium	Nd	60	144.24
Californium	Cf	98	251	Neon	Ne	10	20.183
Carbon	C	6	12.011	Neptunium	Np	93	237
Cerium	Ce	58	140.12	Nickel	Ni	28	58.71
Cesium	Cs	55	132.905	Niobium	Nb	41	92.906
Chlorine	Cl	17	35.453	Nitrogen	N	7	14.0067
Chromium	Cr	24	51.996	Nobelium	No	102	254
Cobalt	Co	27	58.9332	Osmium	Os	76	190.2
Copper	Cu	29	63.54	Oxygen	O	8	15.9994
Curium	Cm	96	247	Palladium	Pd	46	106.4
Dysprosium	Dy	66	162.5	Phosphorus	P	15	30.9738
Einsteinium	Es	99	254	Platinum	Pt	78	195.09
Erbium	Er	68	167.26	Plutonium	Pu	94	239
Europium	Eu	63	151.96	Polonium	Po	84	209
Fermium	Fm	100	25	Potassium	H	19	39.102
Fluorine F	9	18.9984		Praseodymium	Pr	59	140.907
Francium	Fr	87	233	Promethium	Pm	61	145
Gadolinium	Gd	64	157.25	Protactinium	Pa	91	231
Gallium	Ga	31	69.72	Radium	Ra	88	226
Germanium	Ge	32	72.59	Radon	Rn	86	222
Gold	Au	79	196.967	Rhenium	Re	75	186.2
Hafnium	Hf	72	178.49	Rhodium	Rh	45	102.905
Helium	He	2	4.0026	Rubidium	Rb	37	85.47
Holmium	Ho	67	164.93	Ruthenium	Ru	44	101.07
Hydrogen	H	1	1.0079	Samarium	Sm	62	150.35
Indium	In	49	114.82	Scandium	Sc	21	44.956

Appendix 2 (Contd...)

Element	Symbol	Atomic No.	Atomic Weight	Element	Symbol	Atomic No.	Atomic Weight
Selenium	Se	34	78.96	Thulium	Tm	69	168.934
Silicon	Si	14	28.086	Tin	Sn	50	118.69
Silver	Ag	47	107.87	Titanium	Ti	22	47.9
Sodium	Na	11	22.9898	Tungsten	W	74	183.85
Strontium	Sr	38	87.62	Uranium	U	92	238.03
Sulfur	S	16	32.064	Vanadium	V	23	50.9412
Tantalum	Ta	73	180.948	Xenon	Xe	54	131.3
Technetium	Tc	43	99	Ytterbium	Yb	70	173.04
Tellurium	Te	52	127.6	Yttrium	Y	39	88.906
Terbium	Tb	65	158.925	Zinc	Zn	30	65.37
Thallium	TI	81	204.37	Zirconium	Zr	40	91.22
Thorium	Th	90	232.038				

Source: Tekalign et al. (1991).

Appendix 3. Solution Concentrations.

System Name	Abbreviation	Definition
Molar	M	gram-molecular weight (mole of solute) per liter of solution.
Molal	M	gram-molecular weight (mole of solute) per kilogram of solvent.
Formal	F	gram-formula weight of solute per liter of solution.
Normal	N	gram-equivalent weight of solute per liter of solution.
Weight per volume,	w/v, %	number of grams of solute × 100 percent per volume of solvent (mL).
Volume percent	Vol % or v/v %	Volume of solute × 100 per volume of solution.
Weight percent	wt % or w/w %	Weight of solute X 100 per weight of solution.
Parts per million	ppm	milligrams of solute or milligrams per liter of solution kilogram.
Parts per billion	ppb	micrograms of solute or micrograms per liter (kilogram) of solution.

Appendix 4. Some Useful Relationships.

1 g = 1000 mg = 1,000,000 µg	ppm = µg/g (solid per liquid) 1 µg = 0.001
mg = 0.000001 g	ppm = µL/L (liquid per liquid) 1 L = 1000
mL	ppm × 2 = 1lbs/A
1 mL = 0.001 L	ppm × 10^{-4} = %
ppm = µg/mL (solid per liquid)	1% = 1 gm/100 ml ppm = mg/L (solid per
liquid)	1% = 10,000 ppm

Appendix 5. Soil pH Levels and Associated Conditions.

Soil pH	Indications	Associated Conditions
< 5.5	Soil is deficient in Ca and/or Mg, and should be limed	Poor crop growth due to low cation exchange capacity and possible Al^{3+} toxicity.Expect P deficiency.
5.5 - 6.5	Soil is lime-free, should be closely monitored	Satisfactory for most crops
6.5 - 7.5	Ideal range for crop.	Soil cation exchange capacity is production near 100% base saturation.
7.5 - 8.4	Free lime ($CaCO_3$) exists in soil	Usually excellent filtration and percolation of water due to high Ca content of clays. Both P and micronutrients are less available.
>8.4	Invariably indicates sodic soil	Poor physical conditions. Infiltration and percolation of soil water is slow. Possible root deterioration and organic matter dissolution.