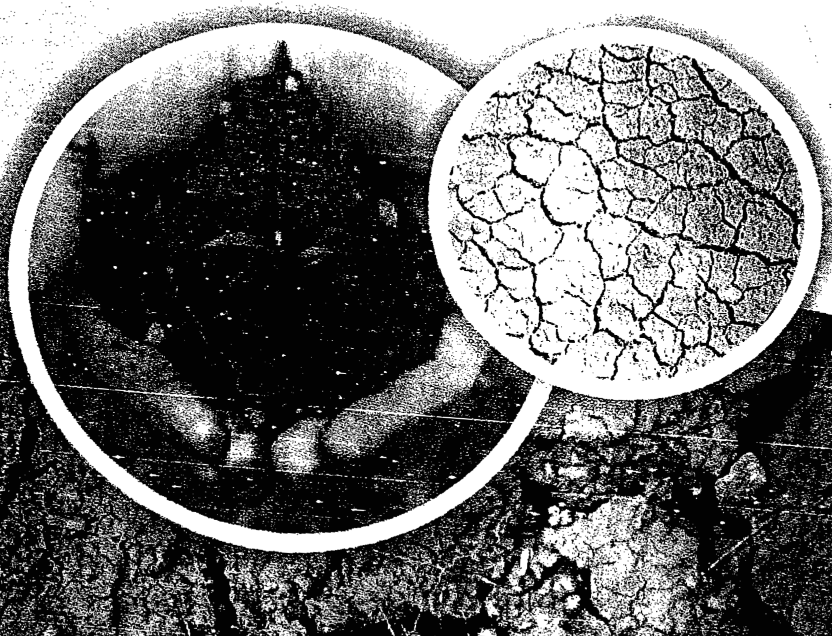
Fundamentals of SOIL SCIENCE



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Fundamental of Soil Science

—A Text Book

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Foreword

The world is on the threshold of next millenium and agricultural scientists have to face ever increasing challenge of feeding the growing population with social security and sustainability.

We are all aware that soil is an essential resource for sustained quality of human life and the foundation of agricultural development. Unfortunately, at present soil science is not getting its due importance and support it deserves.

Despite significant successes in soil science, our soil resources continue to undergo increasing stress from population pressure, loss of vegetative cover, soil degradation, pollution, climatic change and loss of bio-diversity. The vagaries of seasons with flood on one part of the country and drought in the other part, unseasonable and erratic precipitation adversely affect crop production resulting in serious impact on the society. With the intensification of agriculture and increased use of heavy farm machinery, soil physical and chemical constraints like traffic soil pan, soil crusting, soil structure deterioration due to decline in organic matter, soil nutrient depletion, non-judicious water management, soil pollution due to application of insecticides, pesticides and weedicides will badly reflect soil health and crop production in near future.

In these changing paradigm and national scenario, soil science will be subjected to scrutiny of the human society and how soil science can contribute to social security and sustainability. Soil scientists will have not only to continue to play a pivotal role in creating new technology for the safe, economic production of food, fibre, feed and fuel for the ever increasing population, prevention/restoration of degradation of land, pollution and efficient management of soil but also to perpetuate this knowledge for the younger generations so as to face the challenging problems in the 21st century.

The education in soil science and knowledge of soil are important to increase people's participation and the importance of soil and other natural resources. Soil science, as a general feeling 'a tedious subject', needs reorientation of the subject matter in a simple language and lucid manner to make it perfect learning aid and create an interest among the students about the subject matter. To cater this need, Dr. V.D. Patil and Dr. C.V. Mali, have indeed rendered significant service in bringing out this book " Fundamentals of Soil Science – A Text Book".

The book has been well reviewed. It covers all the basic requirements laid down in the syllabus for the graduate students of agriculture. There was a great need for such a book that covered comprehensive information on all basic facts and aspects of soil science. The information is presented in most readable form with figures and diagrams wherever necessary. It contains massive information and illustrations on all aspects of soil science and I am sure that it will act as a friend to the students and guide to those looking for employment.

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About the book

Soil is a basic natural resource, which supports life in all forms. Development, conservation and management of the soil resources which are posing serious problems of degradation in several forms such as erosion, pollution, salinization etc. there by limiting the land area and therefore needs an immediate attention for sustainable agriculture production to meet food, fibre, fuel and fodder demand of ever increasing population.

Our country experienced the green revolution through seed, fertilizer and water managemant. However, the production has reached a plateau and further boost in yield is not observed. Hence, the only way to increase the food production is only through appropriate soil management. However no due attention was paid to soil and its management. This is because of knowledge and understanding of soil is either limited or not being exploited for practical application. No development plan can be successful unless it is based on reliable Knowledge on types and ecology of soil. It is therefore necessary to introduce soils to the students of agriculture and general reader to make them understand the soil and its fundamentals.

The Book "Fundamentals of soil science – A text Book" by V.D. Patil and C.V. Mali will help establish understanding among the students and teachers about the concepts of soil, its development, management, and application. Eventhough there are many books available on soil science the chapters are strewn. The compilation of information on different chapters in this book is a good attempt by authors. The book is simple and understandable and supported by appropriate figures and exercises for recapitulation of the subject. The students will find this book valuable in clearing their concepts in soil science. It will also be helpful to those appearing at Public Service Commission examinations and to the teachers involved in teaching the soil science. I compliment the authors of this book Dr. V.D. Patil, and Dr. C.V. Mali for bringing out such a useful book for the cause of soil science.

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Aurangabad

PREFACE

"One who publishes a book runs a vary great hazard, since nothing can be more impossible than to compose one that may secure the approbation of every reader" — Don Quixste.

In the 21st century, agriculture will be practiced under quite different ecological technical and socio-economic conditions than in the decades before. There is not only increasing competition for the space for food production through an exponential growth of urban and unurban areas but also sever competition between food production on one side and decrease in land sarfaces for agricultural production at another side. This means that in the future, food production will occur on increasingly reduced areas which will further deteriorate the soil health.

To overcome this situation there is growing need to deal soil in such a way that it will be understandable to reader and create interest among the students. Foundation of soil science subject is being laid in the colleges. It is our experience that the students of soil science during their education hardly use the books. Most of them rely on the class notes rather than refer books, thereby losing note making and writing skills. Further the notes are inadequate to understand the concepts. In fact proper explanation in simple language helps the students to understand and develop interest in the subject. Therefore, efforts have been made to cater their need. Hence it is an attempt in this direction to offer the tips on soil science in most precise manner with a view to help the students of soil science. While writting the book information available from various books, journals and periodicals has been solicited. Endeavour has been made to adhere to the syllabi prescribed. Primarily it is textbook for graduate students presented in lucid style. Figures, wherever necessary is provided for better understanding. It is also a helping hand and guide for those appearing at competitive examinations and extension workers who are actually engaged in transfer of technology.

The book deals with twenty-one chapters arranged systematically. First six chapters present the historical developments in soil science, soil forming minerals and rocks, weathering of rocks and minerals and soil formation. The emphasis is given on properties of soil viz. soil texture, soil structure, density of soil, soil colour and soil temperature in the chapters from 7 to 9. Further, the chapters 10 to 15 deal with soil colloid, ion exchange, soil reaction, soil solution, soil organic matter and soil water. The chapters 16 to 20, on problematic soil, quality of irrigation water. soil classification and soil survey will cater the primary requirement of the students and extension workers. A special feature of this book is that the chapter Soils of India is discribed in light of their properties, area and distribution along with the cropping pattern. At end of the each chapter. exercise in the from of multiple choice questions, short questions for the comprehension are given. In addition the book is also supported by Glossary.

It is hoped that the student's and reader's interest in the subject matter will be roused, which will make them to have a good foundation in soil science. If this is achieved we shall be very much satisfied.

The authors wish to acknowledge the persons who have in some way contributed to the outcome of this book. We would also like to thank our families for their encouragement and continued support throughout the shaping of this book.

It is our experience that there is a general feeling among the students about the soil science/soil chemistry as a tedious and bore subject. In fact, proper explanation in simple language help the students to understand and create an interest in the subject. Before writing this book, we convinced ourselves that there is need of such a book that will help the student to understand the basic concepts in soil science and create the interest in subject matter rather than making it tedious. No doubt, excellent text books on soil science authored by Non-Indian as well as Indian scientists are available, but for some reasons, they do not give the information on the soils of India, their formation, properties and behaviour in a compiled form. However, the information available is wide spread under varying chapters in different books. Even then we depend on these books that are so elaborate that the students are, very often, reluctant to read them. From long time, we have experienced that the students depend mostly on class notes and hardly they go through the books. Consequently, the students are losing writing skill. Therefore, we have prepared this book that is very concise but precise and suitable for college/ university students of agriculture.

One of the special features of this book is that it has been written as per the prescribed syllabus by Maharashtra Council of Agricultural Education and Research (MCAER), Pune, for the students of agriculture. Thus, this book is primarily intended for use as a text book at the undergraduate level. The endeavor has been made to write this book in a simple and lucid style. The figures in a lucent form are also depicted wherever necessary so as to make more clear and easy to understand the basic concepts in soil science. Though it is primarily intended for the use of under graduate students of agriculture, it will also be useful for the students appearing in competitive examinations like Public Service Commission (PSC), Indian Administrative Services (IAS), Indian Forest Services (IFS), Indian Police Service (IPS) etc. This will also help the general reader and Extension workers in the state Agriculture Department, and Non-Government Organisations (NGOs) to get an introduction to soil and transfer the knowledge to the farmers community.

The book is also written with a view of new generation of Indian farmers who are literate and eager for the development in agriculture, but not fully conversant with the soil, its formation, properties and behaviour. Therefore efforts have been made to write it in any easy style so that it can be understood by majority of the people. The compilation work has been done with the help of published papers, books, journals and periodical reports.

The book has been divided into twenty one chapters, systematically arranged starting with evolution of earth, rock, soil formation, characteristics and behaviour of soil, problematic soils such as salt affected soils, acid soils, waterlogged soils, their characteristics and management, irrigation water and its quality soil survey and its classification. The major soil groups of India and soils of Maharashtra are also discussed in a lucid manner for the benefit of students.

We have fully utilized our long teaching experience to make the book more effective learning aid for students. At the end of each chapter, questions are given. These are multiple choice question, questions of short answers and match the pairs etc. These questions, we hope, will assist the students to develop the answering skill and also make the basic concepts more clear. These questions will also help them for All India Competitive Examinations such as Junior fellowship Competitive Examination (JFCE) and competitive examination for recruitment to Agricultural Research Service (ARS) conducted by Indian Council of Agricultural Research (ICAR) to prepare themselves for these prestigious examinations.

The explanations of facts and reactions, language and presentation of the subject matter are such simple and self explanatory so that the students can easily understand themselves without any further help. We hope, it will catalyses the students interest in the subject matter and give the students good foundation in soil science and inspire them to take up further studies in the subject. It is hoped that this book will receive a favourable response from student and teachers in agriculture. If it is achieved, we will be fully satisfied for this work. Helpful suggestions and comments are most welcome.

V.D. Patil

Place : Parbhani

C.V. Mali

CONTENTS

1

History and Development of Soil Science

Contribution made by–Van Helmont, Woodword, Laws and Gilbert, Hens Jenny, Boussingault, De Saussure, Liebig, Warington, Glinka, Hilgard, Dokuchaiev, Marbut, Leather, Scholasky, Ramamoorthy, Scope of soil science, Approaches of soil study.

Great civilization has almost invariably good soils. The dynasties of the Nile, Indus flourished along the rivers and good management of soil. Mismanagement of soil was associated with the downfall of some civilizations. Even today there are many who do not fully recognize the long-term significance of soil. This may be due to ignorance about the soils. The careful preservation of soil can be the difference between a prosperous society and poverty.

Early scientists were curious about what items growing plants needed. The search was made to identify the plant nutrients and to improve the soil ability to supply them. Until 1860 (Hilgard in Mississippi) and 1870 (V.V. Dockuchaiev in Russia) soil was not considered worthy to have detailed study in its own right. Finally, soil rather than plants began to receive the major interest of many scientists who were geologist, not agriculturists or chemists. The contributions made by various scientists in the development of soil science are summarized in this chapter.

Jan Baptista Van Helmont (1577-1644) a physician/chemist, concluded from five year Willow tree experiment that increased dry matter (169 lbs. and about 3 oz.) production came primarily from water supplied since soil lost no weight.

Theodore De Saussure demonstrated that plants absorbed O_2 and liberated CO_2, the general process of respiration. In addition he found that plant absorb CO_2 and release O_2 in the presence of light; however plants died when kept in CO_2 free environment. De Saussure concluded that the soil furnishes only small fraction of plant nutrients needed by plant.

John Woodword a English researcher, found that muddy water produced more plant growth than rain water or river water and concluded that the "fine earth" was the principle of growth.

Jean Baptista Boussingault (1802-1882) a French chemist established a farm in Alsace on which he carried field plot experiments from 1834 and thus is considered as *"father of field plot technique"*. He evidenced that rain, soil, and air were the primary sources of C, H and O in plant tissues.

Justus Von Liebig (1803-1873) a German chemist jarred the conservative thinkers of the day to such an extent that only a few scientists since that time have dared to suggest that C in plants comes from any source other than CO_2. Liebig made the following statements :

- Most of the carbon in plants comes from the CO_2 of the atmosphere.
- Hydrogen and O_2 come from water.
- The alkaline metals are needed for the neutralization of acids formed by plants as a result of their metabolic activities.
- Phosphorus is necessary for seed formation.
- Plants absorb everything indiscriminately from the soil but excrete from their roots those materials that are nonessentials.

His research led to the concept that certain factors were essential for plant growth and if any one of these factors was limiting, plant produce reduces accordingly. This principle called the *"Law of minimum"* is still valid and it may be stated as: " the level of plant production can not be greater than that allowed by the most limiting of the essential plant growth factors".

J.B. Laws and J.H. Gilbert (1855) from Rothamsted Experiment Station in England proved that for cereals, nitrogen did not come from the air, as Liebig reported, but from the soil and N-containing chemicals added to soils. Their investigations of P-containing materials led to the development of acid treated phosphate rock or "super-phosphate" which is still a commercial fertilizer source of phosphorus.

J.T. Way (1856) demonstrated cation adsorption properties and discovered that ammonium compounds were changed to nitrates in soil, while **R. Warrington** (1876) demonstrated that the process of conversion was biological in nature.

E.W. Hilgard (1860) worked at Mississippi and observed that several kinds of soils developed have relationship with the climate, vegetation and rock materials.

V.V. Dokuchaiev (1846–1903) with his brilliant team of soil scientists in Russia found unique layers in soil. Further they observed that these layerings are associated with climate, vegetation and under laying material. He also developed a concept that "soil is a natural body". Zonality concept of soil classification was the outcome of his studies, which is well established in Russian studies.

K. D. Glinka (1914) a Russian soil scientist published the work of V.V. Dokuchaiev and his team in German. Then after the concept of soil and its classification on the basis of zonality was grasped by C.F. Marbut (1927) of the United State Department of Agriculture. **Marbut and his associates** classified the USA soils based mostly on the Russian concept. He translated the book " The great soil groups of the world" of Glinka from German to English.

Hens Jenny (1941) showed a quantitative relationship between any soil property and soil forming factors as

$$S = f(cl, o, r, p, t \ldots)$$

pedology - soil genesis classification and mapping)

Where, S - Any soil property
f - Function of
cl - Climate
o - Organism or Biosphere ...
r - Relief or Topography
p - Parent material
t - Time or Age
- Unspecified factors

Dr. J.W. Leather (1906), an Imperial Agricultural Chemist of Imperial Institute of Agricultural Research, Pusa India can rightly be regarded as the *father of soil science and agricultural chemistry in India*. He devised indigenous mode of characterizing the soils of India into four major groups viz. Alluvial, black, red and laterite. He also worked on Usar (sodic soils). His name is closely associated with a classical contribution in the establishment of permanent manurial experiments.

Madam Scholasky had prepared the first time a soil map of India which she showed in 1932 in England. A map depicting the physio-graphical and geological features and describing the geological foundations of the country's soil was published in 1935 by **D.N. Wadia, J.N. Mukharjee and M.S. Krishnan** under the aegis of Geological Survey of India. Further the soil map of India on the basis of soil characteristics was prepared early in 1943 by **B. Viswanath** and **A.C. Ukil** at the Imperial (Indian) Agricultural Research Institute, New Delhi

Ramamoorthy (1967) and his associates developed a concept "targated yield".

Definition of Soil :

Soil may be defined as : "A dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms."

"Soil is a natural body developed by natural forces acting up on natural materials. It is usually differentiated into horizons from mineral and organic constituents of variable depth which differ from the parent material below in morphology, physical properties and constituents, chemical properties and composition and biological characteristics."

"Soil is the more or less loose and crumbly part of the outer earth crust in which, by means of their roots, plants find foot-hold and nourishment as well as all other conditions essential to their growth."

"Soil is the upper most weathered layer of the earth's crust, which consists of rocks that have been reduced to small fragments and have been more or less changed chemically together with the remains of plants and animals that live on it and in it."

SCOPE OF SOIL SCIENCE

The soil science has six well-defined and developed disciplines. Scope of soil science is reflected through these discipline.

Soil science : The science dealing with soil as a natural resource on the surface of the earth, including, Pedology (soil genesis, classification and mapping) and the physical, chemical, biological and fertility properties of soils and these properties in relation to their managements for crop production. The soil science has the following six well-defined disciplines : (Fig. 1.1).

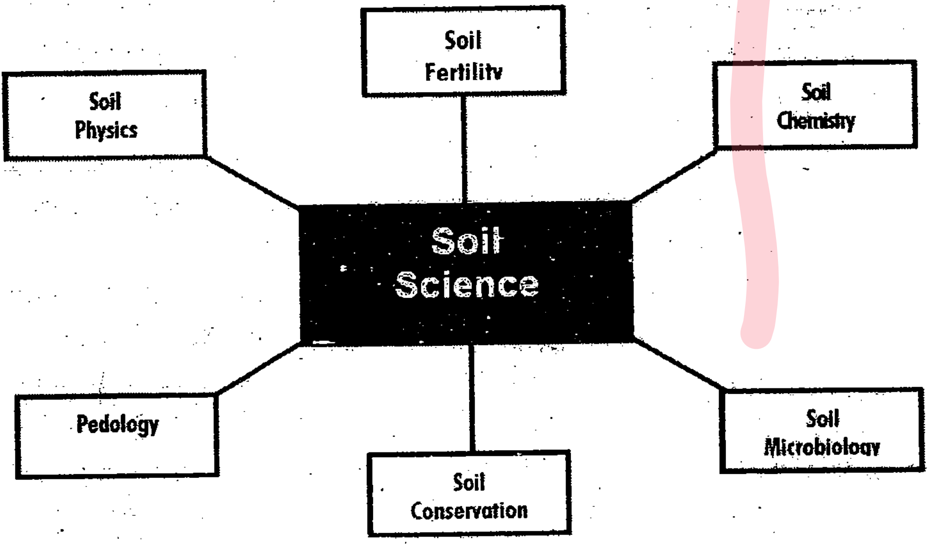


Fig. 1.1 : Scope of Soil Science.

1. Soil fertility : It denotes the status of a soil with respect to the amount and availability of elements to plant necessary for its growth. Soil fertility, therefore, refers to the nutrient supplying properties of the soil. It is best understood by considering (i) the nutrient requirement of plants; (ii) the supply of nutrients by the soil, (iii) ways in which nutrients are lost from the soil and (iv) methods by which soil fertility may be maintained or restored. While, *soil productivity* is the capacity of a soil, in its natural environment, to produce crops under a specified system of management and expressed in terms of yield. In the definition, specifications are necessary, since no soil can produce all crops with equal success nor can a single system of management produces the same effect on all soils.

2. Soil chemistry : It is a division of soil science concerned with the chemical constituents, the chemical properties and the chemical reactions of soil. It is the study of chemical composition of soil in relation to crop needs.

3. Soil physics : Soil physics is a division of soil science that involves the study of physical properties of soil. Soil is a complex system and is made up of solid, liquid and gaseous materials. The chemical and physical relationships among solid, liquid and gaseous phases are affected not only by their own respective properties but also by temperature, pressure and light.

4. Soil microbiology : Soil microbiology is the science, which deals with microscopic population of the soil, its role in various transformations and its importance in plant nutrition and crop production. Soil microbiology is concerned not only with enumeration and classification of soil-inhabiting microorganisms, but also with measurements of their activities in the soil. These activities are like decomposition of organic substances that are present in the soil or that find their way into the soil, with production of ammonia, nitrates, fixation of nitrogen and numerous such transformations.

5. Soil conservation : It is a division of soil science dealing with the protection of soil against physical loss by erosion or against chemical deterioration;

pedology - origine of soil. classificatin & examine
edaphology - producin of food and fibre and their ultimate goal

that is excessive loss of nutrients by either natural or artificial means. It deals with a combination of all management and land use methods, which conserve the soil against degradation or deterioration by natural or human-induced factors. It is the management of the soil with the purpose of producing high yields and at the same time, protecting it from degradation.

6. Pedology : The science dealing with the genesis, survey and classification, and the laws of geographic distribution of soils as a body in nature.

THE APPROACHES OF SOIL STUDY

Historic development of science gives out two concepts of soil study. One treats soil as a natural body, weathered and synthesized product of nature. While other treats soil as a medium for plant growth. These conceptions lead to the two approaches that can be used in studying soils, Pedological and Edaphological.

Pedological approach : The origin of the soil, its classification, and its description are examined in pedology (from the Greek word *pedon*, which means soil or earth). Pedology is the study of the soil as a natural body and does not focus primarily on the soil's immediate practical use. A pedologist studies, examines, and classifies soils as they occur in their natural environment.

Edaphological approach : Edaphology (from the Greek word *edaphos*, which means soil or ground) is the study of soil from the standpoint of higher plants. Edaphologists consider the various properties of soils in relation to plant production. They are practical and have the production of food and fiber as their ultimate goal. To achieve that goal, Edaphologists must determine the reasons for variation in the productivity of soils and find means of conserving and improving productivity.

EXERCISE

Q.1. Select the correct word :

1. The scientist ____________ concluded that increase in dry matter production of plant comes primarily from water.
(a) J.V. Liebig (b) K.D. Glinka
(c) Ramamoorthy (d) Van Helmont

2. ______________ is considered as father of field plot techniques.
(a) D.N. Wadia (b) Hens Jenny
(c) Boussingault (d) John Woodword

3. Fine earth was main principle of plant growth was concluded by __________.
(a) J.B. Laws (b) B. Vishwanath
(c) John Woodword (d) Madam Scholasky

4. Soil map of India on the basis of characteristics was firstly prepared by______
(a) Madam Scholasky (b) B. Vishwanath
(c) A.C. Ukil (d) B. Vishwanath and A.C. Ukil.

5. The science which deals with genesis, survey and classification of soil known as ____________.
(a) Soil survey (b) Soil science
(c) Pedology (d) Edaphology

Q.2. Answer to the point :

1. Name the scientist who recorded the absorption of CO_2 and release of O_2 by plant.
2. Who stated the law of minimum ?
3. What is the contribution of J.T. Way in history of soil science ?
4. Who is said to be father of soil science and Agricultural Chemistry in India ?
5. Name the different branches of soil science.
6. State the two approaches of soil study.
7. Who has developed a concept "Targeted yield" ?
8. Who showed the quantitative relationship between soil properly and soil forming factors?
9. Name the branch of soil science dealing with the protection of soil against physical loss.
10. State the contribution of Warington in development of soil science.

Q.3. Define the following terms :

(1) Soil
(2) Soil pedology
(3) Soil microbiology
(4) Soil chemistry
(5) Soil fertility
(6) Edapholody
(7) Soil productivity
(8) Soil physics.

2

Evolution and Structure of Earth

Earth's origin, Present condition of the earth, Atmosphere, Hydrosphere, Lithosphere, Composition of earth crust.

In history some information regarding the process of evolution of the earth and planets is written before 30,000 years ago. While, Regarding movement of sun, moon and earth was written 3000 years before. The information regarding start of agriculture was available before 5000 years ago.

EVOLUTION OF EARTH

It is said that the earth was evolved from a big blast, which occurred at a time throughout. Solid and hot pieces were distributed throughout the space. This blast was nothing but the blast of this universe and the pieces were distributed in space for which we call "Akash Ganga". At that time, it is said that, temperature of the earth was 180 crores degree centigrade. Protons, neutrons were available on large scale. The blast continued and these pieces spread away and temperature started reducing. By this, proton and neutron centered together in a nucleus. One proton plus one neutron converted in one **Hydrogen**. Two protons plus two neutrons combined together to form **Helium**. All these items were very hot. As soon as hydrogen and helium formed because of heat, they repelled from each other. After thousands of years they cooled down. Because of gravitational force, they came together and the stars and planets were formed. Slowly this universe got steady state.

According to the "Nebular" hypothesis the whole solar system is supposed to have existed at one time as a nebula or a cloudy mass of matter in the form of vapour or gases. As such it was intensely hot and incandescene. It was also supposed to be perpetually revolving. With the lapse of time the nebula began to cool. On cooling, the outer layers of the vapours condensed and were thrown out in the form of rings. In this way several rings were thrown out at different times. These rings, on further condensation and disruption became what we now know as the planets. The planets themselves, on further cooling, threw off their own rings as is seen at present in the case of Saturn. In some cases the planet rings broke up in their turn and formed satellites like our moon. The central mass that is still incandescent and not yet condensed is the sun.

DIVISIONS OF THE EARTH'S SPHERE

Classically there are three divisions of earth's sphere corresponding to the three states of matter (solid, liquid and gas) which constitute the Earth. The solid zone is the **Lithosphere.** The incomplete covering of water forming seas and oceans is the Hydrosphere and the gaseous envelope over the earth's surface is the **Atmosphere** (Fig 2.1).

Table 2.1: The mean radius, distance from sun, rotation period and revolution period around the sun of different planets

Sr. sNo.	Name of Planet	Radius (km)	Mean Distance from sun (km)	Rotation Period (Hrs./days)	Revolution Around sun Period (days)
1	Mercury	2439	5.8 x 107	58 days	88
2.	Earth	6378	1.5 x 108	23 hrs. 56 min	365.25
3.	Venus	6052	1.1 x 108	243 days	245
4	Mars	3397	2.3 x 108	24 hrs. 37 min	687
5	Jupiter	71398	7.7 x 108	9 hrs. 55 min	4333
6	Saturn	60000	1.4 x 109	10 hrs. 30 min	10743
7	Uranus	23620	2.8 x 109	17 hrs.14 min	30700
8	Neptune	24300	4.5 x 109	18 hrs.	60280
9	Pluto	1150	5.9 x 109	69 hrs. 17 min	90130

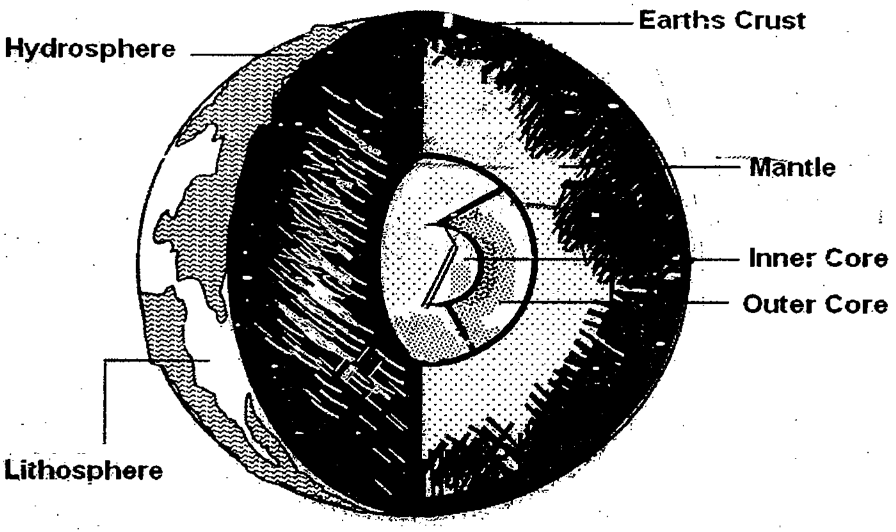


Fig. 2.1 : Internal structure of the earth.

1. Atmosphere

The envelope of air that covers both the lithosphere and hydrosphere is called atmosphere. It contains water molecules and dust, which may act as nuclei for the condensation of water vapour to form clouds or fog. The atmosphere is composed of various gases. The average composition of atmospheric air shows nitrogen as a dominant gas (78%) followed by oxygen (21%) and other gases (1%) (Fig 2.2). In addition, inert gases, such as neon, helium, krypton and xenon are present. The water vapours present in the air vary in amounts at different places and times. The air becomes less dense with height until it gets too thin to support life. It is further divided into four regions as given below (Table 2.2).

Table 2.2: Major regions of the atmosphere

Region	Altitude range (km)	Temperature range (°C)	Salient chemicals
Troposphere	0 to 11	15 to – 56	N_2, O_2, CO_2, H_2
Stratosphere	11 to 50	– 56 to – 2	O_3
Mesosphere	50 to 85	– 2 to – 92	O_2, NO
Thermosphere	85 to 500	– 92 to 1,200	O_2, O, NO

Troposphere : The lower portion of the atmosphere is called troposphere and usually extends up to 11 km from the earth's surface. It is characterized by a steady decrease of temperature with altitude averaging 0.6°C per 100 meters. This decrease in temperature is known as **lapse-rate.** The portion of the atmosphere at which the negative temperature gradient of the troposphere changes to constant temperature is known as the **tropopause.** About 80 per cent of the mass of the atmosphere is contained in the troposphere.

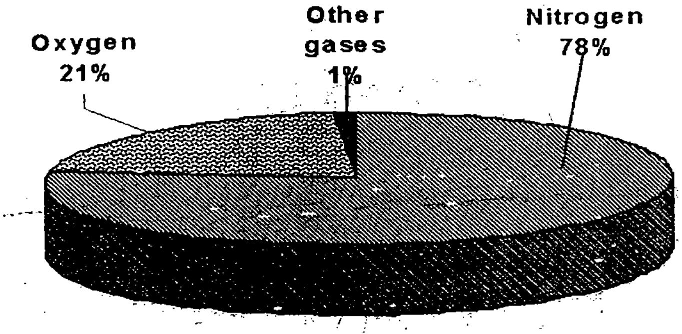


Fig. 2.2 : Composition of atmosphere.

Stratosphere : Above the tropopause, there is a stable layer of air, which usually extends up to 50 km from the earth's surface and is called stratosphere. The physical properties of the stratosphere are similar to those of the troposphere except that there is a reversal in the temperature gradient, with the temperature rising to 10-20°C at 50km. In this region, ozone molecules absorb ultraviolet radiation from the sun and decompose into oxygen molecules (O_2) and single oxygen atoms (O). When these particles recombine, energy is released in the form of heat, which causes the temperature to increase with altitude. The upper surface of stratosphere is called stratopause.

Mesosphere : Above the stratopause, there is *mesosphere*. The temperature of this layer falls again with increase in altitude. The ozone concentration in mesosphere decreases rapidly with height and decrease in temperature is due to decreased absorption of solar radiation by ozone. The mesopause makes the separation of mesosphere and thermosphere.

Thermosphere : The *thermosphere,* also known as *ionosphere,* is characterized by steady rise in temperature with altitude. The temperature increase is related to the absorption of solar ultraviolet radiation by molecular oxygen and nitrogens and the layer extends up to 500 km.

2. Hydrosphere

The hydrosphere is the layer of water surrounding the lithosphere. It is present in the form of seas and oceans. It covers nearly 70 per cent of the surface of the earth leaving only about 30 per cent above the sea level. The surface of the water of the various seas is in one level in contrast with the surface of the land. This surface is known as the *sea level.* The depth of water in the various oceans varies considerably. The average depth is 4 km. and the maximum depth is 9.6 km. The total volume of water is about 15 times the volume of land above sea level. If all the land on the earth is leveled, the water will stand to a height of about 3.2 km.

The seawater contains a good deal of mineral matter dissolved in it. The mineral matter had been dissolved from the land over which the water flowed before it poured into the sea. The average content of mineral matter in the sea water is 3.5 per cent. The composition of sea water is given below :

Table 2.3: Mineral composition of sea water.

Mineral	Per cent
Calcium carbonate	0.012
Calcium sulphate	0.126
Magnesium sulphate	0.166
Magnesium chloride	0.381
Magnesium bromide	0.007
Potassium sulphate	0.086
Sodium chloride	2.721

The sea water has a higher specific gravity than terrestrial water due to the salts it contains in solution. The average density is 1.026, but it varies slightly from place to place. It is the least dense at places where rivers enter the sea and very heavy at places where evaporation is high.

3. Lithosphere

It is the solid surface (continents, ocean basins, plains, plateaus and mountains, valley, sand-dunes and lava flows and fault scarps) and interior of the earth which consists of rocks and minerals. It is covered by gaseous and watery envelope. It amounts to 93.06 per cent of the earth's mass.

Interior of the Earth : The earth-ball consists of 3 concentric rings; crust, mantle and core (inner and outer) (Fig. 2.1)

Crust : The earth crust is 5-56 km thick and consists of rocks with density of 2.6-3.0 g cc-1 separated from mantle by Mohorovic or Moho or M-discontinuity. The soil scientists are interested in it, especially in its skin. It varies from 5 to 11 km in the oceans and 35 to 56 km in the continents.

Mantle : Mantle of the earth is 2,900 km and comprises mixed metals and silicates and ultra basic rocks with density of 3.0-4.5 Mg m^{-1}.

Core: The innermost portion of the earth is 3,500 km. in thickness; comprises metals, such as nickel and iron with average density of 9-12 Mg m^{-1}.

The density of the earth as a whole is 5.5 Mg m-3, whereas the density of the common rocks varies from 2.56 to 2.7 Mg m-3, and of the heaviest rock is 4.0 Mg m-3. The density of the core is 9.0 Mg m-3. From this it is evident that the density increases from the crust to the core.

COMPOSITION OF THE EARTH'S CRUST

The earth's crust is principally composed of mineral matter. Altogether, 106 elements known to us are found in earth crust in various combinations to form compounds. Oxygen is most abundant element but it usually occurs in combination with other elements. The composition of earth crust is shown in the Fig. 2.3.

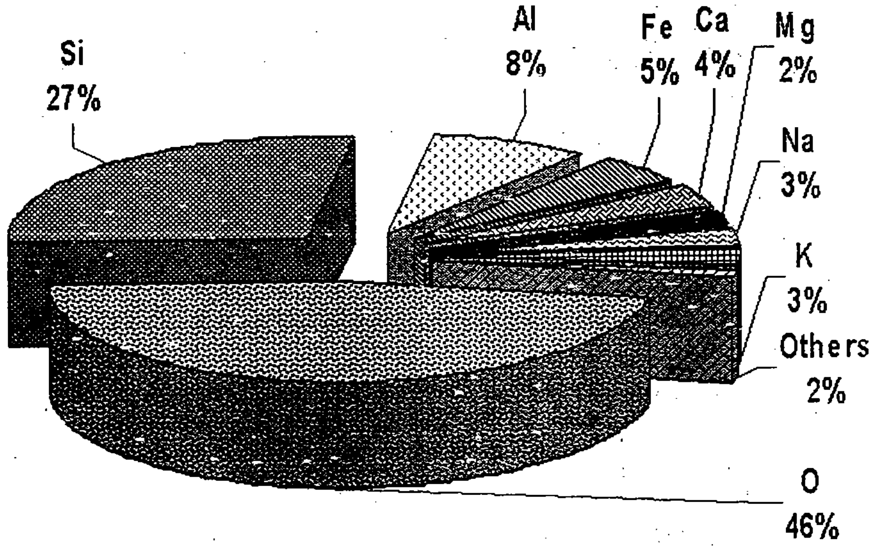


Fig. 2.3 : Average composition of the earth's crust.

It is seen from the figure that out of 106 elements known, 8 are sufficiently abundant as to constitute 98.6 per cent (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 comprise nearly three-fourth of the total composition of the crust. The other six elements are metals. The commonly known valuable metals, like gold, silver, nickel, copper and zinc, are of rare occurrence. Most of the hard, naturally formed substance of the earth is referred to as rock. Rock is composed of elements, which in turn are made up of atoms. The materials of the earth's crust fall into two principal categories, namely minerals and rocks. These are discussed in detail in subsequent chapters.

EXERCISE

Q.1 Choose the correct word :

1. The envelope of air covering the hydrosphere and lithosphere is known as _______.
(a) Mesosphere (b) Stratosphere
(c) Atmosphere (d) Thermosphere

2. The percentage of N in atmospheric air is ______________.
(a) 72 (b) 74
(c) 76 (d) 78

3. The lowermost region of atmosphere is ________________.
(a) Troposphere (b) Tropopause
(c) Stratosphere (d) Stratopause

4. ___________ is differentiating region of troposphere and stratosphere.
(a) Tropopause (b) Stratopause
(c) Thermosphere (d) Mesopause

5. The temperature increase in thermosphere is related to absorption of solar radiation by molecular ____________ .
(a) oxygen and hydrogen (b) Nitrogen and ozone
(c) Ozone and oxygen (d) Oxygen and nitrogen

6. Troposphere is characterized by steady decrease in temperature with altitude averaging 0.6°C per 100 m. This is known as ____________.
(a) Lapse-rate (b) Temperature gradient
(c) Thermopause (d) Ionosphere

7. The average content of mineral matter in sea water is _____________.
(a) 2.0% (b) 2.5%
(c) 3.0% (d) 3.5%

8. The most abundant metallic element occurring in earth crust is _______.
(a) Si (b) O
(c) Al (d) Fe

9. The density of the earth as a whole is ___________ Mg m-3.
(a) 2.56 (b) 2.72
(c) 4.00 (d) 5.5

10. The sea water has higher specific gravity than terrestrial water because__________.
(a) High Na content (b) High Ca content
(c) High salt content (d) Low salt content.

Q.2 Define the following terms :

1. Atmosphere 2. Hydrosphere 3. Lithosphere 4. Sea level

Q.3. Write to the points :

1. Name different parts of atmosphere.
2. Name the region differentiating mesosphere and thermosphere.
3. Which is the upper most region of stratosphere ?
4. What is the content of oxygen in atmospheric air ?
5. Name the metals present in earth crust present in significant amount.
6. What is the density of earth as a whole ?
7. Write the thickness of earth crust.

3

Rock Forming Minerals

Mineral-definition, properties, classification, Primary and secondary minerals, Important soil forming minerals.

The earth's crust (outer solid layer) principally composed of mineral matter, which is made up of various elements combined together to form compounds. Almost all the elements are present in the earth's crust (For example; oxygen, silicon, iron, calcium etc.). Each element is in combination with one or more other elements to form definite chemical compounds known as *minerals.*

Definition

Precisely a *mineral* is a naturally occurring homogenous element or inorganic compound that has a definite chemical composition and a characteristic geometric form.

Most minerals consist of two or more elements combined to form a compound such as gypsum($CaSO_4.2H_2O$), olivine (Mg, Fe_2SiO_4) and feldspar ($KAl.Si_3O_8$) etc. Some minerals, however, may consist of only one of the naturally occurring chemical elements, which may be a metal, such as copper, iron, calcium or a non-metal such as carbon, sulphur and silicon.

CLASSIFICATION OF MINERALS

On the basis of mode of formation minerals are classified into two groups viz. Primary and Secondary mineral.

Primary mineral : A mineral that forms an original component of a rock is known as primary mineral e.g. Feldspar, hornblende, mica. They are originated from original molten magma. They are most prominent in the sand and silt fractions.

Secondary mineral : The minerals which are formed, deposited or introduced as a result of subsequent changes in rocks are known as secondary minerals e.g. Limonite, gibbsite, etc, and clay minerals. Secondary minerals tend to dominate in the clay and in some cases the silt fraction of soil.

Minerals are classified on the basis of characteristic component of the rock, as essential mineral and accessory mineral.

Essential mineral : Minerals which form the chief constituents of a rock and are regarded as the characteristic components of that rock, are known as *essential minerals* e.g. Feldspars, pyroxenes, amphiboles and mica.

Accessory mineral : Minerals which occur only in small quantities and whose presence or absence is of no consequence as far as the character of the rock is concerned, are called *accessory minerals* e.g. Tourmaline, magnetite, etc.

Based on specific gravity, minerals are grouped into two groups. viz. light minerals and heavy minerals.

Light minerals : The Minerals having specific gravity less than 2.85 g cc^{-1} are known as light minerals e.g. quartz (2.6), feldspar (2.65), muscovite (2.5 to 2.75).

Heavy minerals : The Minerals having specific gravity more than 2.85 g cc^{-1} are called as heavy minerals. e.g. haematite (5.3), pyrite (5.0), limonite (3.8), olivine (3.5)

Based on chemical composition minerals are grouped in to seven groups :

1. **Native elements,** e.g. graphite, sulphur, gold, copper, etc.
2. **Oxides and Hydroxides,** e.g. quartz-SiO_2, haematite-Fe_2O_3, gibbsite – $Al(OH)_3$
3. **Sulphates,** e.g. gypsum-$CaSO_4.2H_2O$
4. **Sulphides,** e.g. pyrite FeS_2
5. **Carbonates,** e.g. calcite $CaCO_3$
6. **Halides,** e.g. rock salt-NaCl
7. **Silicates,** e.g. orthoclase (KAl Si3O_8), micas (muscovite-KAl_2 ($AlSi_3$ O_{10})$(OH)_2$, olivine ($MgFe.SiO_4$) etc.

General Properties of Minerals

The important physical properties of minerals that characterize them are given below :

(1) Colour
(2) Lustre
(3) Light transmission
(4) Hardness
(5) Streak
(6) Specific gravity
(7) Form and structure
(8) Cleavage
(9) Fracture
(10) Tenacity
(11) Chemical nature

1. Colour : The colour of mineral depends on reflection of certain colour vibrations which are exhibited by ordinary light. Ordinary light contains number of colour vibrations like red, pink, yellow, green, white and purple and these colours are absorbed by minerals, reflecting one of them which gives colour to the minerals. Minerals may be colourless, white, yellow, pink, purple, green etc, e.g. (1) Calcite - white (2) Magnetite – black (3) Orthoclase – pink (4) Iron pyrite–yellow (5) Appophylite–green (6) Amethyst–purple. (7) Quartz–colourless.

2. Lustre : It is the appearance shown by each mineral e.g. shining of the mineral or the manner in which a substance reflects light. There are two types of lustres: *Metallic lustre* : It is the lustre resembling lustre of metal e.g. Iron Pyrite and

Non-Metallic lustre : lustre like non metals.The nonmetalic lustre is of following types.

(i) Adamantine lustre : Lustre resembling diamond e.g. Diamond.

(ii) Vitreous lustre : Lustre like ordinary glass e.g. Rock crystal.

(iii) Sub-Vitreous lustre : Lustre like milky glass. e.g. Milk quartz

(iv) Resinous lustre : Lustre like resin e.g. Talc.

(v) Pearly lustre : Lustre like pearl e.g. Zeolite.

(vi) Earthy lustre : Lustre like earth e.g. Gypsum

(vii) Waxy lustre : Lustre like wax e.g. Appetite.

(viii) Silky lustre : Lustre like silk e.g. Asbestos.

3. Light transmission : It is the property of mineral to judge whether a mineral is transparent, translucent or opaque. *Transparent* : When the out line of the object appears distinct and clear through a mineral, it is called transparent e.g. Rock crystal, Muscovite, Mica, Calcite and Biotite. *Translucent* : When the outline of the object does not appear clear and distinct but it is indistinct then it is called translucent e.g. Milk quartz, Flint. *Opaque* : When no light passes through a mineral, it is called opaque e.g. Magnetite, Iron pyrite, Copper pyrite.

4. Hardness : It is the resistance offered by a mineral to a scratching. Mohr has found a scale of hardness to determine the hardness of different minerals. This scale is called as Mohr's scale. Relative hardness (1 to 10) of some minerals in increasing order of hardness is as :

1.Talc (Softest) 2. Gypsum 3. Calcite 4. Flurite (Fluorspar) 5. Apatite 6. Feldspar 7. Quartz 8. Topaz 9. Corundum 10. Diamond (hardest). Roughly the hardness of finger nail is 2, Copper wire 3, Glass piece 5.5 and Sharp steel 6.5

5. Streak : It is the colour of the powder of a mineral. It may be different from the colour of mineral. Generally white minerals have got white streak. The streak of some mineral is given in the table 3.1 .

Table 3.1 Streak of some important minerals.

Sr. No.	Name of Mineral	Colour of Mineral	Streak
1.	Rock crystal	White	White
2.	Orthoclase	Pink	White
3.	Iron Pyrite	Yellow	Green
4.	Magnetite	Black	Black
5.	Haematite	Black	Cherry Red.

6. Specific gravity : ~~It is the~~ ratio of weight of mineral to the weight of equal volume of water.

$$\text{Sp. Gravity of mineral} = \frac{W_1}{W_1 - W_2}$$

Where, W_1 = Wt. of mineral in air

W_2 = Wt. of mineral in water

$W_1 - W_2$ = Wt. of equal volume of water displaced

7. Forms and structure :

A. Forms : Minerals have got various forms. When a definite form is developed, it is called *crystalline form* and when no form is developed, it is called *massive* or *amorphous form*. The forms are : (1) Massive or amorphous and (2) Crystalline-There are six basic systems of crystalline form : (i) Monometric (Isometric, Cubic, Regular) (ii) Dimetric (Tetragonal, Octahedron) (iii) Trimetric (Orthorhombic) (iv) Monoclinic (v) Triclinic (vi) Hexagonal.

(i) Monometric : The three axes are of equal length and at right angle to one another, as in cube, e.g. Halite and Garnet.

(ii) Dimetric : Two axes are equal and one unequal. All three axes are at right angle to one another e.g. Zircon.

(iii) Trimetric : All three axes are unequal but they are at right angle to one another e.g. Sulphur, Olivine.

(iv) Monoclinic : All three axes are unequal, two of which not at rightangle to one another, while third makes right angle with the plane of the other two. eg. Orthoclase, Gypsum, Mica, Hornblende.

(v) Triclinic : All three axes are unequal and none of them forms a right angle with one other e.g. Plagioclase.

(vi) Hexagonal : There are three equal axes at 1200 and one more fourth axis of a different length at right angle to the other three e.g. quartz, calcite.

B. Structure : The arrangement of crystals gives rise to several kinds of structures.

(i) Granular : Appear in fine grains
(ii) Lamellar : Like plates or leaves
(iii) Columnar or Fibrous : Needle like reticulated or net like
(iv) Stellated : It is radiating like a star
(v) Drusy : The minute crystals are implanted.

8. Cleavage : It is the tendency of some minerals to split along the planes related to their molecular structure, sometimes parallel to crystal faces and yielding more or less smooth surfaces, Cleavage may be *perfect or imperfect*. Perfect e.g. Diamond.

9. Fracture : Not all minerals show good cleavage. Most of them show fracture or breakage in directions other than cleavage planes. The fracture may be conchoidal, even and uneven,

(i) Conchoidal : Development of more or less curved surfaces.

(ii) Even : Development of smooth and plane surfaces.

(iii) Uneven : Development of rough surface

10. Tenacity : Mineral may be :

(i) Brittle : When it falls to powder at the time of cuttings,

(ii) Flexible : When it can be easily bent and

(iii) Malleable : If its pieces flatten under a hammer.

11. Chemical nature: It refers to the chemical nature of the minerals like oxides, hydroxides, carbonates silicates etc. The chemical nature of some minerals is given below :

(i) Elements : eg. Sulphur –S.

(ii) Oxides : eg Haematite-Fe_2O_3

(iii) Hydroxides : eg. Gibbsite $Al(OH)_3$

(iv) Sulphides : eg. Iron pyrite–FeS_2

(v) Sulphates : eg. Gypsum–$CaSO_4.2H_2O$

(vi) Carbonates : eg. Calcite–$CaCO_3$

(vii) Phosphates : eg. Apatite–$Ca_5(PO_4)_3$ (Fe,Cl)

(viii) Silicates : eg. Microcline–KAl Si_3O_8

IMPORTANT SOIL FORMING MINERALS

According to Clarke (1924), the approximate proportion of essential minerals (major minerals) in the earth's crust is Feldspars 58%, amphiboles and phyroxenes 10%; quartz 13% and mica 4%. The remaining portion consists of accessory minerals such as zircon, pyrite, rutile, magnetite, ilmenite, apatite, and titanite. It is thus evident that feldspars constitute by far the largest part of soil forming minerals. The important minerals and their chemical composition are given in table below :

Table 3.2 Important minerals in soils and their chemical composition.

Group	Minerals	Chemical composition	Specific gravity
Quartz	Quartz	SiO_2	2.66
Feldspar			
Orthoclase	Microline	$K_2O.Al_2O_3.6SiO_2$	2.56
Plagioclase	Albite	$Na_2O.\ Al_2O_3.6SiO_2$	2.60
Carbonate	Calcite	$CaCO_3$	2.71
Carbonate	Calcite	$CaCO_3$	2.71
faauto	Dolomite	$Ca(Mg, Fe)(CO_3)_2$	2.83-3.00
Mica	Muscovite	$2H_2O.K_2O, 3(Al, Fe)_2O_3.6SiO_2$	2.80-2.88
	Biotite	$K_2O.4(Mg, Fe)O.\ 2(Al, Fe)_2O_3.\ 6SiO_2.\ 4H_2O$	2.7-3.1
Chlorite		$4(Mg, Fe^{++})O.Al_2O_3.3SiO_2.4H_2O$	2.5-3.0
Amphibole	Hornblende	$Ca_4(Na_2)(Mg, Fe)_{10}(Al, Fe)_2SiO_{14}O_{44}(OH, F)_4$	2.9-3.5
Pyroxene	Augite	$CaO.2(Mg, Fe)O, (Al, Fe)_2O_3.\ 3SiO_2$	3.4
Accessory	Apatite	$Ca_5(F, Cl)(PO_4)_3$	3.16-3.22
	Tourmaline	$(Na, Ca)R_3^*(Al, Fe)_6$	
		$B_3Si_6O_{27}(O, OH, F)_4$	3.0 – 3.3
	Zoisite	$4CaO.3Al_2O_3.6SiO_2.H_2O$	3.3
	Epidote	$Ca_2(Al, Fe)_3Si_3O_{12}(OH)$	3.36

	Olivine	$(Mg, Fe)_2 SiO_4$	3.5
	Zircon	$ZrO_2.SiO_2$	4.6 - 4.7
Opaque	Ilmenite	$FeTiO_3$	4.6 – 4.9
	Pyrite	FeS_2	5.02
	Magnetite	$FeO.Fe_2O_3$	5.17
	Hematite	Fe_2O_3	5.2

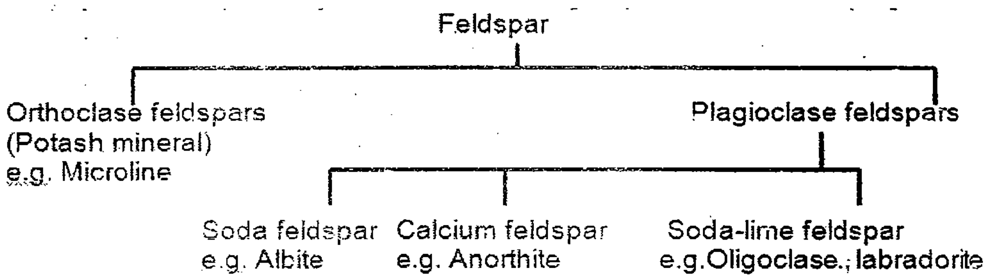
*R = Mg, Fe^{2+}, Fe^{3+}, Al, Li, Mn and Cr.

Few of the most important minerals are discussed here.

SILICATE MINERALS

Quartz : It is one of the four silica (SiO_2) minerals. It is crystalline in nature and most abundant of all the four forms. It is one of the most resistant minerals. Number of varieties of quartz are present and they differ from each other mainly in colour and form. Quartz is important constituent of all the three classes of rocks and is the dominant mineral in granite, rhyolite, sandstone, conglomerate, gneiss and quartzite. It is present almost in all soils of which sand and coarse silt fractions contain the largest amount of quartz. Even the clay fraction of some soils contains quartz.

Feldspars : Feldspars may be divided into two groups-orthoclase and plagioclase.



Orthoclase feldspars are mainly potash feldspars while plagioclase feldspars are either soda feldspars, calcium feldspars or soda-lime feldspars.Potash feldspars are present in granite, syenite and similar other igneous rocks like basalt, gabbro etc. in the soil. Feldspars are usually present in the sand and silt fractions.

Pyroxenes : The pyroxene group includes numerous minerals which differ both mineralogically and chemically from one another. This is also called *ferromagnesium* minerals. The pyroxenes having the general formula, $R_2 (Si_2O_6)$, where R stands for Ca, Mg, Fe^{2+} chiefly and Mn, Zn to small extents are most abundant in soils. Important amongst pyroxenes are augite $Ca.Mg. (SiO_3)_2$ together with $(Mg, Fe).(Al,Fe) (Al,Fe)_2 Si_2O_6$, diopside $Ca(Mg,Fe)(SiO_3)_2$, hypersthene $(Fe, Mg) SiO_3$ and enstatite $MgSiO_3$.

Amphiboles : These are also called as ferromagnesium minerals. These are chemically more complicated than the pyroxenes. Thus simple chemical formula can not be given as in pyroxenes. Hornblende $(K_2, Na, Mg, Ca, Mn). SiO_3$ is the most abundant amphibole found in soils. The minerals in this group are easily weatherable and are the *main source of micronutrient elements* such as Mn, B, Cu, Zn, Ni etc. as well as Ca, Mg, Fe in soil. *Hornblende and actinolite* are the two important minerals of the amphibole group of silicate, and also known as ferromagnesium minerals. These minerals contain a number of bases like calcium, magnesium, iron (ferric), manganese, titanium, sodium, potassium etc. Hornblende is very widely distributed in acid as well as basic igneous rocks. It is found in soils especially in sand and silt fractions.

Micas : Chemically, rock-forming micas fall into two main groups. These are muscovite and biotite. These are widely distributed primary minerals. These minerals have a very characteristic plate-like structure. They are present in all the three classes of rocks. viz. igneous, aqueous and metamorphic. Biotite, $H_2K(Mg, Fe^{2+})_3 (Al,Fe^{3+}) (SiO_4)_3$ is usually dark in colour, more rich in Fe and Mg than muscovite. As they are fairly resistant to weathering, they are found in soils mainly in the fine sand fraction. Muscovite, $H_2KAl_3(SiO_4)_3$ also found in soil with biotite.

NON-SILICATES MINERALS

The important non-silicate minerals are discussed under the following groups :

Oxides, Hydroxides or Hydrous-oxide group : The oxides are usually harder than any other mineral, except the silicates. The most important soils-forming oxides and hydroxide are :

Haematite : Fe_2O_3	Limonite : $2Fe_2O_3.3H_2O$
Goethite : $FeO(OH).nH_2O$	Gibbsite : $Al_2O_3.H_2O$

Haematite : It varies in colour from red to blackish red and has a reddish streak. It has a metallic lustre and hardness of about 5. It's presence in rocks is indicative of quick chemical change. Haematite alters to limonite, magnetite, pyrite and siderite. It occurs as a coating on the sand grains and acts as a *cementing agent*. It swells on absorbing water to form hydrated iron oxide, i.e. limonite, $2Fe_2O_3.3H_2O$ and geothite, $FeO(OH).nH_2O$.

Limonite : It is a hydrated ferric oxide, yellow to brown in colour and is of wide occurrence. It is the final product of most of iron minerals, and hence is resistant to any further change, except for absorption of water. It is an important *colouring and cementing agent* in soils. On dehydration, limonite forms haematite. On reduction and carbonation, it yields soluble iron. Limonite is a common alteration product of pyrite, magnetite, hornblende and pyroxene. It may be present in the form of iron concretion.

Goethite : Most materials, called limonite, are goethite with some adsorbed water. It is usually white but may be pink or grey in colour. Its hardness is 5.3.

Gibbsite : It is the most common aluminum compound in soils. Its natural colour is white. It is abundantly found in highly weathered soils of the tropical zones, called Laterites (Oxisol). Its presence in soils suggests high degree of weathering and leaching under well-drained conditions. The red, yellow or brown colours in soils are due to the presence of goethite and haematite, which occur as coatings on the surfaces of soil particles (especially clay).

CARBONATE GROUP

The basic compound like $Ca(OH)_2$, combine with CO_2 or carbonic acid (H_2CO_3) to form carbonates, as below :

$$Ca(OH)_2 + CO_2 = CaCO_3 \text{ (calcite)} + H_2O$$
$$Ca(OH)_2 + H_2CO_3 = CaCO_3 \text{ (calcite)} + 2H_2O$$

Calcite : A white mineral widely distributed in sedimentary rocks (like limestone), its hardness is 3. It decomposes very easily into soluble form.

Dolomite : Dolomite is less readily decomposed than calcite. It is the chief source of Mg in soils.

SULPHATE GROUP

Sulphate is a complex group formed by the combination of 1 sulphur and 4 oxygen ions, which further reacts with Ca to from calcium sulphate (anhydrite, $CaSO_4$). On hydration it forms gypsum ($CaSO_4.2H_2O$).

Gypsum : It is a common mineral in desert soils and in sedimentary rocks with hardness of 2. It is slightly soluble in water and is most easily leached.

PHOSPHATE GROUP

Apatite : Rock Phosphate [$Ca_3(PO_4)2$] is primary source of phosphorus in soils. Its hardness is 5 in mohr's scale. It decomposes readily under the influence of carbonic acid. It becomes immobile in soils as it readily combines with clays.

EXERCISES

Q.1. Select the correct word :

1. A Mineral that forms an original component of rock is called ________.
(a) Primary (b) Secondary
(c) Essential (d) Accessory

2. The minerals whose presence or absence is of no consequence as far as the character of the rock is concerned are called ____________.
(a) Primary (b) Secondary
(c) Essential (d) Accessory

3. The minerals which are formed by subsequent changes in rocks are called ________ minerals.
(a) Primary (b) Secondary
(c) Essential (d) Accessory

4. The minerals which form the chief constituent of rock are called ______ minerals.
(a) Primary (b) Secondary
(c) Essential (d) Accessory

5. Light minerals have the specific gravity less than ________ g cc^{-1}.
(a) 2.6 (b) 2.65
(c) 2.75 (d) 2.85

6. Iron pyrite is an example of __________ group.
(a) Sulphate (b) Sulphide
(c) phosphate (d) Halide

7. The colour of the mineral depends upon __________ of certain colour vibration.
(a) Absorption (b) Adsorption
(c) Reflection (d) Vibration

8. The colour of magnetite mineral is __________.
(a) White (b) Black
(c) Green (d) Yellow

9. The luster of mineral talc is __________.
(a) Waxy (b) Earthy
(c) Pearly (d) Resinous

10. When a light passes through the mineral, it is called as __________.
(a) Transparent (b) Translucent
(c) Opaque (d) Nontransparent

11. Mohr's scale is used to measure the ______ of mineral .
(a) Colour (b) Light transmission
(c) Hardness (d) Specific gravity

12. Mineral __________ has highest hardness.
(a) Talc (b) Calcite
(c) Appetite (d) Diamond

Q.2 Define the following terms

1. Heavy minerals 2. Primary mineral 3. Essential mineral
4. Streak 5. Specific gravity 6. Mineral
7. Cleavage 8. Secondary mineral

Q.3 Write in one sentence

1. What is the hardness of finger nail ?
2. Write the chemical composition of quartz.
3. Name the pink coloured minerals.
4. Name the mineral having vitreous luster.
5. Give one example of transparent mineral.
6. What is the streak of haematite.
7. Enlist different types of minerals structures.
8. Name two cementing minerals in soil.
9. Name two forms of minerals.
10. Name the mineral group which is main source of micronutrient in soil.

Q.4 Match the pairs :

1. Iron pyrite	1. Fe_2O_3
2. Limonite	2. Chief source of Ca
3. Phosphate group of minerals	3. Pearly luster
4. Graphite	4. Monometric form
5. Dolomite	5. Green streak
6. Zeolite	6. Silky luster
7. Garnet	7. Apatite
8. Diamond	8. Granular structure
	9. $2Fe_2O_3.3H_2O$
	10. perfect cleavage
	11. chief source of Mg
	12. Native element.

petrology - science of rocks

4

Soil Forming Rocks

Rocks-definition, formation, classification, Rock cycle

Petrology is the science of rocks, which forms the units of the earth's crust. A **rock** may be defined as a hard mass of mineral matter comprising two or more rock-forming minerals. It implies that most of the rocks are made up of two or more minerals; some may be mono-mineralic. (rocks having one minerals in domination) e.g. olivine, dolomite, limestone, while some are multimineralic (rocks having two or more than two minerals in domination) e.g. granite, basalt.

FORMATION AND CLASSIFICATION OF ROCKS

The various processes that lead to the formation of rocks (Fig. 4.1) are :

Cooling and consolidation of magma : Rocks are formed by cooling and consolidation of molten magma within or on the surface of the earth, e.g. igneous or primary rocks.

Transportation and cementation of fragmentary material : Disintegration and decomposition lead to the breaking down of pre-existing rocks. The resulting fragmentary material is either compacted in situ or transported in solution by the natural agencies of wind, water and ice to low-lying areas, like oceans. Consolidation of these materials after their deposition results in the formation of rocks, called sedimentary or secondary rocks.

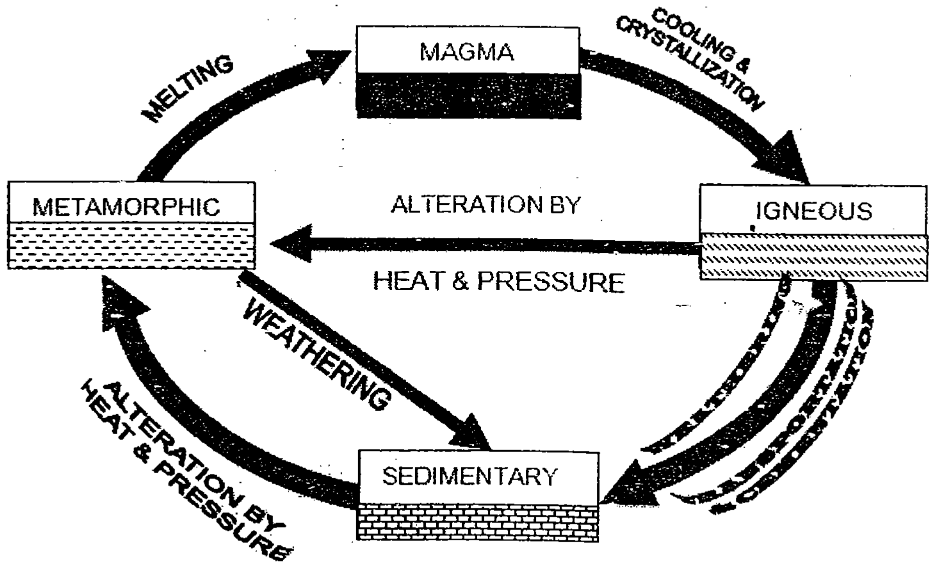


Fig. 4.1. Schematic diagram showing various processes of rock formation.

Alteration of pre-existing Rocks : The primary and the secondary rocks when subjected to earth's movement and to high temperature and pressure are partially or wholly reconstituted or altered to new rocks, called metamorphic rocks.

According to the mode of formation, the rocks are divided into three main classes viz. *Igneous or Primary Rocks, Sedimentary or Secondary Rocks and Metamorphic Rocks.*

Igneous Rocks (Latin *ignis*, means fire)

95% of earth crust

The igneous rocks are formed by the cooling and crystallization of molten material-magma-on or beneath the surface of earth. They are characterized by non-laminar massive structure and on the whole, make up 95 per cent of the earth's crust. They are a source of parent-material for other rocks and ultimately for soils. These rocks are first to form and hence they are called as oldest rocks. They mostly consist of primary minerals like quartz, mica, feldspar, pyroxenes, etc.

PqFm

Classification

On the basis of mode of formation igneous rocks are grouped into two groups: *Intrusive or plutonic rocks and extrusive or volcanic rocks.*

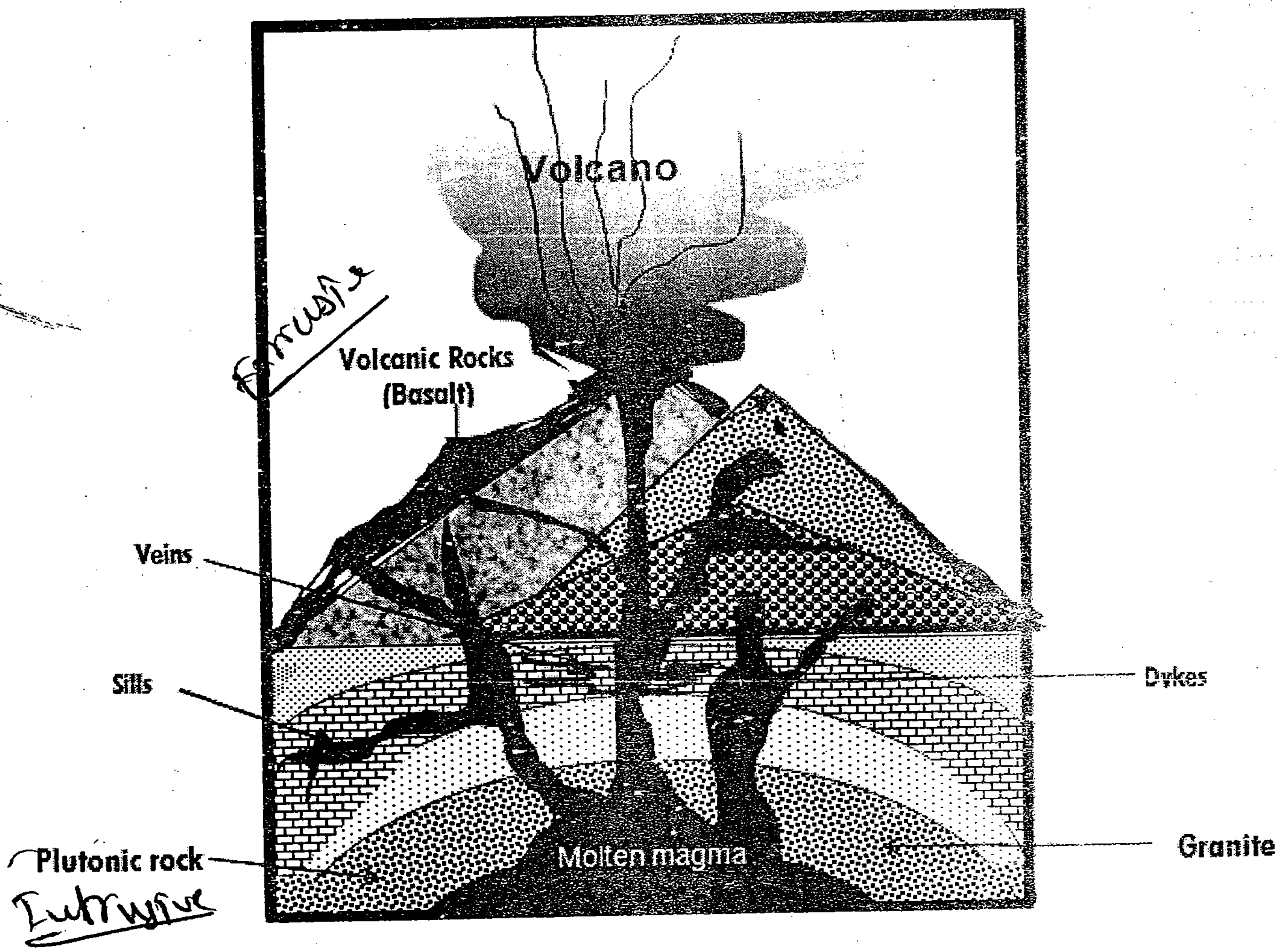


Fig. 4.2. A schematic diagram of volcanic eruption showing the occurrence of plutonic (intrusive) and volcanic (extrusive) igneous rocks.

grout

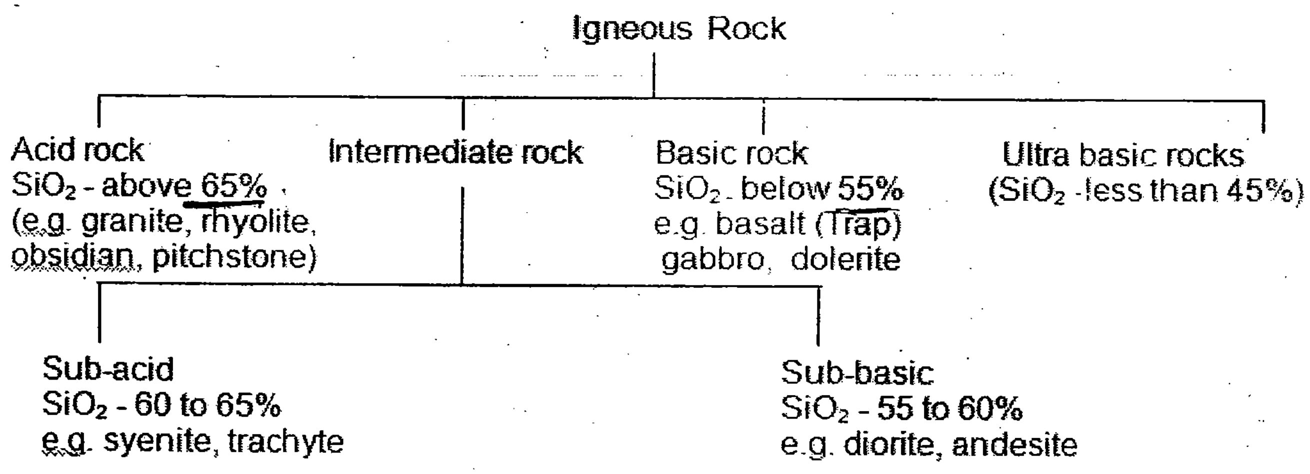
1. Intrusive or Plutonic rocks : The rocks that are formed by the cooling of the original magma beneath the surface are called *intrusive rocks e.g. granite.* They occur at greater depth in the earth's crust. They are very compact. During the formation of intrusive rocks slow cooling of molten magma takes place and hence the crystal formation is coarse. Therefore these rocks are called as coarse crystalline rocks.

Among the intrusive rocks, those that are consolidated at a much greater depth than others are known as *plutonic rocks* e.g. granite, syenite, diorite and gabbro. The rocks formed as a result of the molten mass having been forced among the pre-existing solid rocks through cracks and other planes of weakness. The rocks consolidated in vertical cracks and formed wall like masses are known as dykes. The rocks consolidated in horizontal cracks or planes are known as sills. In some cases the molten material is forced in irregular and narrow cracks or fissures and consolidated in this way is called a *vein.*

2. Extrusive or Volcanic rocks : Extrusive rocks are those that formed when the molten mass poured out on the surface of the earth where it is consolidated on cooling. As the molten magma comes to the surface, the pressure is released and the water at once turned into steam. As the steam can not escape it forms a globular cavity within the rocks. This globular cavity is known as *vesicle.*

Based on mode of origin, the rocks, which contain gas cavities or vesicles, are known as *vesicular rocks*. The vesicles are very often filled with some minerals. The rock having these minerals embeded in its vesicles looks as though it is studded with almonds or amygdales. Hence these rocks are known as *amygdaloidal rocks*. The minerals so embeded are quartz, calcite, zeolite, glauconite etc. During the formation of these rocks molten magma spreads over the surface of the earth and hence rapid cooling of the magma takes place. As a result, fine crystals are formed hence these rocks are called *fine crystalline rocks.*

The igneous rocks are also classified into four groups according to their chemical composition *i.e. Silica content.*



There are few igneous rocks containing less than 45% silica known as ultra-basic rocks.

Sedimentary Rocks (Latin *sedimentum*, means settling)

The sedimentary rocks are formed from sediments, derived from the breaking down of pre-existing rocks. The sediments are transported to new places, and deposited in new arrangements and cemented to form secondary rocks. Stratification is the most common feature of these rocks and as such these are also termed as ***stratified rocks.***

Formation

In the formation of sedimentary rocks, four stages are recognized. These are :

1. Weathering : The igneous (primary) and other rocks disintegrate owing to physical, chemical and biological weathering. The percolating water having carbonic and humic acids decompose the rocks and minerals (by chemical weathering) giving rise to quartz and other secondary minerals, and soluble substances, like calcium, magnesium, iron and salts :

$$\underset{\text{orthoclase}}{2KAlSi_3O_8} + H_2CO_3 + H_2O = Al_2Si_2O_5(OH)_4 + K_2CO_3 + \underset{\text{quartz}}{4SiO_2}$$

The products of these weathering agencies provide the basic materials (gravels, sand, silt and mud) for the formation of sedimentary rocks.

2. Transportation : The disintegrated material is transported by the agencies such as water, wind, glaciers, runoff and gravity. Transportation is a function of speed of water. The speed varies from place to place and is a function of several factors, including the distance from the bottom. The dust clouds in dry months carry finer fractions by wind to far-off places. This process is called *saltation.*

The deposition of colluvium at the foot of hills is due to gravity. When saturated with water, the loose material on gentle slopes may move, carrying with it the well-established plants down the slope. This process is called *solifluxion or soil creep.*

The moving glaciers carry materials (big boulders and stones) to other places. The moraine deposits in the Kangra Valley of Himachal Pradesh are the result of such a process.

3. Deposition or Sedimentation : The detrital materials, comprising minerals and rock fragments, are deposited when the carrying agent has no longer energy enough to move it further. For instance, a stream flowing at a certain velocity possesses enough energy to move particles of a certain size. With the decreasing velocity, the carrying capacity also declines. This is how the coarser particles settle first and the finer particles later. This kind of deposition is called *graded bedding.*

4. Diagenesis : It refers to the transformation of unconsolidated sediments to hard rock. It involves *compaction* and *cementation.*

Compaction : The weight of the upper incumbent layers-thousands of meter thick-causes compression of the lower layers or deposits. The sediments consolidate and the internal water and air are removed by the pressure of overlying sediments. The fine-grained deposits under such environments are transformed to clays, shales, etc.

Cementation : The most common materials that serve as cementing agents are *lime, silica* and *iron oxide*. Water that percolate carries the binding minerals/ materials in solution, deposits these in the voids of the loose sediments and binds the sediments together on desiccation. The interior of the earth is sufficiently hot to help in consolidation of the sediments.

Classification : Sedimentary rocks are classified on the basis of mode of formation into six groups as under. (1) Arenaceous, (2) Argillaceous, (3) Calcareous, (4) Siliceous, (5) Carbonaceous and (6) Precipitated.

1. Arenaceous rocks : These rocks are formed of the deposit of coarse grained particles. They are composed mainly of siliceous material derived from the disintegration of older rocks. The fragmented material so derived is deposited in beds of varying thickness through the agency of water. They vary considerably in texture and structure. Depending upon the nature of cementing material present, some rocks are hard and refractory, but most of them are loose and fall away very easily. The most common arenaceous rocks are sandstone, grit, conglomerate and breccia.

2. Argillaceous rocks : These rocks consist of small size particles usually known as clay. They are composed of hydrated silicates of alumina in admixture with sand, various other silicates and calcareous matter. When the clay is deposited in more or less pure state consisting mainly of silicate of alumina, obtained as a result of decomposition of feldspars, it is known as *Kaolin* or *china clay*. The important rocks belonging to this group are clay, mudstone, shale and Fuller's earth.

3. Calcareous rocks : These rocks consist of carbonate of lime or lime and magnesia. They are formed in many different ways. They may be of sedimentary origin or formed by chemical precipitation or by organic agency. When these rocks are formed by organic agency, they are composed mainly of debris from plant and animal life. They are formed either by the growth and decay of the organisms in situ or by the transport and subsequent accumulation of their remains. The rocks so formed are found in layers, which vary considerably in depth and thickness. When formed by chemical precipitation, the calcareous material is deposited in the form of sheets or layers from water containing calcium carbonate in solution. The precipitate when first formed is soft and chalky, but soon acquires a hard and compact structure. The important calcareous aqueous rocks are limestone, dolomite and ferruginous limestone etc.

4. Carbonaceous rocks : These rocks are formed from decomposing vegetation under anaerobic condition. When plants undergo decomposition under restricted air supply as happens under water or in lower layers of the earth, a greater portion of its carbonaceous matter is retained and the material is slowly converted into coal. Depending on the extent of change several varieties of carbonaceous rocks viz. Peat, lignite, coal, anthracite, etc. are formed.

5. Siliceous rocks : These rocks are also of organic origin having been formed from parts of minute plants and animals, like diatomaceous earth.

6. Precipitated rocks : These rocks consist mainly of deposits formed as rock masses either by cooling, evaporation or by direct chemical precipitation. Water charged with acid or alkaline material, acting under great pressure, dissolves various mineral substances from rocks with which it comes in contact. When the pressure is released as the water flows from place to place, or when evaporation takes place as it comes to the surface, it is not able to hold all the material in solution and deposits it either wholly or in part. In other cases, the dissolved material is thrown down as a chemical precipitate when the water, in the course of its percolation or movement comes in contact with other solutions. The salts or rocks that are formed in these ways form deposits ranging from few inches to several thousand feet. These are found underground or on the surface.

According to their chemical composition these rocks are :

Oxides	: *e.g.* Haematite , limonite, pyrolusite, bouxite, quartz
Carbonates	: *e.g.* Limestone, magnesite, stalactite
Sulphates	: *e.g.* Gypsum, anhydrite
Phosphates	: *e.g.* Phosphrite
Chlorides	: *e.g.* Rock salt

Metamorphic rocks

Formation : The igneous and aqueous rocks after their formation undergo a considerable change known as *metamorphosis* and the rocks so formed by metamorphosis are known as *metamorphic rocks*. The metamorphosis is brought about by the action of water, heat or pressure, or by the combined action of any two.

Classification : Metamorphic rocks are divided into three groups on the basis of their formation or metamorphosis.

1. Hydro-metamorphic rocks : The change in igneous and aqueous rocks brought about by water is known as *hydrometamorphism* and the rocks so formed are known as *hydrometamorphic rocks*. The action of water tends to remove some material or introduce new materials in the existing rocks. By the introduction of cementing materials like silica, lime or iron oxide, a loose sand may be turned into a sandstone or a sandstone into a quartzite. By the removal of certain constituents by percolating waters, a basalt or a granite may be converted into a laterite.

2. Thermo-metamorphic rocks : The change in rocks brought about by heat is known as *thermo-metamorphism* and the rocks so formed are known as *thermo- metamorphic rocks*. The action of heat hardens the rocks and often develops new crystals in it. The hot molten matter, as it comes out of volcano and spreads over an older rock or as it thrusts itself through cracks and fissures, produces series of changes in the surrounding rocks with which it comes in contact. The accompanying vapours and solutions also help to bring about changes in the older rock. *e.g.* formation of marble rock from limestone is a best examples of thermo-metamorphic rock. A conversion of sandstone to quartzite is also brought about by thermo- metamorphism.

3. Dynamo-metamorphic rocks : The change in rocks brought about by pressure is known as *dynamo-metamorphism* and the rocks so formed are *dynamo-metamorphic rocks.* The action of pressure tends to change the structure of the rock. In some cases it also brings about chemical changes. The pressure may be produced by the movement of the earth crust. Due to this pressure, the crystals get foliated and form folia (folia means thick in the middle and thin at the edges). The process is called *foliation*. If the foliation is complete and layers are distinct and separable then the new structure of rock is called as *schist* (e.g. mica schist, diorite schist and hornblende schist). and if foliation is slight and layers are not separable and distinct then the structure is known as *gneiss* (granite gneiss, diorite gneiss). Shale is often converted in slate by the action of pressure.

The rock cycle :

Igneous rocks, when exposed to the element may be broken down to reform as sedimentary rocks, these in turn, may be changed by great temperatures and pressures to form metamorphic rocks. If however, temperatures become so great that the rocks melt, they once more become igneous. This inter conversion of different rock types is known as the rock cycle. (Fig. 4.1)

EXERCISE

Q.1. Select the appropriate word :

1. ____________ is the science which deals with study of rock.

(a) Pedology (b) Petrology

(c) Rock science (d) Edaphology

2. The rocks formed by cooling and consolidation of molten magma are called _________ rocks.

(a) Sedimentary (b) Secondary

(c) Igneous (d) Metamorphic

3. Rocks formed by consolidation and deposition of fragmented material are known as ____________ rocks.

(a) Igneous (b) Primary

(c) Metamorphic (d) Sedimentary

4. The rocks formed by alteration of heat and pressure are called as ______ rocks.

(a) Igneous (b) Sedimentary

(c) Primary (d) Metamorphic.

5. The rocks formed beneath the surface at much greater depth than other are called ____________ rocks.

(a) Extrusive (b) Plutonic

(c) Dykes (d) Sills

6. The rocks containing gas cavities are known as __________ rocks.
(a) Intrusive (b) Extrusive
(c) Plutonic (d) Vesicular

7. The example of sub-basic rock is ______________.
(a) Dolerite (b) Diorite
(c) Dolomite (d) Synite

8. On the basis of silica content, granite is an example of ________ rock.
(a) Acid (b) Sub-acid
(c) Sub-basic (d) Basic

9. Basic rocks contain ____________ % silica.
(a) > 65 (b) 60-65
(c) 55-60 (d) < 55

10. Stratification is most common feature in ______________ rocks.
(a) Igneous (b) Sedimentary
(c) Intrusive (d) Metamorphic

11. The sedimentary rocks formed by deposition of coarse grain particles are called __________.
(a) Arenaceons (b) Argillaceous
(c) Calcareous (d) Siliceous

Q.2 Write answers to the point :

1. Name any two minerals present in igneous rocks.
2. What is vesicle ?
3. Give two examples of basic rocks.
4. Name the processes involved in the formation of sedimentary rocks.
5. What is saltation ?
6. State three cementing agents in soil.
7. What is foliation ?
8. What do you mean by metamorphosis?
9. What is rock cycle ?
10. What is solifluxion?

Q.3 Match the pairs :

1. Argillaceous
2. Carbonaceous
3. Dynamo-metamorphic
4. Arenaceons
5. Colluvium
6. Thermo-metamorphic
7. Calcareous

1. Conglomerate
2. Limestone
3. Quartzite
4. Igneous
5. Dykes
6. Extrusive
7. Slate
8. Mudstone
9. Peat
10. Due to gravity.

5

Weathering of Rocks and Minerals

Weathering- definition, physical, chemical and biological.

Rocks and minerals, which are formed under a very high pressure and high temperature, exposed to atmospheric conditions of low pressure and low temperature, they become unstable and weather.

Soils are formed from rocks through the intermediate stage of formation of regolith, which is the resultant of weathering. The sequence of processes involved in the formation of soils is weathering of rocks and minerals and formation of regolith or parent material and formation of true soil from the regolith.

Definition

"Weathering is a process of disintegration and decomposition of rocks and minerals which are brought about by physical agents and chemical processes, leading to the formation of ***regolith*** (unconsolidated residues of the weathering rock on the earth's surface or above the solid rocks)".

OR

"Weathering is the process by which the earth's crust or the lithosphere is broken down by the activities of the atmosphere, with the aid of the hydrosphere and the biosphere"

OR

The process of transformation of solid rocks into parent material or regolith is known as ***weathering".***

The regolith, or atleast it's upper portion, may therefore be termed as parent material of soil. ***Parent material*** may be defined as the unconsolidated and more or less chemically weathered mineral material from which soils are developed.

The parent materials are further acted upon by chemical and biological agencies, which facilitate further grinding and leaching. Chemical weathering becomes more effective as the bedrock is broken down into smaller and smaller fragments because chemical reactions occur largely on the surfaces and therefore smaller the fragments, the greater is the surface area exposed to chemical reactions.

Rocks, which are the original starting point in the weathering process, are first broken down into smaller rocks and eventually into the individual minerals of which they are composed. Simultaneously the rocks disintegrate and the minerals therein are attacked by weathering forces and are changed to new minerals either by alterations or by decomposition, resulting in the release of soluble constituents.

Weathering Processes

There are two basic processes of weathering viz. Physical or Mechanical and Chemical. The former is designated as disintegration and the latter decomposition. Another process which plays its role is biological. All these processes often work hand in hand, although in some environment one may predominate over the other. The different agents of weathering are given in Table 5.1 and discussed as under.

Depending upon the agents taking part in weathering processes, it is classified into three types, viz. Physical, chemical and biological weathering.

Table 5.1: Different agents of weathering.

Physical/mechanical (Disintegration)	**Chemical (Decomposition)**	**Biological (Disintegration and decomposition)**
1. Physical condition of rocks .	1. Hydration	1. Man and animals
2. Change in temperature	2. Hydrolysis	2. Higher plant and their roots
3. Action of water: Fragmentation and transportation; Action of freezing; Alternate wetting and drying; Action of Glaciers.	3. Solution	3. Micro organisms
4. Action of wind and sand blast	4. Carbonation	
5.Atmospheric electric phenomena	5. Oxidation	
	6. Reduction	

A. Physical Weathering

By physical weathering, the rocks are disintegrated, that is broken down into comparatively smaller pieces, without producing any new substance. The result of physical weathering can be compared with the hammering or crushing of the rocks under a great force. The different agencies that take part in the process of physical weathering are :

1. Physical condition of rocks : The permeability of a rocks is probably the most important single factor which determines the rate of weathering. For instance, a coarse-textured (porous) sandstone will weather more readily than a fine-textured (almost solid) basalt. Unconsolidated fine deposits of volcanic ash weather rather quickly as compared with unconsolidated coarse deposits, such as gravels. This is because the water percolates between and not through the gravels.

2. Action of temperature : The variations of temperature, especially if quite wide and sudden, greatly influence the disintegration of rocks. During the day, rocks get heated by the sun and expand. At night, the temperature falls and the rocks get cooled and contract. This alternate expansion and contraction due to diurnal changes in temperature is more common in hot and desert regions where the surface of the rock weakens and even crumbles since the rocks do not conduct heat easily. The minerals within a rock also vary in their rate of expansion and contraction. The cubical expansion of quartz is twice as that of feldspars. The dark-coloured rocks are subject to fast changes in temperature as compared with the light -coloured rocks. This differential expansion of minerals in a rock surface generates stress between the heated surfaces and the cooled unexpanded parts, resulting in fragmentation of rocks. This process, with time, may cause the surface layer to peel off from the parent mass and the rock may ultimately disintegrate. This phenomena is called *exfoliation*.

3. Action of water : Water acts as disintegrating, transporting and depositing agent. It beats over the sruface of rock as the rain falls and starts its journey towards the ocean. The moving water has a great cutting and carrying force. It forms gullies and ravines and carries with it the suspended soil material of variable sizes.

The transporting power of water varies. It is estimated that the transporting power of stream varies as the sixth power of its velocity, that is the greater the speed of water, the more is its transporting power and carrying capacity. A current moving at a speed of 15 cm, 30 cm, 1.2 m and 9 m per second can carry fine sand, gravel, stones (of about 1.0 kg weight) and boulders of several tonnes, respectively. The greater the amount of suspended matter, the quicker will be the disintegration of rocks. Hence the disintegration of rocks is greater near the source of a river than its mouth where it slows down steadily before meeting the sea.

Action of freezing : Frost is much more effective than heat in producing physical weathering. In cold regions, the water in the cracks and crevices freezes into ice and its volume increases by one-tenth (approximately). As the freezing starts from the top, there is no possibility of its upward expansion. The increasing volume; due to freezing of subsurface water, exerts an enormous outward pressure, which breaks apart the rocks.

Alternate wetting and drying : Some natural substances increase considerably in volume on wetting and shrink on drying. A practical example in support is of smectite clays. In dry weather, such clays shrink considerably forming a large number of wide cracks in ground. On subsequent wetting, it swells. The effect of alternate wetting and drying on clay-enriched rocks with platy structure, especially shale, is to make them loose and eventually the rock breaks.

Action of glaciers : In cold regions, when snow falls, it accumulates and sometimes turns into ice sheet. Ice, as an erosive and transporting agent, is of great importance and is only next to water. The big glaciers start moving owing to change in temperature and/or slope gradient. On moving, the glaciers exert a tremendous pressure on rocks over which they pass. They ride over the big mountains, grind the rocks, crush the trees and/or buildings that come across their way. The loose material is pushed forward and carried by the moving glacier and is ultimately deposited on reaching warmer regions, where its movement stops with the melting of ice. The material left behind forms a structureless mass termed as *moraine*.

4. Action of wind and sand blast : Very often when the wind is laden with fine material, such as fine sand, silt or clay particles, it has a serious abrasive effect and the sand laden winds itch the rock, which ultimately breaks down under its force. All of us are familiar with the dust-storm, which may transport tonnes of material from one place to another. This shifting of the soil causes serious wind erosion problem and may render the cultivated land as degraded, for example, sandy deserts of Rajasthan.

5. Atmospheric electrical phenomenon : This is also an important phenomenon during rainy season, when the lightening breaks up rocks and/or widens cracks.

B. Chemical Weathering

Decomposition of rocks and minerals by various chemical processes called as *chemical weathering*. Chemical weathering takes place mainly at the surface of rocks and minerals with the disappearance of certain minerals and the formation of secondary products. This is called chemical transformation. No chemical weathering is possible without the presence of water. The rate of chemical reactions increases with dissolved carbon dioxide and other solvents in water and with increases in temperature. The principal agents of chemical weathering are described below :

1. Solution : Some substances (*e.g.* halite, NaCl) present in a rock are directly soluble in water. When the soluble substances are removed by the continuous action of water, the rock no longer remains solid and falls to pieces very soon.

$NaCl$ + H_2O Na^+, Cl^-, H_2O
(soluble (water) (dissolved ions, surrounded
salt) salt) by water molecules)

2. Hydration : Hydration means chemical combination of water molecules with a particular mineral. Soil-forming minerals occurring in rocks do not contain any water. They undergo hydration when exposed to humid conditions. Upon hydration there is swelling and increase in volume of minerals. The minerals loose their lustre and become soft. A large number of minerals, like feldspar, mica etc. become hydrated, forming hydrous compound, for example :

$$2Fe_2O_3 + 3HOH \longrightarrow 2Fe_2O_3 . 3H_2O$$
Haematite water Limonite (yellow)
(red)

$$Al_2O_3 + 3HOH \longrightarrow Al_2O_3 . 3H_2O$$
Bauxite Hyd. Aluminium, Oxide

$$CaSO_4 + 2H_2O \longrightarrow CaSO_4 . 2H_2O$$

Anhydrite Gypsum

$$MgO.FeO.SiO_2) + 2H_2O \longrightarrow 3MgO.2SiO_2.2H_2O + SiO_2 + 3H_2O$$

Olivine Serpentine

Due to this reaction the minerals increase in volume and become soft and more readily weatherable.

3. Hydrolysis : It is one of the most important processes in chemical weathering. Hydrolysis depends on the partial dissociation of water into H and OH ions. An increase in H ion concentration, results in the accelerated hydrolytic action of water. Thus water acts like a weak acid on silicate minerals, e.g.

$$KAlSi_3O_8 + HOH \longrightarrow HAlS_3O_8 + KOH$$

Orthoclase Water Acid silicates Potassium
(dissociated) clay hydroxide

$$2HAlSi\ _3O_8 + 8HOH \longrightarrow Al_2O_33H_2O + 6H_2SiO_3$$

(recombination) Hyd. Aluminium Silicic acid
oxide

The products of hydrolysis are either wholly or partially leached by percolating water. They may also recombine with other constituents to form clay. In a way, hydrolysis may be considered as principal agent of clay formation. This reaction is important because the substances formed in these reactions are available to growing plants.

4. Oxidation : Oxidation means addition of oxygen to minerals. The absorption of an oxygen is usually from oxygen dissolved in soil water and that present in atmosphere. This process of combination of oxygen with mineral is known as ***oxidation.*** The oxidation is more active in presence of moisture and results in hydrated oxides. The minerals containing iron, manganese etc, are more subjected to oxidation, *e.g.*,

$$4FeO + O_2 \longrightarrow 2Fe_2O_3$$

Ferrous Oxygen Ferric oxides
oxides

$$4Fe_3O_4 + O_2 \longrightarrow 6Fe_2O_3$$

Magnetite Haematite

A rusty looking (red) crust is formed on the surface of the rock because of the formation of haematite. The crust thickens and then slowly gets separated from the parent rock. As process continues, the changes produced in the mineral weaken the rock and ultimately the rock itself crumbles to pieces.

5. Reduction : The process of removal or loss of oxygen is called ***reduction.*** It is equally important in changing colour of soil to grey, blue or green as ferric iron is converted to ferrous iron compounds. Under condition of excess water or waterlogged condition (less or no oxygen), reduction takes place, *e.g.*,

$$2Fe_2\,O_3 - O_2 \longrightarrow 4FeO$$

Ferric oxide Oxygen Ferrous oxide
(Haematite) (reduced form)

This reaction is not very important from the point of view of soil formation.

6. Carbonation : Carbon dioxide when dissolved in water it forms carbonic acid:

$$\underset{\text{Water carbon dioxide}}{2H_2O + CO_2} \longrightarrow \underset{\text{Carbonic acid}}{H_2CO_3}$$

The carbonic acid or carbonated water attacks many rocks and minerals and brings them into solution. The carbonated water has an etching effect upon some rocks, especially limestone. The removal of cement that holds sand particles together leads to their disintegration.

$$\underset{\substack{\text{Calcite}\\\text{(slightly}\\\text{soluble)}}}{CaCO_3} + \underset{\substack{\text{Carbonic}\\\text{acid}}}{H_2CO_3} \longrightarrow \underset{\substack{\text{Calcium bicarbonate}\\\text{(readily soluble)}}}{Ca\ (HCO_3)_2}$$

C. Biological Weathering

Physical disintegration (physical weathering) and chemical decomposition (chemical weathering) of rocks and minerals carried out by biological agents is called as *biological weathering.* The important biological agents are man, animal, plants micro-organisms etc.

1. Man and animal : The action of man in the disintegration of rocks is well known as he cuts rocks to build dams, channels and constructs roads and buildings. All these activities result in increasing the surface area of rocks for attack by chemical agents and accelerate the process of rock decomposition.

In the tropical and subtropical regions, ants and termites build galleries and passages; carry materials from lower to upper surface and excrete acid. The oxygen and water, with many dissolved substances, reach every part of the rock through the cracks, holes and galleries, and thus bring about speedy disintegration.

Rabbits, by borrowing into the ground, destroy soft rocks. Moles, ants and bodies of the dead animals, provide substances which react with minerals and aid in decaying process.

The earthworms pass the soil through their alimentary canal and thus bring about chemical and physical changes in the soil material.

2. Higher plants and their roots : The roots of trees and other plants penetrate into the joints and crevices of rocks. As they grow, the roots exert a great disruptive force and the hard rock may be broken apart. An example is of 'pipal' tree growing in 'pucca' wall, which on growing result in the development of cracks in the wall. The grass roots may form a sponge-like mass, conserve moisture and check erosion. These may help to form aggregates in soils thus allowing moisture and air find their way to the rock below for further action.

Some roots go quite deep into the soil and may open a sort of drainage channel. The roots running in crevices in limestone or marble in search of food produce acids . These acids have a solvent action on carbonates and thus itch walls of fissures by dissolving a part of the rock with which they come in contact. If the plants die, the leaves and other plant remains decompose and produce carbon dioxide which is of great importance in weathering.

3. Micro-organisms : In the very early stages of mineral decomposition and soil formation, the lower forms of plants and animals, like mosses, bacteria, fungi, actinomycetes, etc. play an important role. They extract nutrients from the solid rock, nitrogen from the air and can live with a very small amount of moisture. In due course of time the soil develops under the cluster of mosses, lichens, algae and bacteria. The micro-organisms are closely associated with the decay of plants and animal remains and thus liberate nutrients for use of the next generation plants and also produce carbon dioxide and complex organic compounds which aid in mineral decomposition.

WEATHERING—AT A GLANCE

Weathering is basically a combination of destruction and synthesis (Fig. 5.1). Weathering starts with breaking down of rocks physically into smaller pieces or fragments, and finally into the individual minerals of which they are composed. Simultaneously, the rock fragments and the minerals there in are attacked by chemical forces and changed to new minerals either by minor modifications or by

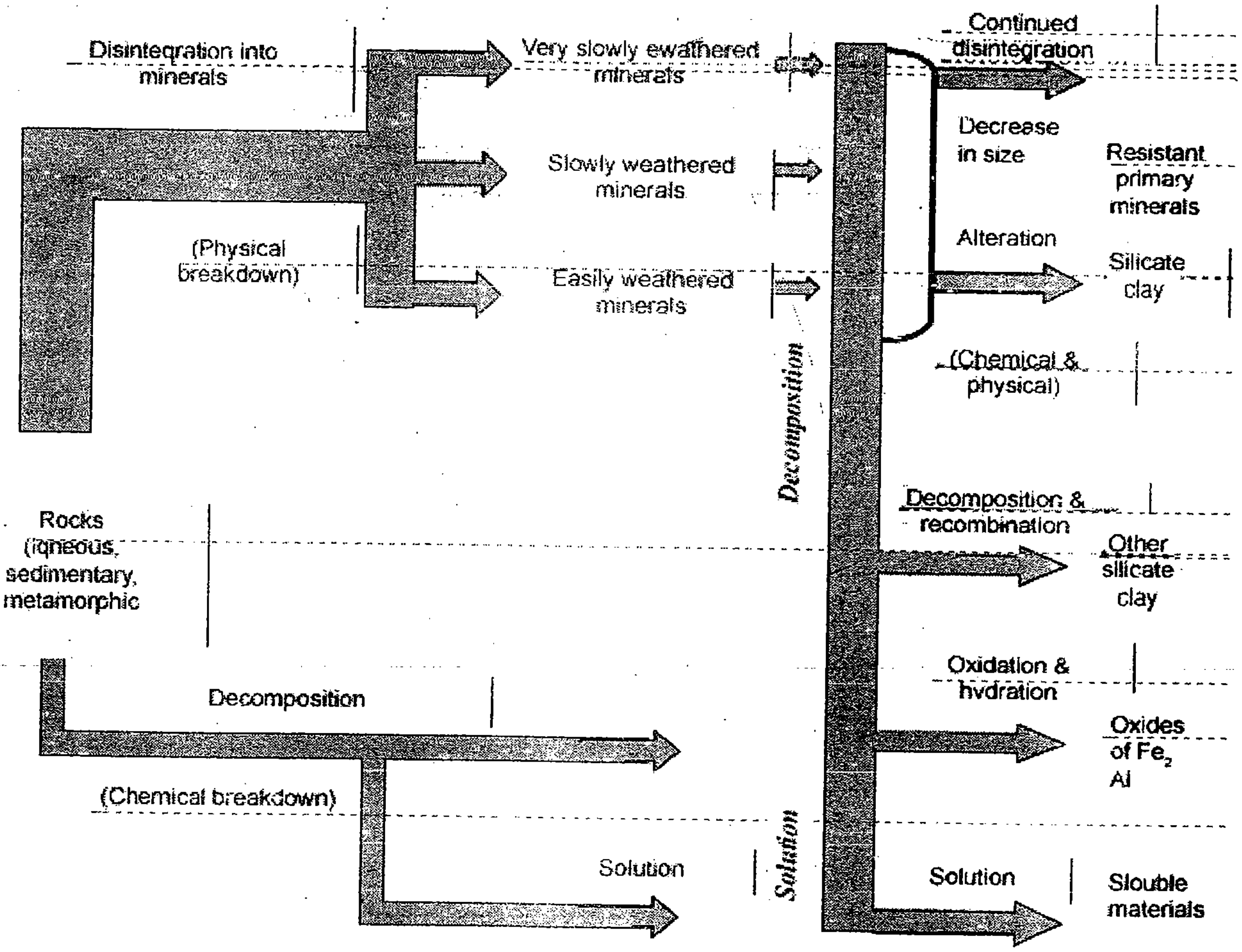


Fig. 5.1. Pathway of weathering that occur under common humid temperate region.

chemical forces and changed to new minerals either by minor modifications or by complete chemical changes. Chemical changes are accompanied by continued decrease in particle size and by the release of soluble constituents, which are subject to recombination into new secondary minerals that are formed in two groups : (a) the silicate clays, resulting from the alteration or decomposition and recombination and (b) the very resistant end products, including iron and alluminium oxide clays.

COMPONENTS OF SOIL

The soils consist of four major components i.e, mineral matter, organic matter, soil air and soil water (Table 5.2). The proportion of these components may vary from time to time and from place to place. The inorganic or mineral material is relatively permanent, but the organic material may vary in amount rather rapidly. The amount of water and air in soils fluctuate. These bear an inverse relationship with each other (fig. 5.2).

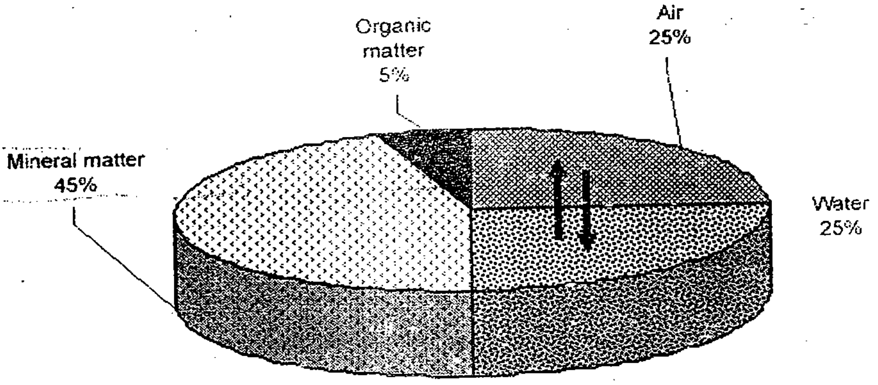


Fig. 5.2. Major components of mineral soils.

Table 5.2: Volumetric composition of mineral (inorganic) soil.

Sr. No.	Component		Content
1.	Mineral matter	-	45%
2.	Organic matter	-	5%
3.	Soil water	-	25%
4.	Soil air	-	25%

Mineral matter : The minerals are extremely variable in size. Some are as large as the smaller rock fragments; others, such as colloidal clay particles, are so small that they cannot be seen without the aid of an electron microscope. Quartz and some other primary minerals (biotite, muscovite etc) have persisted with little change in composition from the original rock. In general, the primary minerals dominate the coarser fractions of soil. Secondary minerals (silicate clay, limonite, hematite etc.) are prominent in the fine materials, especially in clays. Clearly, mineral particle size does much effect on the properties of soil.

Organic matter : Soil organic matter represents partially decayed and partially synthesised plant and animal residues. Such material is continually being broken down by the action of soil microorganisms. Consequently, organic matter is a transitory soil constituent and renewed constantly by the addition of plant residues.

In soil (CO2) is higher and (oxigen) is low

Organic matter influences soil properties and consequently on plant growth. Organic matter functions as a granulator of mineral particles. It is responsible for the loose, easily managed condition of productive soils. Organic matter improves the physical condition of soils and its water holding capacity. It is a major source of plant nutrients i.e. nitrogen, phosphorus, and sulfur. Finally, organic matter is the main source of energy for soil microorganisms.

Soil water : Soil water is the major components of the soil in relation to plant growth. The water is held within the soil pores. If the moisture content of a soil is optimum for plant growth, plants can readily absorb the soil water. Not all the water, soils can hold is available to plants. Much of water remains in the soil as thin film. Soil water dissolves salts and makes up the soil solution, which is important as a medium for supply of nutrients to growing plants. There is an exchange of nutrients between the soil solids and the soil solution and then between the soil solution and plants.

Soil air : A part of the soil volume that is not occupied by soil particles, known as pore space, is filled partly with soil water and partly with soil air. As the pore space is occupied by both water and air, volume of air varies inversely with that of water. As the moisture content of the soil increases, the air content decreases and vice versa. The soil air contains a number of gases viz., nitrogen, oxygen, carbon dioxide and water vapour. Soil air differs from the atmosphere in several respects. First, soil air contains much greater proportion of carbon dioxide and a lesser amount of oxygen than atmospheric air. Second, soil air has a higher moisture content than the atmosphere. ~~Soil air has~~ a marked effect on the plant and their root growth. It has also effect on soil microorganisms, plant nutrients and their availability.

EXERCISE

Q.1 Select the appropriate word

1. Regolith is formed by the action of __________ processes on the rocks.
(a) Soil forming (b) Weathering
(c) Osmotic (d) Photosynthetic

② Formation of true soil is the result of action of soil forming factors on ___.
(a) Disintegrated material (b) Decomposed material
(c) Rock [✓ (d) Regolith]

3. Physical weathering is essentially a process of ________________.
(a) Decomposition - chemical (b) Disintegration
(c) Soil formation (d) Solution

4. Peel-off of rock due to temperature variation is called ____________.
(a) Flocculation (b) Foliation
[✓ (c) Exfoliation] (d) Decomposition

5. The __________ of rocks is probably the most important single factor which determines the rate of weathering.
(a) Composition (b) Permeability
(c) Mineral content (d) Surface

6. Due to variation in temperature differential expansion of minerals in a rock surface generate __________ between the heated surface and the cool unexpanded part.
(a) Adhesion (b) Cohesion
(c) Stress (d) Affinity

- physical Disintegration

7. The variation in temperature greatly influence the ________ of rock.
(a) Disintegration (b) Decomposition
(c) Composition (d) Hydration

8. A current of water moving at a speed of 15 cm/sec can carry ____ with it.
(a) Fine sand (b) Gravels
(c) Stones (d) Boulders

8. The loose materials left behind by the glaciers form a structureless mass termed as _____.
(a) Lacustrine (b) Moraine
(c) Marine (d) Alluvium

9. Atmosphere electric phenomenon is important physical weathering agent during _____ season.
(a) Rainy (b) Winter
(c) Summer (d) Rainy and summer

10. ____ means chemical combination of water molecules with a particular mineral.
(a) Solution (b) Hydration
(c) Hydrolysis (d) Oxidation

11. When ______ substances are removed by continuous action of water, the rock no longer remain solid.
(a) Chloride (b) Acidic
(c) Alkaline (d) Soluble

12. The minerals containing ___________ are more subjected to oxidation
(a) Cu and B (b) B and Fe
(c) Fe and Mn (d) Mn and Cu

13. In chemical weathering, carbonation results in __________ of rock.
(a) Cementation (b) Decementation
(c) Composition (d) Decomposition

14. In general _________ minerals dominate the coarser fraction of soil.
(a) Essential (b) Accessory
(c) Primary (d) Secondary

Q.2. Define the following terms :

(1) Weathering (2) Parent material (3) Regolith (4) Oxidation
(5) Hydration (6) Hydrolysis (7) Reduction (8) Biological weathering

Q.3. Answer in one sentence :

1. State different types of weathering.
2. Why chemical weathering is more effective with smaller fragments of rocks.
3. Enlist the various agents of physical weathering.
4. Why disintegration of rocks is greater near the source of river than its month.
5. State the principal processes of chemical weathering.
6. Give the reaction of conversion of hematite to limonite.
7. How acid silicate clays are formed by hydrolysis ?
8. How rusty looking crust is formed on the surface of the rock ?
9. State the components of minerals soil.
10. What are the components of soil air ?
11. Which type of minerals are prominent in clay soils ?
12. How the plant roots play role in weathering ?
13. How secondary minerals are formed?
14. Which is the major source of plant nutrients among the soil components?

□□

6

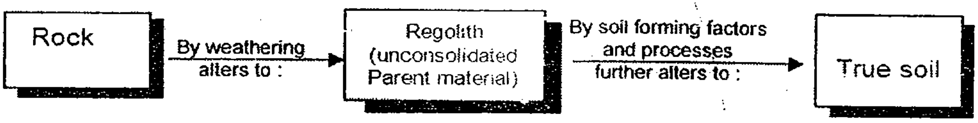
Soils Formation-Factors and Processes

Soil formation–active and passive factors, fundamental and specific processes, soil profile, pedon and polypedon.

The soil formation is a process of two consecutive but overlapping stages. (i) The weathering of rock (R) into regolith (C) and (ii) the formation of true soil from the regolith.

In the previous chapters, we have seen the first stage of weathering, that is disintegration and decomposition of rocks giving rise to a loose and unconsolidated material, called regolith. It is also termed as parent material of the soil. In the subsequent stage (s), the evolution of true soil from the regolith (parent material) takes place by the combined action of soil-forming factors and processes. There are two consecutive steps leading to the formation of true soil.

The first step is accomplished by weathering (disintegration and decomposition) of rocks and minerals giving rise to regolith. The second step is associated with the action of soil forming factors and processes resulting in true soils. They may be shown as :



Dokuchaiev (1889), the father of soil science was the first person to show that soils usually form a pattern in the landscape. He further established that the soils develop as a result of the interplay of soil-forming factors, viz. Parent material, climate and organisms, which he put forward in the form of an equation :

$$S = f\,(P, Cl, O)$$

Further, Jenny (1941) formulated the following equation :

$$S = f\,(cl, o, r, p, t, \ldots)$$

Where S – any soil property, such as pH, N, clay etc.

f – function

cl – environmental climate ;

o – organisms and vegetation (biosphere)

r – relief or topography

p – parent material

t – time

... – additional unspecified factros (like fire, storms etc.)

The five soil forming factors, acting simultaneously at any point on the surface of the earth, to produce soil (Fig. 6.1) are grouped in to two as passive and active.

Passive soil forming factors

(i) Parent material
(ii) Relief or topography
(iii) Time

Active soil forming factors

(iv) Climate
(v) Vegetation and organisms (biosphere)

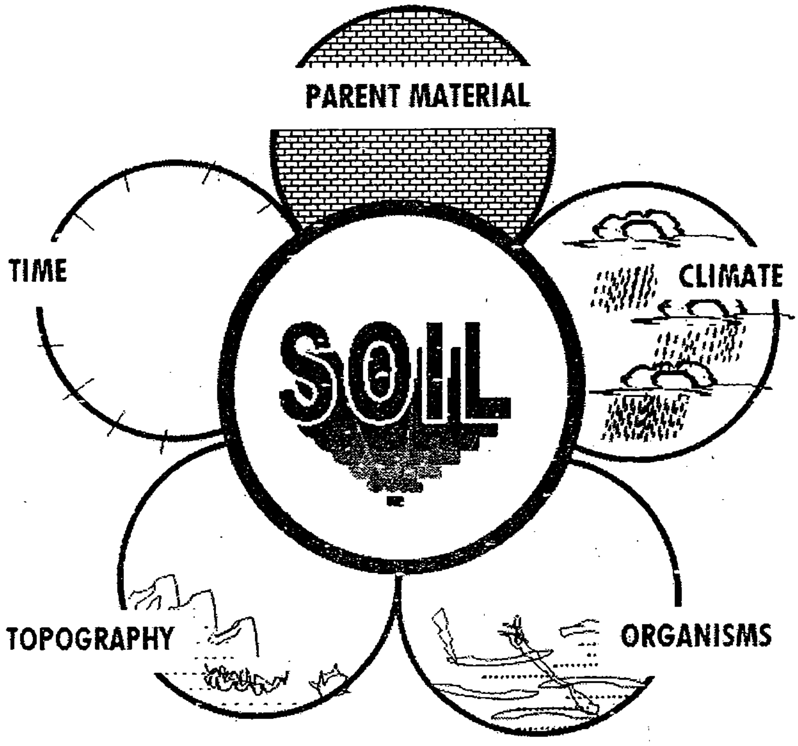


Fig. 6.1. Soil the end-product of soil forming factors.

Passive Soil-Forming Factors

The passive soil-forming factors are those which represent the source of soil forming mass and conditions affecting it. These provide a base on which the active soil-forming factors work or act for the development of soil. Such factors are *parent material, relief or topography and time.*

1. Parent material : Parent material is that mass (consolidated rocks, such as igneous, metamorphic or sedimentary to unconsolidated sediments) such as alluvium, colluvium, aeolian/loess, glacial-till, etc. from which the soil has formed.

Parent materials differ as widely as the rocks of the earth's crust. The parent material transported from their place of origin are named according to the main force responsible for the transport and redeposition.

The material transported and deposited by water is *alluvium*, found along major stream courses, at the bottom of slopes of mountains and along small streams flowing out of drainage basins. *Colluvium* is used for poorly sorted materials near the base of strong slopes transported by the action of gravity. *Lacustrine* consists of materials that have settled out of the quiet water of lakes. *Glacial* consist of all the materials picked up, mixed, disintegrated, transported and deposited through the action of glacial ice or of water resulting primarily from melting of glaciers. The wind blown materials are termed *loess* when the texture is silty and *aeolian* sand when these are primarily sand. The materials deposited by the melting glaciers vary widely in particle size called as *till* or *moraine*. If the parent material is transported by water and fine sediments deposited at the bottom of the sea and get exposed at the surface due to change in sea level named as *marine*. The soils developed on such transported parent materials bear the name of the parent material, viz. Alluvial soils from alluvium, colluvial soils from colluvium, etc. In the initial stages, however, the soil properties are mainly determined by the kind of parent material. With advanced development and excessive leaching, the influence of parent material on soil characteristics gradually diminishes.

There are soils wherein the composition of parent material subdues the effects of climate and vegetation; such soils are called *Endodynamomorphic Soils*. These soils are temporary and persist only until the chemical decomposition becomes active under the influence of climate and vegetation. They differ from *Ectodynamomorphic Soils* which develop a normal profile under the influence of climate and vegetation.

Soil properties as influenced by parent material : Different parent materials affect profile development and produce different soils, especially in the initial stages under humid conditions.

- Acid igneous rocks (like granite, rhyolite) produce light-textured Podzolic soils (Alfisols),
- Basic igneous rocks (basalt), alluvium or colluvium, derived from limestone or basalt, produce fine-textured cracking-clay soils (Vertisols) as in northern Iraq and central India.
- Basic alluvium or aeolian materials produce fine to coarse-textured soils (Entisols or Inceptisols).
- The nature of thse elements released during the decaying of rocks has specific role in soil formation. For instance :
- Silicon and aluminium furnish the skeleton for the production of secondary clay minerals.
- Iron and manganese are important for imparting red colour to soils and for oxidation and reduction phenomena.
- Sodium and potassium are important dispersing agents for clay and humus colloids.

- Calcium and magnesium have a flocculating effect and result in favourable and stable soil structure for plant growth.

2. Relief or Topography : The relief and topography sometimes are used as synonymous terms. They denote the configuration of the land surface. The relief units are geomorphologically the distinct areas, such as an undulating plain, an escarpment, or an alluvial plain. Relief may be described in terms of relative relief, drainage spacing, slope and slope angle. The topography refers to the differences in elevation of the land surface on a broad scale. The prominent types of topography designations, as given in FAO Guidelines (1990) are :

Land surface	with slopes of
1. Flat to almost flat	0-2%
2. Gently undulating	2-5%
3. Undulating	5-10%
4. Rolling	10-15%
5. Hilly	15-30%
6. Steeply dissected	> 30% with moderate range of elevation(<300 m)
7. Mountainous	> 30% with great range of elevation (>300 m)

Soil formation on flat to almost flat position : On level topographic positions, almost the entire water received through rain percolates through the soil. Under such conditions, the soils formed may be considered as representative of the regional climate. They have normal solum with distinct horizons. But vast and monotonous level land with little gradient often has impaired drainage conditions (as in the Mesopotamia that may result in retarded soil development since some slight gradient is essential for normal development of soils).

Soil formation on undulating topography : With identical rainfall and comparable parent-material, the soil climate is more humid on gentle slopes than on steeply sloping land and still moist or wet in valleys and depressions or valley land. The soils on steep slopes are generally shallow, stony and have weakly-developed profiles with less distinct horizonation. It is due to accelerated erosion, which removes surface material before it has the time to develop. Reduced percolation of water through soil because of surface runoff, and lack of water for the growth of plants, which are responsible for checking of erosion and promote soil formation.

Soil formation in depression : The depression areas in semi-arid and subhumid regions reflect more moist conditions than actually observed on level topographic positions due to the additional water received as runoff. Such conditions (as in the Tarai region of the Uttar Pradesh) favour more vegetative growth and slower rate of decay of organic remains. This results in the formation of comparatively dark- coloured soils rich in organic matter (Mollisols).

Soil formation and Exposure/Aspect : Topography affects soil formation by affecting temperature and vegetative growth through slope exposures (aspect). The southern exposures (facing the sun) are warmer and subject to marked fluctuations in temperature and moisture. The northern exposures, on the other hand, are cooler and more humid. The eastern and western exposures occupy intermediate position in this respect.

3. Time : Soil formation is a very slow process requiring thousands of years to develop a mature pedon. The period taken by a given soil from the stage of weathered rock (i.e. regolith) up to the stage of maturity is considered as time. By matured soils we mean soils with fully developed horizons (A, B, C). In soil formation nature works slowly. It has been reported that is takes hundreds of years to develop an inch of soil. The time that nature devotes to the formation of soils is termed as *Pedologic Time*.

It has been observed that rocks and minerals disintegrate and/or decompose at different rates; the coarse particles of limestone are more resistant to disintegration than those of sandstone. However, in general, limestone decomposes more readily than sandstone (by chemical weathering).

Minerals weather at different rates and are classified, as per various schemes according to their weatherability. Mohr suggested five stages of weathering that are dependent on mineralogical features of soils (Table 6.2).

Table 6.2 : Weathering stages in soil formation.

Stages	**Characteristic**
1. Initial	Unweathered parent material.
2. Juvenile	Weathering started; but much of the original material still unweathered.
3. Virile	Easily weatherable minerals fairly decomposed; clay content increased, slowly weatherable minerals still appreciable.
4. Senile	Decomposition reaches at a final stage; only most resistant minerals survive.
5. Final	Soil development completed under prevailing environments.

The soil properties also change with time, for instance :

Nitrogen and organic matter contents increase with time provided the soil temperature is not high (thermal, hyperthermal , or megathermal).

$CaCO_3$ content may decrease or even lost with time provided the climatic conditions are not arid. The Dutch Polder soils lost 2 per cent $CaCO_3$ in less than 300 years. The soils from Punjab (Gurdaspur series) are non-calcareous because of decalcification.

In humid regions, the H^+ concentration increases with time because of chemical weathering.

The horizonation (into A, B, C layers) develops with time.

Soils mature with time (Fig. 6.2). For instance, recent flood plain soils (Lodhowal series) with A-C profile grade, through Samana and Tulewal series (with A-B-C profiles), to well-developed soils with A-B-C profiles (Naura and Gurdaspur series).

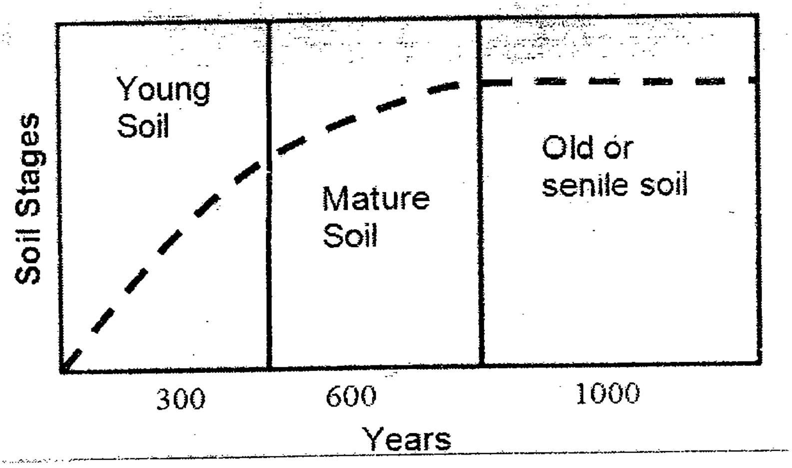


Fig. 6.2. Soil formation as a function of time.

B. Active Soil Forming Factors

The active soil forming factors are those which supply energy that acts on the mass for the purpose of soil formation. These factors are *climate* and *vegetation (biosphere)*.

1. Climate : Climate is the most significant factor controlling the type and rate of soil formation. The dominant climates recognised are :

- **Arid Climate.** The precipitation here is far less than the water-need. Hence, the soils remain dry for most of the time in a year.
- **Humid Climate.** The precipitation here is much more than the water need. The excess water results in leaching of salts and bases, followed by translocation of clay colloids.
- **Oceanic Climate.** Moderate seasonal variation of rainfall and temperature.
- **Mediterranean Climate.** The moderate precipitation, winters and summers are dry and hot.
- **Continental Climate.** Warm summers and extremely cool or cold winters.
- **Temperate Climate.** Cold, humid conditions with warm summers.
- **Tropical and Subtropical Climate.** Warm to hot, humid with isothermal conditions in the tropical zone.

Climate affects the soil formation directly and indirectly. Directly, climate affects the soil formation by supplying water and heat to react with parent material. Indirectly, it determines the fauna and flora activities which furnish a source of energy in the form of organic matter. This energy acts on the rocks and minerals in the form of acids and salts are released. The indirect effects of climate on soil formation are most clearly seen in the relationship of soils to vegetation.

Precipitation and temperature are the two major climatic elements which contribute most to soil formation.

Precipitation : Precipitation is the most important among the climatic factors. As it percolates and moves from one part of the parent material to another, it carries with it substances in solution as well as in suspension. The substances so carried ore redeposited in another part or completely removed from the material through percolation when the soil moisture at the surface evaporates causing an upward movement of water, the soluble substances move with it and are translocated to the upper layer. Thus, rainfall brings about a redistribution of substances both soluble as well as in suspension in soil body.

Temperature : Temperature is another climatic agent influencing the process of soil formation. High temperature hinders the process of leaching and causes an upward movement of soluble salts. High temperature favours rapid decomposition of organic matter and increase microbial activities in soil while low temperatures induce. Leaching by reducing evaporation and thereby favour the accumulation of organic matter by slowing down the process of decomposition, temperature thus controls the rate of chemical and biological reactions taking place in the percent material. It is computed by Jenney (1941) that in the tropical regions the rate of weathering proceeds three times faster than in temperate regions and nine times faster than in arctic .

Organisms and Vegetation :

Organisms : The soil and the organisms living on and in it comprise an ecosystem. The active components of soil ecosystem are the plants, animals, micro-organisms and man. The role of micro-organisms in soil formation is related to the humification and mineralisation of vegetation they bring about.

The action of animals especially the burrowing animals to dig and mix-up the soil mass and thus disturb the parent material.

Man influences soil formation through his manipulation of natural vegetation, his agricultural practices and other activities. Compaction by traffic of man and animal decrease the rate of water infiltration into the soil and thereby increase the run off and erosion.

Vegetation : The roots of the plant penetrate into the parent material where they act both mechanically as well as chemically. They facilitate percolation and drainage and bring about greater dissolution of minerals through the action of CO_2 and other acidic substances secreted by them. The decomposition and humification of the material further adds to the solublisation of minerals. The substances so dissolved are subject to movement in the parent material.

Forests reduce the temperature, increase humidity, reduce evaporation and increase precipitation.

Grasses reduce runoff and result greater penetration of rainwater into the parent material.

SOIL FORMING PROCESSES

Most natural processes, such as the upliftment of a mountain mass and th filling of an island in sea, take place rather slowly. In contrast, the pedogenic processes, although slow in terms of human life, yet work faster than the geological processes in changing lifeless parent material into true soil full of life.

The pedogenic processes are extremely complex and dynamic involving many chemical and biological reactions and usually operate simultaneously in a given area. One process may counteract another, or two different processes may work simultaneously to achieve the same result.

Different processes or combination of processes operate under varying natural environment. The collective interaction of various soil forming factors under different environmental conditions set a course to certain recognized soil forming processes.

A. Fundamental Soil Forming Processes

The basic process involved in soil formation (Simonson, 1959) include the following (Fig. 6.3) :

- 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 (i) movement of solution (leaching) and, (ii) movement in suspension (eluviation) of clay, organic matter and hydrous oxides.

1. Humification : Humification is the process of decomposition of organic matter and synthesis of new organic substances. It is the process of transformation (i.e. decomposition) of raw organic matter into humus. It is an extremely complex process involving various organisms, such as bacteria, fungi, actinomycetes, earthworms and termites. The waxy pine needles after falling on the ground are attacked by waves of fungi breaking down complex plant compounds. First the simple compounds, such as sugars and starches, are attacked, followed by the proteins, cellulose, and finally the very resistant compounds, such as tannins, are decomposed and the dark coloured substance, known as humus, is formed. In contrast, the decomposition of the leaves of deciduous trees by earthworms and bacteria is much faster and may be accomplished within a year or so, leaving little organic matter at the surface.

2. Eluviation : It is the mobilization and translocation of certain constituents viz. Clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$, other salts etc. from one point of soil body to another. *Eluviation means* washing out. It is the process of removal of constituents in suspension or solution by the percolating water from the upper to lower layers. The eluviation encompasses mobilization and translocation of mobile constituents resulting in textural differences. The horizon formed by the process of eluviation is termed as *eluvial horizon* (A_2 or E horizon).

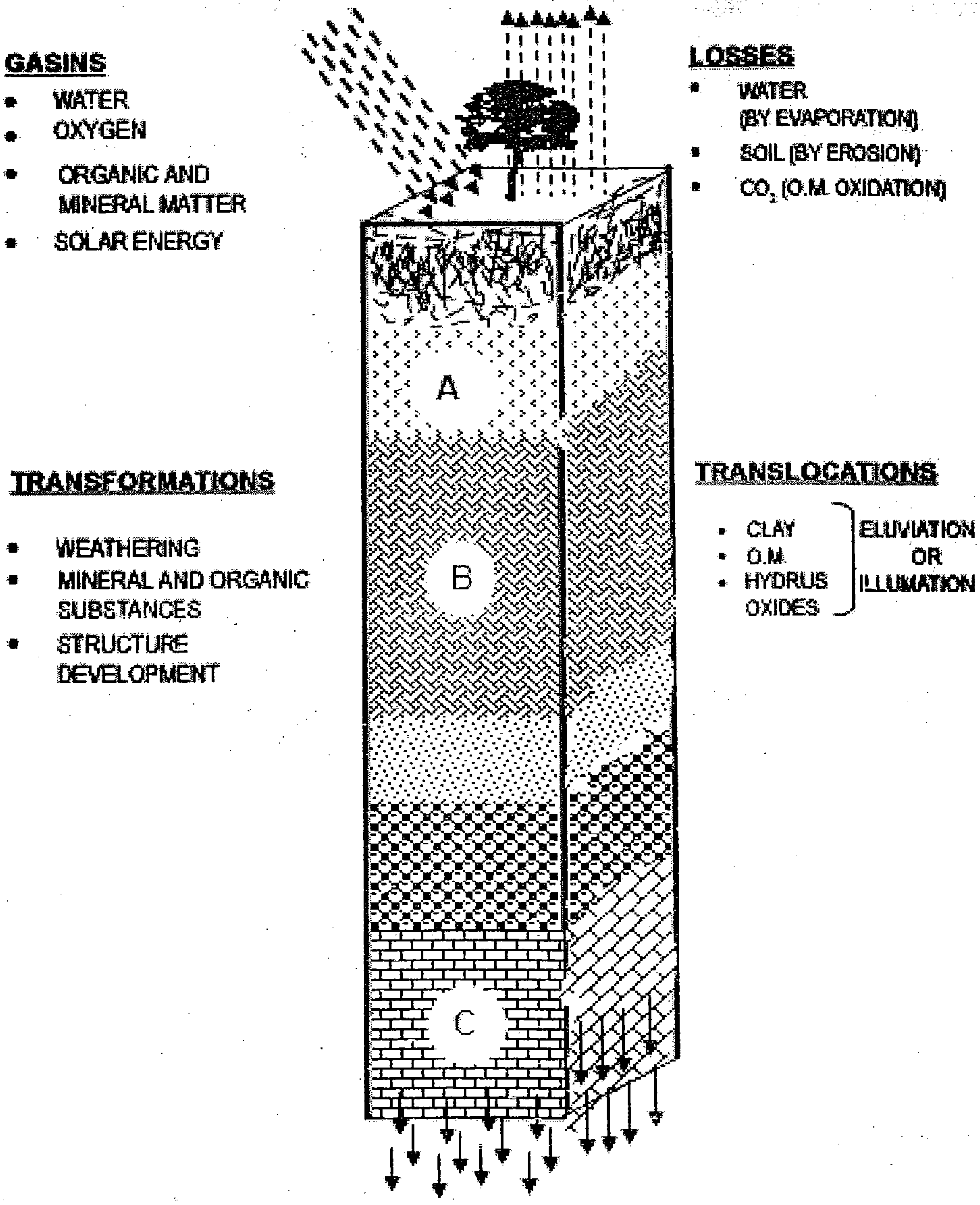


Fig. 6.3. Pedogenic processes in soil formation.

3. Illuviation (Analogous to immigration) : The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer (or horizon of gains having the property of stabilizing translocated clay materials) is termed as *illuviation*. The horizons formed by this process are termed as *illuvial horizons* (B-horizons, especially Bt) The process leads to textural contrast between E and Bt horizons, and higher fine: total clay ratio in the Bt horizon.

4. Horizonation : It is the process of differentiation of soil in different horizons along the depth of the soil body. The differentiation is due to the fundamental proccesses, humification, eluviation and illuviation.

B. Specific Soil Forming Processes

The basic pedologic processes provide a framework for later operation of more specific processes, the same are discussed as under :

1. Calcification : It is the process of 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 acid soil water and/or when CO_2 concentration is high in root zone as :

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

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

$$\underset{\text{(soluble)}}{Ca(HCO_3)_2} \xrightarrow[CO_2]{\text{Temp.}} \underset{\text{(precipitates)}}{CaCO_3 + H_2O + CO_2}$$

The process of precipitation after mobilization under these conditions is called *calcification* and the resulting illuviated horizon of carbonates is designated as *Bk horizon* (Bca).

2. Decalcification : It is the reverse of calcification that is the process of removal of $CaCO_3$ or calcium ions from the soil by leaching

$$\underset{\text{(insoluble)}}{CaCO_3 + CO_2 + H_2O} \xrightarrow[CO_2]{\text{Temperature}} \underset{\text{(soluble)}}{Ca(HCO_3)_2}$$

3. Podzolization : It is a process of soil formation resulting in the formation of Podzols and Podzolic soils. In many respects, podzolization is the negative of calcification. The calcification process tends to concentrate calcium in the lower part of the B horizon, whereas podzolization leaches the entire solum of calcium carbonates. Apart from calcium, the other bases are also removed and the whole soil becomes distinctly acidic. In fact, the process is essentially one of acid leaching. The process operates under favourable combination of the following environments :

(i) Climate : A cold and humid climate is most favourable for podzolization

(ii) Parent material : Siliceous (Sandy) material, having poor reserves of weatherable minerals, favour the operation of podzolization as it helps in easy percolation of water.

(iii) Vegetation : Acid producing vegetation such as coniferous pines, hemlock in forests of northern latitudes and others like Heath and Erica species of Europe and Picea, Populus, Quercus, Betula, etc. are essential to this process.

(iv) Leaching and Translocation of Sesquioxides : In the process of decomposition of organic matter various organic acids are produced. The organic acids thus formed react with sesquioxides and the remaining clay minerals, forming organic- sesquioxide and organic clay complexes, which are soluble and move with the percolating water to the lower horizons (Bh, Bs). Aluminium ions in a water solution hydrolyze and make the soil solution very acidic.

$$2Al + 6H_2O \longrightarrow 2Al(OH)_3 + 6H^+$$

As the iron and aluminium move about, the A horizon gives a bleached grey or ashy appearance. As such the Russians used the term podzol (pod means under, the zola means ash like i.e. ash-like horizon appearing beneath the surface horizon) for such soils.

4. Laterization : 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 and Maharashtra. 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 impregnated with sesquioxides (iron and aluminium oxides) to extent of 70 to 80 per cent of the total mass, are called *laterites* or *latosols* (Oxisols). The soil forming process is called *laterization* or *Lotozation.*

Laterization is 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 the following conditions :

(i) Climate : Unlike podzolization, the process of laterization operates most favourable in warm and humid (tropical) climate with 2000 to 2500 mm rainfall and continuous high temperature (± 25°C) throughout the year.

(ii) Natural Vegetation : The rain forests of tropical areas are favourable for the process.

(iii) Parent Material : Basic parent materials, having sufficient iron bearing ferromagnesium minerals (Pyroxene, amphiboles, biotite and chlorite), which on weathering release iron, are congenial for the development of laterites.

5. Gleization : The term glei is of Russian origin, which means blue, grey or green clay. The ***gleization*** is a process of soil formation resulting in the development of a glei (or gley horizon) in the lower part of the soil profile above the parent material due to poor drainage condition (lack of oxygen) and where waterlogged conditions prevail. Such soils are called ***hydromorphic soils.*** The process is not particularly dependent on climate (high rainfall as in humid regions) but often on drainage conditions. The poor drainage conditions result from :

- Lower topographic position, such as depression land, where water stands continuously at or close to the surface.
- Impervious soil parent material and
- Lack of aeration.

Under such conditions, iron compounds are reduced to soluble ferrous forms. The reduction of iron is primarily biological and requires both organic matter and microorganisms capable of respiring anaerobically. The solubility of Ca, Mg, Fe, and Mn is increased and most of the iron exists as Fe^{++} organo-complexes in solution or as mixed precipitate of ferric and ferrous hydroxides. This is responsible for the production of typical bluish to greyish horizon with mottling of yellow and / or reddish brown colours.

6. Salinization : Salinization 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. 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.

7. Desalinization : It is the removal by leaching of excess soluble salts from horizons or soil profile (that contained enough soluble salts to impair the plant growth) by ponding water and improving the drainage conditions by installing artificial drainage network.

8. Solonization or Alkalization : The process involves the accumulation of sodium ions on the exchange complex of the clay, resulting in the formation of sodic soils (Solonetz). All cations in solution are engaged in a reversible reaction with the exchange sites on the clay and organic matter particles. The reaction can be represented as :

$$Ca.Mg.2NaX \rightarrow Ca^{++} + Mg^{++} + 2Na^{+} + x^{-6} + 3CO_3^{2-} \rightarrow Na_2CO_3 + MgCO_3 + CaCO_3$$

(Where X represents clay or organic matter exchange sites)

9. Solodization or Dealkalization : 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. Much of the dispersion can be eliminated if Ca^{++} and /or Mg^{++} ions are concentrated in the water, which is used to leach the solonetz. These Ca and Mg ion can replace the Na on exchange complex and the salts of sodium are leached out as :

$$2NaX + CaSO_4 \longrightarrow \underset{\text{leachable}}{Na_2SO_4} + CaX$$

10. Pedoturbation : Another process that may be operative in soils is pedoturbation. It is the process of mixing of the soil. Mixing to a certain extent takes place in all soils. The most common types of pedoturbation are :

- **Faunal pedoturbation :** It is the mixing of soil by animals, such as ants, earthworms, moles, rodents and man himself.
- **Floral pedoturbation :** It is the mixing of soil by plants as in tree tipping that forms pits and mounds
- **Argilli 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 of central India.

DEVELOPMENT OF SOIL PROFILE

The development of soil profile is a constructive process where in disintegrated material resulted from weathering of rocks and minerals get converted into a soil body. The development of soil profile is shown in fig. 6.4.

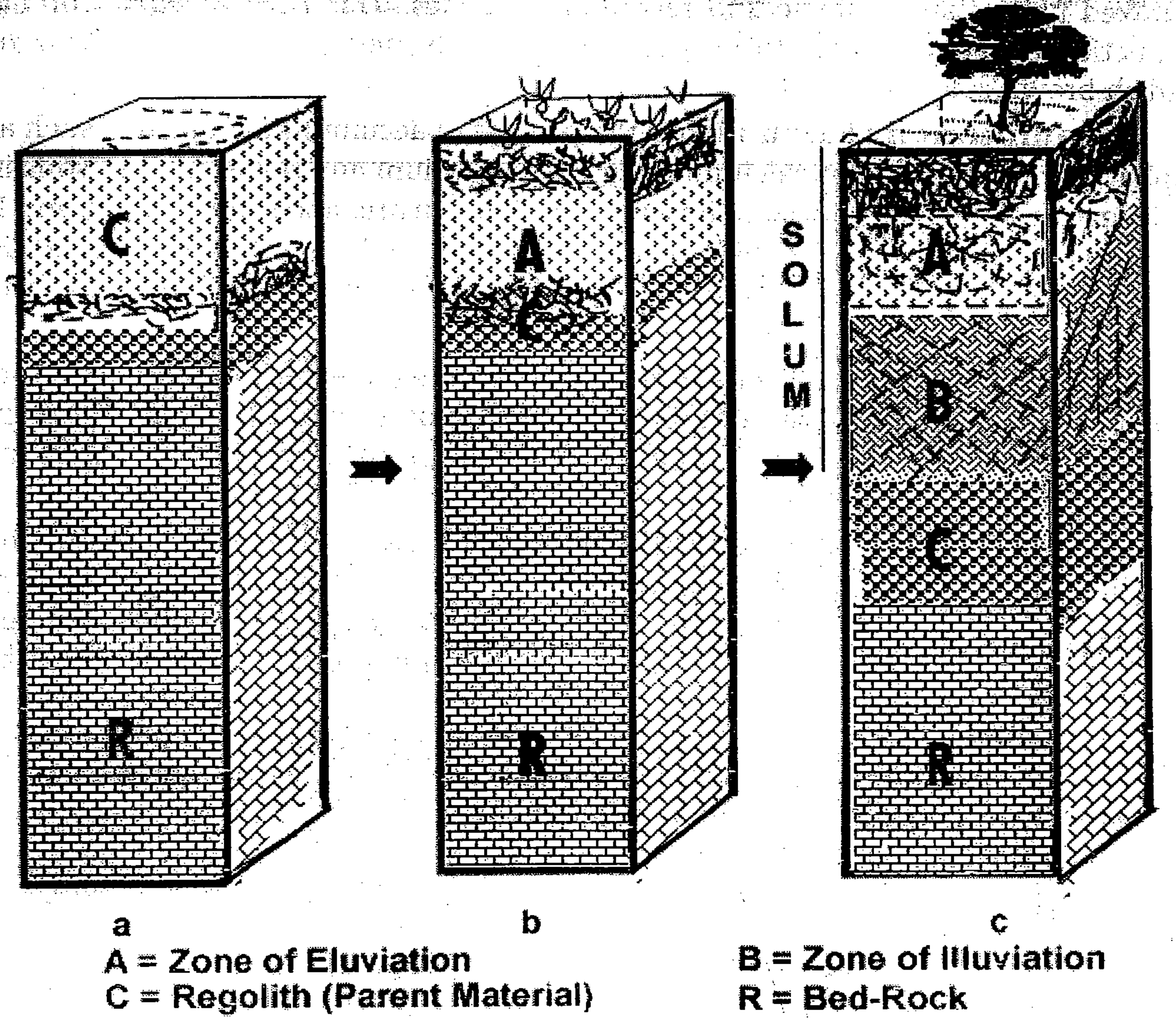


Fig. 6.4. Development stages of soil profile from parent material.

Definition of soil profile : The vertical section of the soil showing the various layers from the surface to the unaffected parent material is known as a *soil profile.* (Fig. 6.4) The various layers are known as *horizons.* A soil profile contains three main horizons.

They are named as *horizon A, horizon B and horizon C.* The parent material from which the soil is formed is known as horizon C. The surface soil or that layer of soil at the top which is liable to leaching and from which some soil constituents have been removed is known as *horizon A* or the *horizon of elluviation.* The intermediate layer in which the materials leached from *horizon A* have been re-deposited is known as *horizon B* or *the horizon of elluviation.*

Table 6.1: Soil horizons and their brief descriptions.

Horizon Designation		**Brief description**
NEW	**OLD**	
O-organic	O	Organic horizon (O) of mineral soils. It may be :
Oa	O_1	Partly decomposed organic matter
Oe	O_2	Highly decomposed organic matter
A	A	Mineral horizon (A) formed at or near the surface with well mixed organic matter. It may be :
Ah	Al	Uncultivated, with high organic matter content (>1%)
Ap	Ap	Mixed by ploughing or other disturbances.
Ag	Ag	Partially gleyed due to intermittent waterlogging, rusty mottles along root channels.
E	A2	Eluvial horizon of low organic matter content from which clay and humus have moved to lower horizons. It may be :
Eg	A2g	Like Ag above, but often overlies a Bt horizon
B	B	Subsurface horizon showing typical colour, texture, structure due to illuviation of material from the over laying horizons (s) and the weathering of parent material. It may be showing :
By	Bcs	Accumulation of gypsum
Bz	Bsa	Accumulation of salts
Bg	Bg	Partially-platy; blocky or prismatic structure: variable black MnO_2 mottles
Bh	Bh	Translocated organic matter with some Fe and Al
Bs	Bir	Enriched with sesquioxides usually by illuviation; orange to red in colour.
Bt	Bt	Accumulation of translocated clay as evidenced by clay coatings on ped faces
Bw	B2/ (B)	Alterations of parent material by leaching, wheathering and structural reorganization
C	C	Parent material, excluding bed rock from which solum is believed to have formed. It may be showing :
Ck	Cca	Accumulation of secondary $CaCO_3$ as concretions or coatings by 1% or more (also occur as Ak , Bk)
Cy	Ccs	Secondary accumulations of $CaSO_4$ as gypsum crystals
Cm	Cm	Continuously cemented, other than by a thin iron pan
Cr	Cr	Weak consolidation but dense enough to prevent root penetration
Cx	Cx	Fragipan characteristics; dense but uncemented; firm when dry and brittle when moist.

Soil Individual or Polypedon :

The Soil Survey Staff (1960) defined the soil individual or polypedon (Gr. Pedon, ground) as a natural unit of soil that differs from its adjoining unit on the landscape in one or more properties to such a degree that the combination of all properties result in different responses to management. The boundaries of such a unit lie at a place where there have been significant differences in one or more soil forming factors.

The term pedon has been proposed for small basic soil entities that are part of the continuum mantling the land. ***A pedon*** is the smallest volume that can be called "a soil".

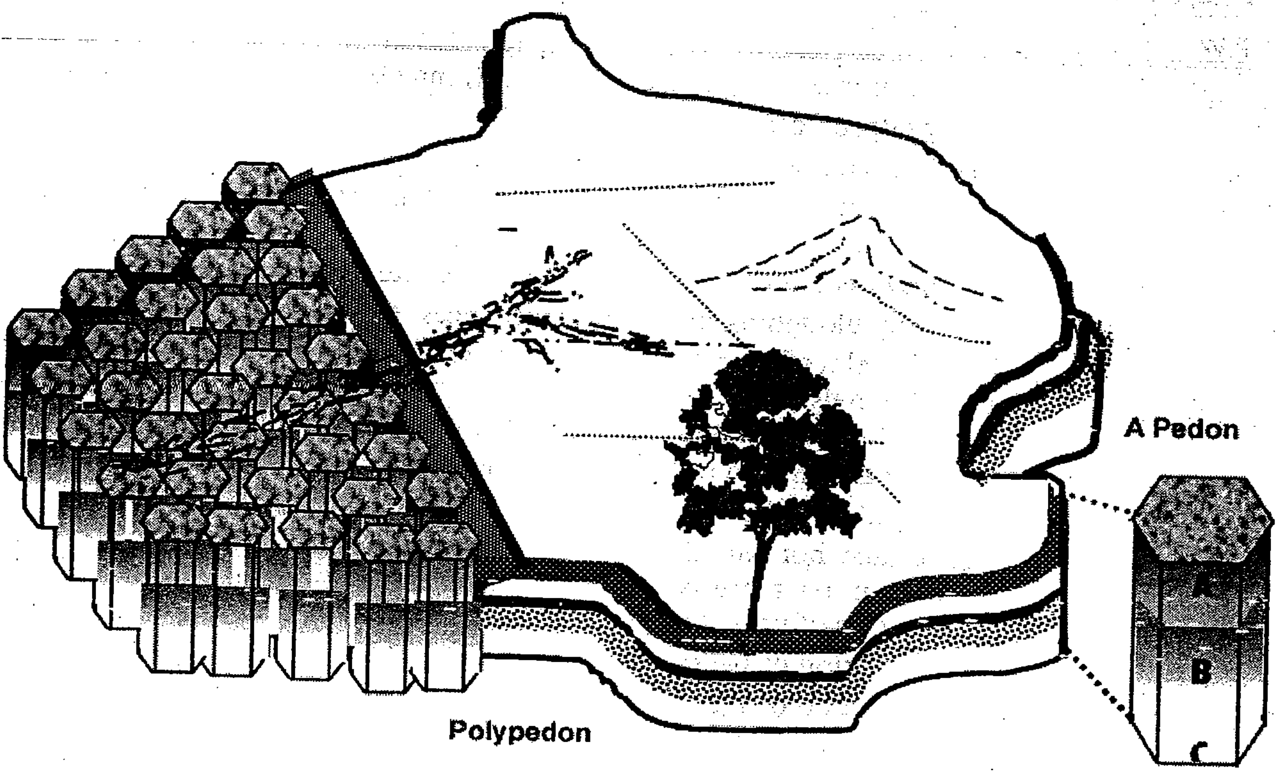


Fig. 6.5. A schematic diagram of illustrate the concept of pedon and of the soil profile that characterizes it.

The set of pedons must fit within the range of one series and occur in a contiguous group to form a polypedon. ***A polypedon*** is therefore, defined as a contiguous similar pedons bounded on all sides by "not-soil" or by pedons of unlike characters.' It is a real physical soils body which has a minimum area of more than 1 sq. km. And an unspecified maximum area.

The relationship between the polypedon and its constituent pedons in single body of soil is illustrated in fig. 6.5 where a part of soil body has been split into pedons. All but a few of the pedons are of the same kind and represent a single polypedon.

EXERCISES

Q.1 Select the appropriate word :

1. ______ established that soils develop as a result of the interplay of soil forming factors.

(a) Jenny (b) Dokuchaiev
(c) Liebig (d) Warington

2. The quantitative relationship between soil forming factors and soil property $S = f$ (Cl, O, r, p, t - - - - -) was given by ______________.

(a) Warington (b) Dokuchaiev
(c) Jenny (d) Liebig

3. ______________ soil forming factors represents the source of soil forming mass and condition affecting it.
(a) Active (b) Passive
(c) Fundamantal (d) Specific

4. The soils, where the parent material subdues the effect of climate and vegetation are called ___________ soils.
(a) Ectodynamomorphic (b) Endodynamorphic
(c) Alluvial (d) Colluvial

5. Basic igneous rocks generally produce ____________ soil.
(a) Coarse textured (b) Fine textured cracking
(c) Light textured (d) Fine textured non cracking

6. ____________ furnish the skeleton for the production of secondary minerals.
(a) Fe and Mn (b) Na and K
(c) Cu and Mg (d) Si and Al

7. The soils formed on steep slopes are generally shallow because of ________.
(a) High rainfall (b) Accelerated erosion
(c) Undulating topography (d) More vegetation

8. The soils formed in depression are comparatively ____________.
(a) Dark coloured rich in organic matter
(b) Dark coloured poor in orga.nic matter
(c) Dark coloured rich in Fe content
(d) Dark coloured rich in P content

9. Mature soil means soil with fully developed __________ horizons.
(a) A and B (b) B and C
(c) A and C (d) A, B and C

10. In humid region ________ ion concentration increase in soil due to chemical weathering.
(a) Ca (b) Mg
(c) H (d) Na

11. ________ are the two major climatic elements which contribute soil formation.
(a) Rainfall and temperature (b) Rainfall and humidity
(c) Humidity and temperature (d) Temperature and vegetation

12. _________ brings about a distribution of soluble as well as insoluble substances in soil body.
(a) Rainfall (b) Temperature
(c) Humidity (d) Glaciers

13. The rate of weathering is __________ times faster in tropical climate than in temperate regions.
(a) Two (b) Three
(c) Four (d) Five

14. The soil forming process in which new organic substances are synthesized is _________.
(a) Podzolization (b) Humification
(c) Laterization (d) Gleization

15. ___________ is the process of removal of excess soluble salts.
(a) Solodization (b) Desalinization
(c) Podzolization (d) Pedoturbation

Q.2 Write the answer in one sentence :

1. Enlist the passive soil forming factors.
2. State the elements responsible for imparting red colour to soils.
3. Name the dispersing agents in soil released during decay of rocks.
4. Which are the flocculating agents in soil ?
5. What do you mean by pedologic time ?
6. Who has suggested the weathering stages depend upon mineralogical features of soil ?
7. Enlist the dominant climates controlling the type and rate of soil formation.
8. How the climate affects indirectly on soil formation ?
9. What do you know by ecosystem ?
10. What is the effect of forests in soil formation ?
11. Name the fundamental pedogenic processes.
12. Enlist the specific soil forming processes.

Q.3 Define the following terms :

1. Horizonation
2. Eluviation
3. Illuviation
4. Podzolization
5. Calcification
6. Laterization
7. Salinization
8. Pedoturbation
9. Alkalization
10. Soil profile
11. Horizon
12. Pedon

Q.4 Match the pairs :

1. Colluvium	1. Material settled out of quiet water of lake
2. Aeolin	2. The material transported to sea and then exposed.
3. Moraine	3. Deposition of soil material in the lower layers.
4. Eluviation	4. Ash like material beneath the surface horizon.
5. Alluvium	5. Material transported by gravity.
6. Marine	6. Materials are blown by wind.
7. Lacustrine	7. Material transported and deposited by water.
8. Illuviation	8. Removal of constituents.
9. Podzol	9. Accumulation of sodium ions.
10. Gleization	10. Material deposited by melting glaciers.
	11. Material transported by plant roots.
	12. Process of mixing of the soil.
	13. Due to poor drainage.
	14. Uncultivated high organic matter.

□□

7

Soils Texture and Structure

Soil separates – size, distribution, proportion and properties, soil textural classes, importance; Soil structure – Mechanism of aggregation, types and importance, factors affecting.

Physical properties (mechanical behaviour) of a soil greatly influence its use and behaviour towards plant growth. The plant support, root penetration, drainage, aeration, retention of moisture and plant nutrients are linked with the physical condition of the soil. Physical properties also influence the chemical and biological behaviour of soil.

The physical properties of a soil depend on the amount, size, shape, arrangement and mineral composition of its particles. These properties also depend on organic matter content and pore spaces. Following are the important physical properties of soils.

1. Soil texture
2. Soil structure
3. Surface area
4. Soil density
5. Soil porosity
6. Soil colour
7. Soil consistence

Soil Texture

Definition : *Soil texture* refers to the relative proportion of particles or separates of various sizes in a given soil. Or soil texture is the relative percentage of sand, silt and clay in a soil.

The size of particles in mineral soil is not readily subject to change. Thus, a sandy soil remains sandy and a clay soil remains clayey. Since the proportion of each size group in a given soil (the texture) can not be easily altered, it is considered a basic property of a soil. The mineral component constitutes the soil mass. This mineral portion consists of particles of various sizes. According to the size, the soil particles are grouped into gravels, sands, silts and clays, which are termed as soil *separates*. The process of determining the amount of individual soil separates below 2 millimeters in diameter is called a *mechanical analysis or particle size analysis.*

Stokes's Law : Particle size analysis is based on a simple principle i.e. "when soil particles are suspended in water they tend to sink. Because there is little variation in the density of most soil particles, their velocity (V) of settling is proportional to the square of the radius 'r' of each particle". Thus $V=kr^2$ where k is a constant. This equation is referred to as *Stokes's law*. Stokes (1851) stated that "the velocity of a falling particle is proportional to the radius square and not to its surface". The relation between the diameter of a particle and its settling velocity is governed by Stokes's Law :

$$V = \frac{2}{9} \times \frac{g\,(ds - dw)\,r^2}{n}$$

Where ,

V - velocity of settling particle (cm/sec.)
g - acceleration due to gravity (981)
ds - density of soil particle (2.65)
dw - density of water (1)
n - coefficient of viscosity of water (0.0015 at 4°C)
r - radius of spherical particles in cm.

Limitations/Assumptions of Stoke's Law :

The application of Stokes' law requires that the soil particles are completely dispersed in a uniform manner at the start of sedimentation and that the concentration of the suspension is sufficiently dilute so that the free fall of the particles is not hindered by collision with other particles. The temperature should be kept constant so that convection currents are not set up, and the densities of the particles and water as well as the viscosity of the medium remain constant. Other assumptions and approximations include existence of a laminar or viscous flow of particles, which are smooth, rigid and spherical. In soil, particles are of various shapes, and may not be smooth and rigid. In order, therefore, to make Stokes' law valid, an equivalent spherical radius is so defined that particles having this radius fall with the same velocity as the soil particles. Density of soil particles is assumed to be uniform, but this is usually not so because of their different chemical and mineralogical composition. For all practical purposes, the value of 2. 65g/cm^3 for particle density is accepted.

Classification of Soil Separates

The soil particles, according to the size are mainly grouped into four groups viz, course and fine sands, silts and clays, which are termed as soil separates. There are a number of systems of naming soil separates. They are (a) The American system developed by USDA, (b) The English system and (c) The International system. The International system is commonly followed in India given in table 7.1.

Table 7.1 International system of naming soil separates

Soil separate	*Diameter range (mm)*
1. Coarse Sand	*2.00 to 0.20*
2. Fine Sand	*0.20 to 0.02*
3. Silt	*0.02 to 0.002*
4. Clay	*Below to 0.002*

Characteristics of Soil Separates

The particle size analysis gives a general picture of the physical properties of a soil. The important physical properties of soil separates are given in table 7.2

Table 7.2 Physical properties of soil separates.

Characteristics	Sand	Silt	Clay
1. Visibility	*Visible by naked eyes*	*Not clearly*	*Visible by ultra microscope*
2. Size of pores	*Large (macro)*	*Medium*	*Micro*
3. Aeration	*Very rapid*	*Medium*	*Slow*
4. Infiltration	*Very rapid*	*Medium*	*Slow*
5. Total pore spaces	*Least*	*Medium*	*Highest*
6. Water holding capacity	*Low*	*Medium*	*High*
7. Tillage	*Easy*	*Moderate*	*Difficult*
8. Plasticity, stickiness, surface area, swelling, adhesion, cohesion etc.	*Very low*	*Medium*	*High*
9. Mineral	*Quartz*	*Quartz, feldspars, Micas, haematite etc.*	*Kaolinite, montmorillonite*
10. Chemical makeup	*Inactive*	*Slightly active*	*Active*
11. Fertility	*Very less*	*Medium*	*High*

Soil Textural Classes

To convey an idea of the textural makeup of soils and to give an indication of their physical properties, soil textural class names are used. These are grouped into three main fractions viz. Sand, silt and clay. According to the proportion of these three fractions, a soil is given a name to indicate its textural composition. Such a name gives an idea not only of the textural composition of a soil but also of its various properties in general. On this basis soils are classified into various textural classes like sands, clays, silts, loams etc.

Sands : The sand group includes all soils in which the sand separates make up at least 70% and the clay separate 15% or less of the material by weight. The properties of such soils are therefore characteristically those of sand in contrast to the stickier nature of clays.

Two specific textural classes are recognized in this group : sandy and loamy sand although, in practice, two subclasses are also used : Loamy fine sand and loamy very fine sand.

Silts : The silt group includes soils with at least 80% silt and 12% or less clay. Naturally the properties of this group are dominated by those of silt. Only one textural class–silt- is included in this group.

Clays : To be designated a clay; a soil must contain at least 35% of the clay separate and in most cases, not less than 40%. In such soils the characteristics of the clay separates are distinctly dominant and the class names are clay, sandy clay and silty clay. Sandy clays may contain more sand than clay. Likewise, the silt content of silty clays usually exceeds clay fraction.

Loams : The loam group, which contains many subdivisions, is a more complicated soil textural class. An ideal loam may be defined as a mixture of sand, silt and clay particles that exhibits the properties of those separates in about equal proportions. Loam soils does not exhibit dominant physical properties of sand, silt or clay. Note that loam does not contain equal percentage of sand, silt and clay. It does, however, exhibit approximately equal properties of sand, silt, and clay.

Determination of Textural Class

In the American system as developed by the United State Department of Agriculture twelve textural classes are proposed. The ranges in the relative percentage of sand, silt and clay in the 12 textural classes are given in Table 7.3.

Table 7.3: General terms used to describe soil texture in relation to the basic soil textural class names.

General Terms	Textural group		Per cent		
Common names	**Texture**		**Sand**	**Silt**	**Clay**
Sandy soils	*Course*	*Sands*	*85-100*	*0-15*	*0-10*
		Loamy sands	*70-90*	*0-30*	*0-15*
Loamy soils	*Moderately coarse*	*Sandy loam*	*45-85*	*0-50*	*0-20*
	Medium	*Loam*	*23-52*	*28-50*	*7-27*
		Silt loam	*0-50*	*50-87*	*0-27*
		Silt	*0-20*	*80-100*	*0-13*
	Moderately Fine	*Sandy clay Loam*	*45-80*	*0-28*	*20-35*
		Silty clay loam	*0-20*	*40-73*	*27-40*
		Clay loam	*20-45*	*15-53*	*27-40*
Clayey soils	*Fine*	*Sandy clay*	*45-65*	*0-20*	*35-55*
		Silty clay	*0-20*	*40-60*	*40-60*
		Clay	*0-47*	*0-40*	*40-100*

The textural triangle (Fig 7.1) is used to determine the soil textural name aft the percentages of sand, silt, and clay are determined from a laboratory analysis Since the soil's textural classification includes only mineral particles and those o less than 2mm diameter, the sand plus silt plus clay percentages equal 100 per cen (note that organic matter is not included.) Knowing the amount of any two fractions automatically fixes the percentage of the third one. In reading the textural triangl any two-particle fractions will locate the textural class at the point where those two intersect (see fig. 7.1).

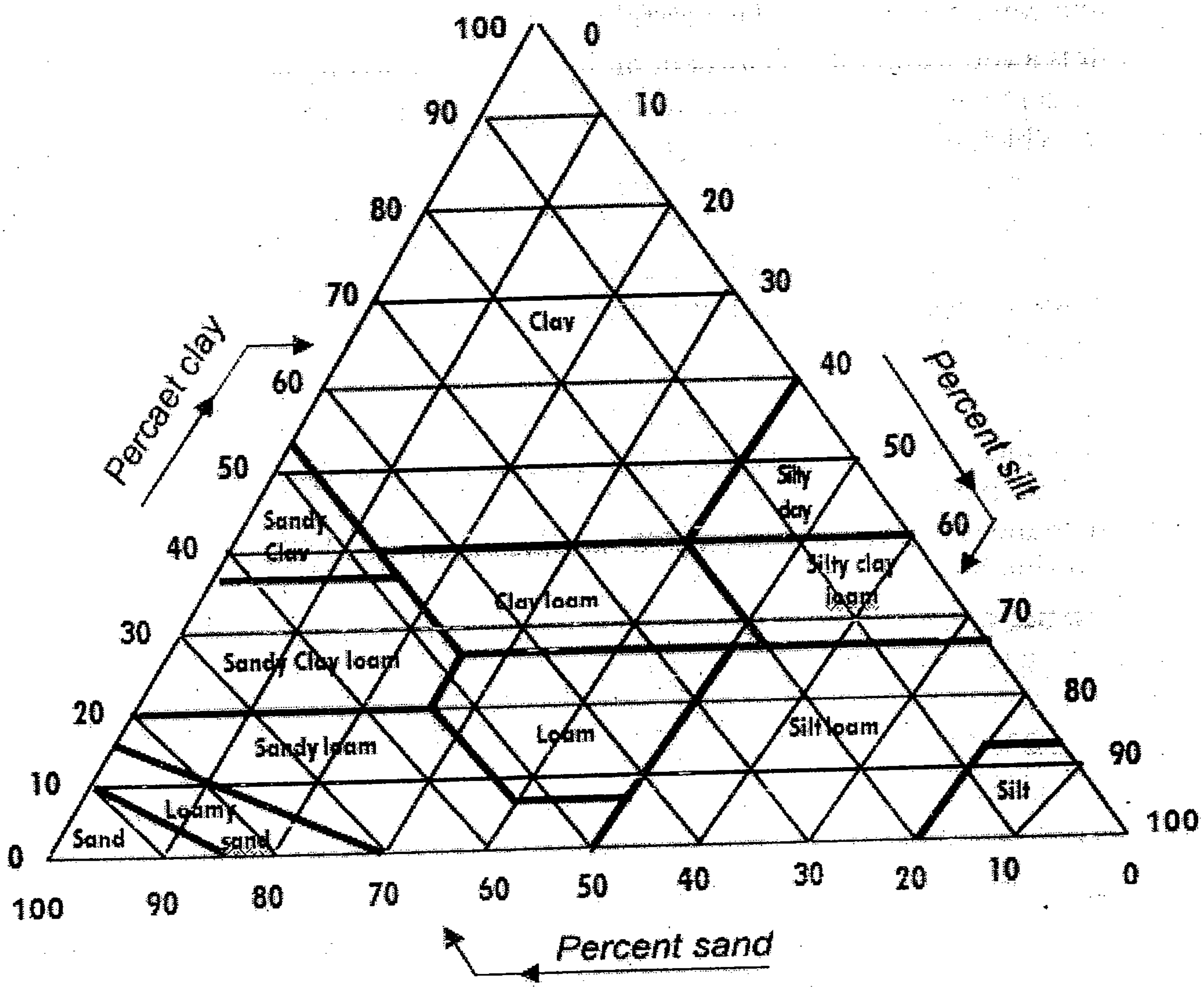


Fig. 7.1. Triangular textural diagram showing percentages of clay (Below 0.002 mm) silt (o.oo2 to o.02 mm) and sand (0.02 to 2.0 mm) in the basic soil textural classes.To use the diagram, locate the percentage of clay first and project inward parallel to sand line as shown by the arrow. Do likewise for the per cent silt (or sand). The point at which the two projections cross will identify the class name.

Importance of Soil Texture

Texture has good effect on management and productivity of soil. Sandy soils are of open character, usually loose and friable. Such type of the texture is easy to handle in tillage operations. Sand facilitates drainage and aeration. It allows rapid evaporation and percolation. Sandy soils have very little water holding capacity. Such soils can not stand drought and unsuitable for dry farming. In sandy soil, few crops can be grown such as potato, groundnut and cucumbers.

Clay particles play a very important role in soil fertility. Clayey soils are difficult to till and require much skill in handling. When moist clayey soils are exceedingly sticky and when dry, become very hard and difficult to break. They have fine pores, and are poor in drainage and aeration. They have a high water holding capacity and poor percolation, which usually results in waterlogging. They are generally very fertile soils, in respect of plant nutrient content. Rice, jute, sugarcane can be grown very successfully in these soils.

Silt is a very valuable constituent of the soil. Good loamy soils contain about 30 to 50 per cent silt. An ideal loam may be defined as a mixture of sand, silt and clay particles, which exhibits light and heavy properties in about equal proportions. In drainage, absorption of water and water holding capacity they are intermediate between sandy soils and clayey soils. Tillage operations are best adapted to this class of soil. In loam soil good tilth is obtained easily. They are practically suited to every kind of crop such as wheat, maize, pulses, oilseeds, potato, groundnut, vegetables, rice, sugarcane etc.

SOIL STRUCTURE

Soil conditions and characteristics such as water movement, heat transfer, aeration and porosity are much influenced by structure. In fact, the important physical changes imposed by the farmer in ploughing, cultivating, draining, liming and manuring his land are structural rather than textural.

Definition : The arrangement and organization of primary and secondary particles in a soil mass is known as *soil structure*. Soil structure controls the amount of water and air present in soil. Plant roots and germinating seeds require sufficient air and oxygen for respiration. Bacterial activities also depend upon the supply of water and air in the soil.

Formation of Soil Structure

Soil particles may be present either as single individual grains or as aggregate i.e. group of particles bound together into granules or compound particles. These granules or compound particles are known as *secondary particles*. A majority of particles in a sandy or silty soil are present as single individual grains while in clayey soil they are present in granulated condition. The individual particles are usually solid, while the aggregates are not solid but they possess a porous or spongy character. Most soils are mixture of single grain and compound particle. Soils which predominate with single grains are said to be structureless, while those possess majority of secondary particles are said to be aggregate, granulated or crumb structure.

Mechanism of Aggregate Formation : The bonding of the soil particles into structural unit is the genesis of soil structure. The bonding between individual particles in the structural units is generally considered to be stronger than between the structural units themselves.

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*. Whatever may be the cementing material, it is ultimately the dehydration of colloidal matter accompanied with pressure that completes the process of aggregation.

Colloidal clay : By virtue of high surface area and surface charge, clay particles play a key role in the formation of soil aggregates. Sand and silt particles can not form aggregates as they do not possess the power of adhesion and cohesion. These particles usually carry a coating of clay particles, they are enmashed in the aggregates formed by the adhering clay particles. Colloidal particles form aggregates only when they are flocculated. There is vast difference between flocculation and aggregation. *Flocculation* is brought about by the coalescence of colloidal particles and is the first step in aggregation. *Aggregation* is some thing more than flocculation involving a combination of different factors such as hydration, pressure, dehydration etc. and requires cementation of flocculated particles. The cementation may be caused by cations, oxides of Fe and Al, humus substances and products of microbial excretion and synthesis. Clay particles form aggregates only if they are wetted by a liquid like water whose molecules possess an appreciable dipole moment.

$$\text{Clay}^{-}\ \_\_\_\ {}^{+}\text{Water}\ \_\_\_\ {}^{+}\text{Cation}^{+}\ \_\_\_\ {}^{-}\text{Clay}^{-}\ \_\_\_\ {}^{+}\text{Water}^{-}\ \_\_\_\ {}^{+}\text{Cation}^{+}\ \_\_\_{}^{-}\text{Clay}^{-}$$

The link between clay-water-cation has been shown diagrammatically above. The aggregation also depends upon the nature of clay particles, size and amount of clay particles, dehydration of clay particles, cations like calcium and anions like phosphate.

Fe and Al oxides : The colloidal Fe oxides act as cementing agent in aggregation. Al oxides bind the sand and silt particles. These act in two ways. A part of the hydroxides acts as a flocculating agent and the rest as a cementing agent.

Organic matter : It also plays an important role in forming soil aggregates. The way in which it helps is not clearly understood. However, it has been shown that it may be due to:

(i) During decomposition, cellulosic substances produce a sticky material very much resembling mucus or mucilage. The sticky properly may be due to the presence of humic or pulmic acid or related compounds produced.

(ii) Certain polysaccharides and polyuronides formed during decomposition.

(iii) Some fungi and bacteria have cementing effect probably due to the presence of slimes and gums on the surface of the living organisms produced as a result of the microbial activity.

Classification

The primary soil particles–sand, silt and clay- usually occur grouped together in the form of aggregates. Natural aggregates are called **peds**, whereas **clod** is an artificially formed soil mass. Structure is studied in the field under natural conditions and it is described under three categories :

1. Type – Shape or form and arrangement pattern of peds.
2. Class – Size of Peds.
3. Grade – Degree of distinctness of peds.

Types of Structure

There are four principal forms of soil structure :

1. Plate-like (Platy) : In this structural type the aggregates are arranged in relatively thin horizontal plates. The horizontal dimensions are much more developed than the vertical. When the units are thick, they are called platy and when thin, *laminar* (Fig. 7.2). Platy structure is most noticeable in the surface layers of virgin soils but may be present in the subsoil. Although most structural features are usually a product of soil forming forces, the platy type is often inherited from the parent material, especially those laid down by water.

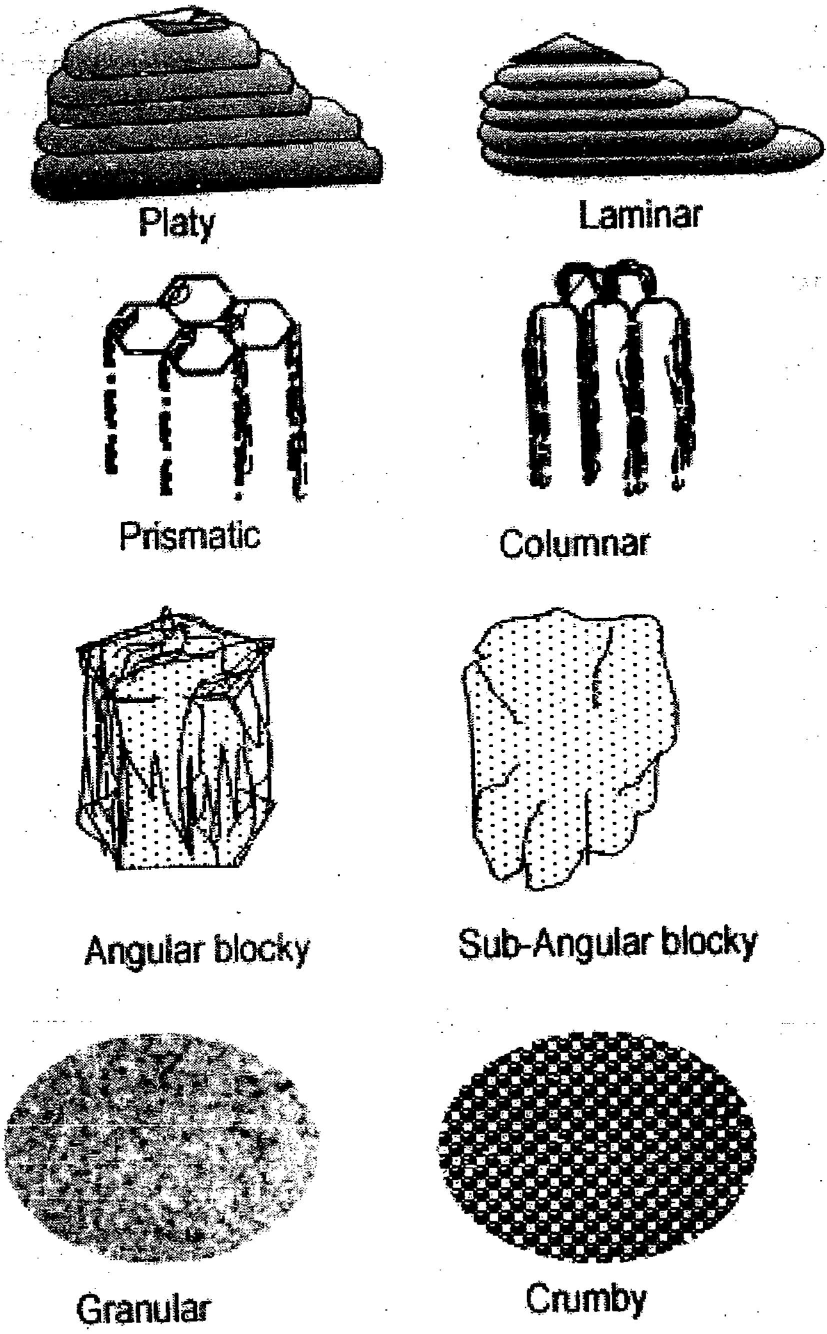


Fig. 7.2. Types of soil structure.

2. Prism-like : The vertical axis is more developed than horizontal, giving a pillar like shape. When the top of such a ped is rounded, the structure is termed as *columnar* and when flat, *prismatic*. They commonly occur in subsoil horizons in arid and semi-arid regions.

3. Block like : All three dimensions are about the same size and the peds are cube-like with flat or rounded faces. When the faces are flat and the edges sharp angular, the structure is named as *angular blocky*. When the faces and edges are mainly rounded it is called *sub-angular blocky*. These types usually are confined to the sub soil and characteristics have much to do with soil drainage, aeration and root penetration.

4. Spheroidal (Sphere like) : All rounded aggregates (peds) may be placed in this category, although the term more properly refers to those not over an inch in diameter. These rounded complexes usually lie loosely and separately (fig. 7.2). When wetted the intervening spaces generally are not closed so readily by swelling as may be the case with a blocky structural condition. Therefore in sphere-like structure infiltration, percolation and aeration are not affected by wetting of soil. The aggregates of this group are usually termed as *granular* which are relatively less porous, when the granules are very porous, the terms used is *crumby*.

Classes of Structure

Each primary structural type of soil is differentiated into 5 size classes depending upon the size of the individual peds. The terms commonly used for the size classes are :

1. Very fine or very thin
2. Fine or thin
3. Medium
4. Coarse or thick
5. 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 Structure

Grades indicate the degree of distinctness of the individual peds. It is determined by the stability of the aggregates. Grade of structure is influenced by the moisture content of the soil. Grade also depends on organic matter, texture etc. Four terms commonly used to describe the grade of soil structure are :

1. Structureless : There are no noticeable peds, such as conditions exhibited by loose sand or a cement-like conditions of some clay soils.

2. Weak Structureless : Indistinct formation of peds, which are not durable.

3. Moderate Structure : Moderately well developed peds, which are fairly durable and distinct.

4. Strong Structure : Very well formed peds, which are quite durable and distinct.

Structure naming : For naming a soil structure the sequence followed is grade, class and type; for example strong coarse angular blocky, moderate thin platy, weak fine prismatic.

Factors Affecting Soil Structure

The development of structure in arable soil depends on the following factors :

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 than arid regions.

2. 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 sticky and slimy material produced by the decomposing organic matter and the associated micro-organism, cement the sand particles together to form aggregates. In case of clayey soil, it modifies the properties of clay by reducing its cohesive power. This helps making clay more crumby.

3. Tillage : Cultivation implements breakdown the large clods into smaller fragments and aggregates. For obtaining good granular and crumby structure, an 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.

4. Plant roots : Large number of granules remain attached to roots and root hairs, which help to develop crumb structure. Plant root secretions may also act as cementing agents in binding the soil particles. The plant roots, on decay, may also bring about granulation due to the production of sticky substances.

5. Soil organism : 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.

6. Fertilizers : Fertilizer like Sodium Nitrate destroys granulation by reducing the stability of aggregates. Few fertilizers for example, Calcium Ammonium Nitrate, help in development of good structures.

7. Wetting and Drying : 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.

Effect of Soil Structure on other Physical Properties of Soil

1. Porosity : Porosity of a soil is easily changed. In plate like structure, pore spaces are less whereas in crumby structure pore spaces are more.

2. Temperature : Crumby structure provides good aeration and percolation of water in the soil. Thus, these characteristics help in keeping optimum temperature in comparison to plate like structure.

3. Density : Bulk density varies with the total pore space present in the soil. Structure chiefly influences pore spaces platy structure with less total pore spaces has high bulk density whereas crumby structure with more total pore spaces has low bulk density.

4. Consistence : Consistence of soil also depends on structure. Plate-like structure exhibits strong plasticity.

5. Colour : Bluish and greenish colours of soil are generally due to poor drainage of soil. Platy structure normally hinders free drainage.

Importance of Structure

Soil structure influences rather indirectly by the formation of an array of pores of various shapes and sizes. These pores are controlling factors governing water, air and temperature in soil. In brief, the role of soil structure in relation to plant growth is given as below :

1. Soil structure influences the amount and nature of porosity.
2. Structure controls the amount of water and air present in the soil. Not only the amount of water and air dependent on soil structure, but their movement and circulation are also controlled by soil structure.
3. It affect tillage practices.
4. Structure controls runoff and erosion.
5. Platy structure normally hinders free drainage whereas sphere like structure (granular and crumby) helps in drainage.
6. Crumby and granular structure provides optimum infiltration, water holding capacity, aeration and drainage. It also provides good habitat for micro-organisms and supply of nutrients.

EXERCISE

Q.1. Select the appropriate word :

1. ______________ properties of soil depend on the amount, size, shape, arrangement and mineral constituents.

(a) Taxonomic (b) Physical

(c) Chemical (d) Biological

2. Relative percent of sand, silt and clay is referred as ____________.

(a) Soil texture (b) Soil structure

(c) Porosity (d) Consistence

3. For all purposes the value of particle density __________ g/cm^3 is accepted.

(a) 1.85 (b) 2.15

(c) 2.65 (d) 2.85

4. The size of clay particles is _______ mm in diameter.

(a) < 2.00 (b) < 0.20

(c) < 0.02 (d) < 0.002

5. Total porosity is highest with ________________.

(a) Course sand (b) Fine sand

(c) Silt (d) Clay

8

Other Physical Properties of Soil

Surface area, density, porosity, colour and consistence of soil.

We have discussed soil texture and structure in previous chapter. This chapter deals with other important soil physical properties.

SURFACE AREA

If two equal volumes are taken, one containing large particles and the other small particles, the surface area of small particles is much greater than the surface area of big particles. This can be very clearly seen from the following case of a particles subdivided into smaller ones. The surface area of a single particle or sphere would fit exactly in a 1cm cube whose volume is 1cc. If the size of the sphere is reduced progressively, the total surface area of the particles will go on increasing as shown in the table below :

Table 8.1: Relation of surface area to particle size.

Diameter of particle (cm)	No. of particles required to fill 1cc cube	Total surface area of Particles (Sq. cm.)
1.0	1	3.1416
0.5	8	6.2832
0.1	1,000	31.4160
0.01	1,000,000	314.1600
0.002	125,000,000	1570.8000
0.001	1,000,000,000	3141.6000
0.0002	125,000,000,000	15708.0000
0.0001	1,000,000,000,000	31416.0000

Table 8.2: Size and surface area of soil particles.

Soil particle	Size (microns)	Surface area*
Gravel	2,000-20,000	0.1-1.0
Coarse sand	600-2,000	1-3.0
Fine sand	60-200	10-30
Silt	2-60	30-1000
Clay	<2	>1000

*Surface area of same volume of different size fractions.

The surface area not only varies with the size of the particles but also with its shape. Clay particles have a flaky or plate like shape. A flake or plate like shape has much greater surface area per unit volume than a sphere. This particular shape of the clay particles still further increases the amount of surface area per unit volume or mass.

On Account of the large surface area exposed, the finer particles are capable of reacting physico-chemically. They possess great surface activity due to which they are able to absorb and hold water and plant food ingredients for the use of plants. The larger the surface area, greater is the surface activity and consequently greater the amount of water and plant nutrients absorbed. Clays and clayey soils, therefore absorb greater quantities of water and food ingredients than sands and sandy soils.

DENSITY OF SOIL

Density represents weight (mass) per unit volume of a substance.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Soil density is expressed in two well accepted concepts as *particle density* and *bulk density*. In the metric system, particle density can be expressed in terms of mega grams per cubic meter (Mg/m^3). Thus, if 1m^3 of soil solids weighs 2.6 Mg, the particle density is 2.6 Mg/m^3 (since 1 Mg = 1million grams and 1m3=1million cubic centimeters) thus particle density can also be expressed as 2.6 g/cm^3.

Particle Density : The weight per unit volume of the solid portion of soil is called particle density. Generally particle density of normal soils is 2.65 grams per cubic centimeter. The particle density is higher if large amount of heavy minerals such as magnetite, limonite and hematite are present in the soil. With increase in organic matter of the soil the particle density decreases. Particle density is also termed as *true density*.

Table 8.3 : Particle density of different soil textural classes.

Textural classes	*Particle density (g/cm^3)*
Coarse sand	*2.655*
Fine sand	*2.659*
Silt	*2.798*
Clay	*2.837*

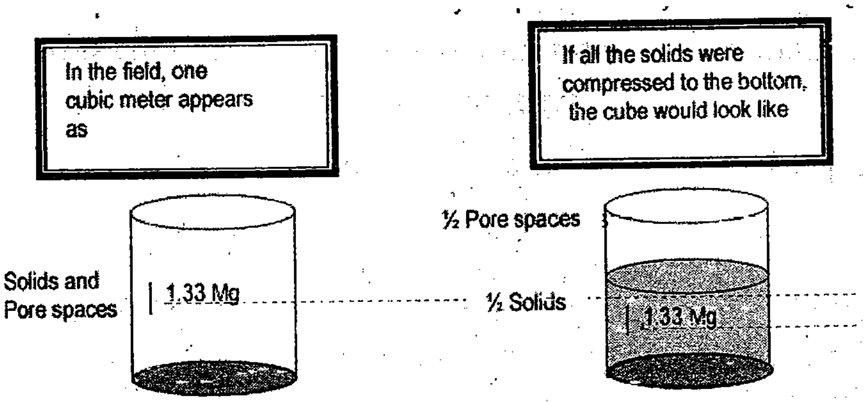
Bulk Density : The oven dry weight of a unit volume of soil inclusive of pore spaces is called bulk density. The bulk density of a soil is always smaller than its particle density. The bulk density of sandy soil is about 1.6 g/cm3., whereas that of organic matter is about 0.5. Bulk density normally decreases, as mineral soils become finer in texture. The bulk density varies indirectly with the total pore space present in the soil and gives a good estimate of the porosity of soil. Bulk density is of greater importance than particle density in understanding the physical behaviour of soils. Generally, soils with low bulk densities have favourable physical conditions.

Bulk density of different soil textural classes is given in Table 8.4.

Table 8.4 : Bulk density of different soil textural classes.

Textural class	Bulk density (g/cc)	Pore space (%)
Sandy soil	*1.6*	*40*
Loam	*1.4*	*47*
Silt loam	*1.3*	*50*
Clay	*1.1*	*58*

The comparative calculations of bulk density and particle density are shown in fig. 8.1.



To calculate bulk density of the soil :

Volume = 1 m³ (solids + pores) Weight = 1.33 Mg (solids only)

$$\text{Bulk density} = \frac{\text{Weight of even dy soil}}{\text{Volume of soil (solids + pores)}}$$

Therefore

$$\text{Bulk density, Db} = \frac{1.33}{1} = 1.33 \text{ Mg / m}^3$$

To calculate solid particle density :

Volume = 0.5 m³ (solds only) Weight = 1.33 Mg (solids only)

$$\text{Solid particle density} = \frac{\text{Weight of solids}}{\text{Volume of solids}}$$

Therefore

$$\text{Solid particle density, Dp} = \frac{1.33}{0.5} = 266 \text{ Mg / m}^3$$

Fig. 8.1: The comparison of bulk density and particle density.

Factors affecting Bulk Density

1. Pore space : Since bulk density relates to the combined volume of the solids and pore spaces, soils with high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. Consequently, any factor that influences soil pore space will affect bulk density.

2. Texture : Fine textured surface soils such as silt loams, clays and clay loams generally have lower bulk densities than sandy soils. This is because the fine textured soils tend to organize in porous grains especially because of adequate organic matter content. This results in high pore space and low bulk density. However, in sandy soils, organic matter content is generally low, the solid particles lie close together and the bulk density is commonly higher than in fine textured soils.

3. Organic Matter Content : More the organic matter content in soil results in high pore space thereby shows lower bulk density of soil and vice-versa.

POROSITY OF SOIL

Pore Space : The volume of soil mass that is not occupied by soil particles is known as *pore space*. The pore space is usually occupied by air and water. In the pore spaces, the plant roots grow and exist. It directly controls the amounts of water and air in the soil and thus indirectly controls plant growth and corp production. Hence, the volume of pore space in soil is a very important factor.

The volume of pore space varies according to the texture, structure and organic matter content of the soil. Soils having big particles contain less pore space than those having small particles do. The following figure (fig. 8.2) shows how the total volume of pore space enclosed between small particles in a cube is greater than enclosed between big particles. In the figure, each sphere having 1 cm diameter has a volume of 0.5238 cc.

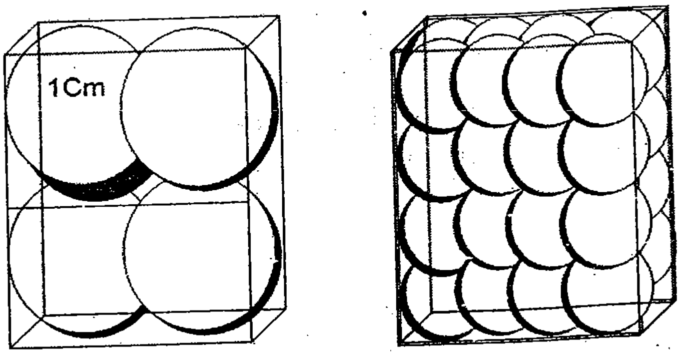


Fig. 8.2. Pore space in coarse-textured and fine-textured soils.

Therefore, the empty space around each sphere is 0.4762 cc. As the space around each sphere is equal to the space between four adjacent sphere (shaded portion), this space, is also 0.4762 cc.

If the diameter of the sphere is reduced to ½ cm, 32 spheres can be accommodated in the same volume as shown in the fig. Keeping the same mode of arrangement in both the cases, by a similar process of calculation, the empty space between the 32 spheres comes to 1.071 cc. Hence, the total volume of pore space enclosed between smaller particles is greater than that between large particles. For similar reason, pore space in clayey soils is greater than in sands and sandy soils.

Size of Pores

The size and shape of pores and pore spaces vary considerably. In general, two sizes are recognised.1. *Macro or non-capillary* and 2. *Micro of capillary pores.*

1. Macro or non-capillary pores: These are the large pores, allow ready movement of air and water and do not hold much water under normal condition. Sands and sandy soils have a large number of macro pores.

2. Micro of capillary pores : In contrast, in the micropores movement of an air and water is restricted to some extent. Clays and clayey soils have a greater number of micropores, than in sands and sandy soils.

Size of individual pores, rather than total pore space in a soil is more significant in its plant growth relationship. For ideal conditions of aeration, permeability, drainage and water retention, a soil should have about an equal amount of macro and micro-pores. The size of pores depends upon the size of particles and the degree of aggregation. Sands and sandy soils have a large number of macro and non-capillary pores, while clays and clayey soils have greater number of small or capillary pores. It is due to the presence of a large number of non-capillary pores that water moves very rapidly in sandy soils, and thereby allows rapid percolation and drainage .On the other hand, in a clay soil water moves slowly as the capillary pores offer great resistance to its movement, there by shows low permeability and poor drainage capacity.

As a soil contains both capillary and non-capillary pores, the proportion of the two sizes of pore space determines the relative amount of water and air in it.

Soil Porosity : Soil porosity is the percentage pore space to total volume of soil. Porosity refers to that percentage of soil volume, which is occupied by pore spaces. It can be calculated by the formula

$$\text{Porosity} = 100 - \left(\frac{\text{Bulk density}}{\text{Particle density}} \times 100\right)$$

OR

$$\left(1 - \frac{BD}{PD}\right) \times 100$$

Since, % pore space + % solid space = 100

Hence, % pore space = 100 – % solid space.

% solid space = 100 – % pore sapce

For example, a soil having bulk density of 1.3 and particle density of 2.65 has the following percentage pore space.

$$\text{Porosiy} = 100 - \left[\frac{1.3}{2.65}\right] \times 100 = 50.94\%$$

OR

$$\left[1 - \frac{1.3}{2.65}\right] \times 100 = 50.94\%$$

Factors Affecting Soil Porosity

Following factors affect the percentage of pore spaces or porosity :

1. Soil Texture : In sandy soils, pores are quite large thus total pore space is less. In fine textured soils there is possibility of more granulation and more total pore space because there are pores (macro) between individual particles and within granules (micro pores). The relationship of soil texture with pore space is given in the table 8.5.

Table 8.5 : Pore Space in relation to soil texture.

Textural class	Clay content (%)	Average pore space (%)
Heavy Clay	*>55*	*51.09*
Clay	*40-55*	*48.45*

Sandy clay loam	20-30	45.45
Sand	<10	42.54

2. Soil Structure : A soil having an aggregate structure has greater pore space than a structureless or single grain soil. For the same size of aggregates as individual grains in a single grain soil and for similar mode of arrangement, a soil having aggregate structure has additional pore space between the primary particles. Granular or Crumby type of structure has more porosity than plate-like.

3. Arrangement of Soil Particle : When the sphere like particles are arranged in columnar form, it gives the most open system of packing. Each particle is in contact with six adjoining particles and they occupy 52 per cent of the total space, leaving 48 per cent unoccupied space. In a soil, however, all particles are not uniform in size. The small particles fit exactly in to the space between large particles, leaving the pore space only 6 per cent. If the smaller particles are packed in unoccupied space again, the pore space is further reduced to only 2 per cent. Thus the number of pore spaces will be less. When the particles are arranged in the pyramidal form it gives the closest system of packing, where each particles touches twelve adjoining particles, the pore space is reduced to 26 per cent. So in this system porosity would be more. Thus, the pore space is independednt of the size of spheres.

4. Organic Matter : Increase in organic matter content in the soil, increase in percentage of pore space.

5. Macro Organism : Macro organism like earthworm and insects increase the macro pores in the soil.

6. Depth of Soil : Pore space in the sub-soil has been found to decrease in comparison to surface soil.

7. Cropping : Cropping tends to lower the total pore space in comparison to virgin or uncropped soils. This reduction is associated with a decrease in organic matter content. Continuous cropping often results in a reduction of large or macro pore spaces.

SOIL COLOUR

The colour of soil varies widely. It is probably the first soil property for the human perception. It is easily observable characteristics and is an important criterion in description and classification of soils.

Even today soil is described by its colour such as black, red and yellow soils. The three variables that combine to give colour are **hue, value** and **chroma.**

- Hue is the dominant spectral colour (rainbow) and is related to wavelength of light.
- Value refers to the relative lightness of colour and is a function of total amount of light.
- Chroma is the relative purity or strength of the spectral colour.

It is rather difficult to quantify soil colour. The present practice is to match colour of a soil with that in **Munsell colour chart.** In the Munsell colour chart, three basic hues are considered viz. red (R) , yellow red (YR) and yellow (Y) preceded by numbers 0 to 10. Increase in the number indicates that the hue becomes more yellow and less red. The notation for value consists of numbers from 0 for absolute black to 10 for absolute white. The extremes are not usually met within soils. The notation for chroma consists of numbers beginning at 0 for neutral grays increasing at equal intervals to 8.

The colour of soil has some relevance to soil constituents viz. organic matter, oxides of iron. Black colour of organic and peat soils is due to organic matter. Under tropical conditions, black soils are rather low in organic matter and the black colour, rather dark grey colour is due to the combination of base status (Na, Ca), humus and montmorillonitic clay mineral. Iron oxides occur in several hydrated and coloured forms, which may impart red to yellow colour to soil.

Colour of a soil is inherited from its parent rock material termed as lithochromic; for example, red soils developed from red sand stone. Often the soil colour is a result of soil forming process and is termed as acquired or *pedochromic.*

(a) Black and dark grey colour : The variations from black to dark grey colour of soil are mainly due to organic matter.

(b) Brown colour : This is the most common soil colour and is due to a mixture of the organic matter and iron oxides.

(c) Red yellow colour : Red colour is associated with unhydrated ferric oxides , whereas yellow colour indicates some degree of hydration.

(d) White colour: Silica and lime generally imparts white colour.

(e) Bluish and Greenish colour : Some of the bluish and greenish colours are due to the presence of ferrous compounds. The reducing condition occurs in ill-drained soil.

(f) Mottling colour : Colour variation or mottling in soils indicates alternating oxidizing and reducing conditions due to fluctuating water table.

SOIL CONSISTENCE

Soil consistence is a term used to describe the resistance of a soil at various moisture contents to mechanical stresses or manipulations. It is a composite expression of those forces of mutual attraction among soil particles that determine the ease with which a soil can be reshaped or ruptured. It is commonly measured by filling and manipulating the soil by hand or by pulling a tillage instrument through it.

Soil consistence represents at varying moisture conditions, the degree and kind of cohesion and adhesion of soil material. *Cohesion* refers to the attraction of substance of like characteristics such as that of one water molecule for another. *Adhesion* is the attraction of unlike materials for example, attraction between soil and water molecule.

Consistence of soil depends on the texture, colloids, structure and especially the moisture content of soil. The consistence of soils is generally described at three soil moisture levels, wet, moist, and dry. The terms used to describe soil consistence at these three moisture levels are shown in the following table 8.6.

Table 8.6 : Terms used to describe the consistence of soils.

	Wet soil		**Moist soil**	**Dry soil**
	Stickness	**Plasticity**		
Increasing coherence	Non sticky	Non plastic	Loose	Loose
	Slightly sticky	Slightly plastic	Very friable	Soft
	Sticky	Plastic	Friable	Slightly hard
	Very Sticky	Very plastic	Firm	Hard
			Very Firm	Very hard
			Extermely Firm	Extremely hard

(i) Consistence when soil is wet : For wet soils (moisture content at field capacity), consistence is described in terms of *stickiness* and *plasticity*.

Stickiness : The quality of adhesion to other objects is called stickiness. The degree of stickiness is identified by the following terms : non sticky, slightly sticky, sticky and very sticky.

Plasticity : Plasticity is the capacity to be moulded or change in shape when stress is applied and after removing the stress it keeps the changed shape. Terms used to describe the degree of plasticity are non-plastic, slightly plastic, plastic and very plastic.

(ii) Consistence when soil is moist : For slightly wet condition of soil (moisture content between air dry and field capacity), consistence is described in the following terms :

Loose : non-coherent
Very friable : coherent but very easily crushed
Friable : easily crushed
Firm : crushed under moderate pressure
Very firm : crushed only under strong pressure
Extremely firm : resists crushing between thumb and forefinger.

(iii) Consistence when soil is dry : For dry condition of soil (air, dry) consistence is characterized by rigidity and hardness. In describing the consistence of dry soils, the following terminology is used :

Loose : Non-coherent
Soft : breaks under slight pressure between thumb and forefinger to a powdery mass.
Slightly hard : breaks under moderate pressure
Hard : breaks with difficulty under pressure
Very hard : very resistant to pressure, cannot be broken between thumb and forefinger.

Extremely hard : extreme resistance to pressure; cannot be broken with the hand.

Soil Consistency

It refers to the attributes of soil material that are expressed by the degree of cohesion and adhesion or by resistance to deformation or rupture. It is expressed with reference to water content of soil. Thus, a soil may be hard when dry, friable when moist and plastic when wet. The cohesive and adhesive forces in soil undergo change with the relative proportions of soil and water. The Swedish agriculturist, Atterberg in 1911, divided the entire cohesive range from the solid to the liquid state into arbitrary limits, called *Atterberg's limit,* in terms of water content of soils.

1. **Liquid limit :** Upper plastic limit. It is the water content above which a mixture of soil and water flow as a viscous liquid and the below which the material is plastic.

2. **Sticky limit :** It is the water content above, which a mixture of soil and water will adhere to a still spatula or other objects, which wets with water.

3. **Plastic limit :** or lower plastic limit . It is the water content at which the soil will start to crumble when rolled into a thread under the palm of the hand.

4. **Shrinkage limit :** It is the lower limit of volume change at which there is no further decrease in volume as water is evaporated. Cohesive soils expand in volume when wetted with water.

Plasticity

It is defined as the property of material which allows it to be deformed rapidly, without rupture, without plastic rebound and without volume change when the material is subjected to an external force.

Thus in term of mass wetness, below the shrinkage limit, the soil is dry and hard. Between the shrinkage limit and the lower plastic limit, the soil is moist and friable ; between the lower plastic limit and the upper plastic limit, the soil is wet and plastic; the sticky limit is just above the upper plastic limit. The difference between the upper plastic limit and lower plastic limit is the *plasticity index.*

EXERCISE

Q.1 Select appropriate word :

1. If the size of the particle reduced the total surface area is ____________.

(a) Decreased (b) Increased

(c) Reduced progressively (d) Remain constant

2. The particles of 0.01 cm in diameter will require ____________ no of particles to fill in 1cc cube.

(a) 100 (b) 1000

(c) 10000 (d) 100,000

3. The __________ particles have greatest surface area among all.

(a) Gravel (b) Sand

(c) Silt (d) Clay

4. _________ particles are most physico-chemically active.
   (a) Clay (b) Silt
   (c) Sand (d) Gravel

5. The presence of minerals such as magnetite, limonite and haematite results is ______ particles density.
   (a) Ordinary (b) Lower
   (c) Higher (d) Minimum

6. The soils of ____________ textural class have lowest particle density.
   (a) Silt (b) Clay
   (c) Coarse sand (d) Fine sand

7. ______ varies indirectly with total pore space and gives indication of porosity of soil.
   (a) Particle density (b) Bulk density
   (c) Surface area (d) Consistence

8. The soil having the bulk density of ___ g/cc will have favourable physical conditions.
   (a) 1.00 (b) 1.25
   (c) 1.50 (d) 1.75

9. The total volume of pore space enclosed between smaller particles is ________ than that between large particles.
   (a) Smaller (b) Greater
   (c) Lower (d) Minimum

10. ____________ in a soil is more significant in its plant growth relationship.
    (a) Size of pores (b) Total pores
    (c) Macro pores (d) Micro pores.

11. ___________ pores offer a great resistance to movement of water in clay soils.
    (a) Noncapillary (b) Dapillary
    (c) Consistence (d) Macro

12. The soil having particle density 2.6 and bulk density 1.3 will have the porosity______ per cent.
    (a) 13 (b) 26
    (c) 50 (d) 52

13. The soils ________ generally have more than 50 per cent pore space.
    (a) Clay (b) Heavy clay
    (c) Sands (d) Sandy clay

14. ___________ is the relative purity or strength of the spectral colour.
    (a) Hue (b) Value
    (c) Chroma (d) Colour

15. The notation for value consists of numbers from 0 to 10 for ______ respectively.
    (a) Absolute white and absolute black
    (b) Absolute black and absolute white
    (c) Absolute red and absolute yellow
    (d) Absolute yellow and absolute red

Q.2 Answer in one sentence :

1. Why clays absorb more water and nutrients than sands ?
2. State the relationship of particle density with organic matter ?
3. What will be the bulk density of soil having 2.66 particle density with 50% porosity ?
4. Why fine textured soils have lower bulk density than coarse textured soils ?

5. Why the clayey soils have more pore space than sandy soil ?
6. Why sandy soils have good drainage capacity?
7. Enlist the factors affecting pore space.
8. What is average pore space % in sandy clay loam soil ?
9. Which type of soil structure has more porosity ?
10. Name the three variables that combine to give colour ?
11. State the three basic hues considered in Munsell colour chart.
12. What is pedochromic character of a soil ?
13. Which constituents in soil impart dark gray colour to the soil ?
14. State the terms used to describe the consistence of wet soils.
15. Name the terms used to identify the degree of stickiness.

Q.3 Define the following terms :

1. Bulk density
2. Particle density
3. Pore space
4. Porosity
5. Soil consistence
6. Plasticity

Q.4 Match the pairs :

1. Red colour of soil	1. In terms of water content of soil
2. Soil consistence	2. Associated with silica and lime
3. Wet soil	3. Lower plastic limit
4. Liquid limit	4. In terms of clay content of soil.
5. Dry soil	5. Relative lightness of colour
6. Plasticity index	6. Very friable
7. Atterberg limits	7. Measured by filling by hand
8. Plastic limit	8. Dominant spectral colour
9. Moist soil	9. Associated with unhydrated ferric oxides
10. Value	10. Extremely hard
	11. Content of sand and clay
	12. Slightly plastic
	13. Upper plastic limit
	14. Difference between upper and lower plastic limits.

9

Soil Air and Soil Temperature

Soil air – Composition, factors affecting, effect on biological activity and plant growth, Soil temperature - importance, absorption and loss of solar energy, movement of heat, control of soil temperature.

This chapter deals with the soil air, its composition, factors affecting and soil temperature, its sources and movement in soil.

SOIL AIR

Soil air is a continuation of the atmospheric air. Unlike the other components, it is constant state of motion from the soil pores into the atmosphere and from the atmosphere into the pore space.

This constant movement or circulation of air in the soil mass resulting in the renewal of its component gases is known as *soil aeration.*

Composition of Soil Air

The soil air contains a number of gases of which nitrogen, oxygen, carbon dioxide and water vapour are the most important. Soil air constantly moves from the soil pores into the atmosphere and from the atmosphere into the pore space. Soil air and atmospheric air differ in the compositions. Soil air contains a much greater proportion of carbon dioxide and a lesser amount of oxygen than atmospheric air. At the same time, soil air contains a far great amount of water vapour than atmospheric air. The amount of nitrogen in soil air is almost the same as in the atmosphere.

Table 9.1 : Composition of soil and atmospheric air.

Air	**Percentage by volume**		
	Nitrogen	**Oxygen**	**Carbon dioxide**
Soil air	79.2	20.6	0.30
Atmospheric air	79.9	20.97	0.03

Factors Affecting the Composition of Soil Air

The composition of soil air is influenced by the number of factors such as nature and condition of soil, type of crop, microbial activity, seasonal variation etc.

1. Nature and Condition of Soil : The quantity of oxygen in soil air is less than that in atmospheric air. The amount of oxygen also depends upon the soil depth. The oxygen content of the air in lower layer is usually less than that of the surface soil. This is possibly due to more readily diffusion of the oxygen from the atmosphere into the surface soil than in the subsoil. Light texture soil or sandy soil contains much higher percentage than heavy soil. The concentration of CO_2 is usually greater in subsoil probably due to more sluggish aeration in lower layer than in the surface soil.

2. Type of Crop : Plant roots require oxygen, which they take from the soil, air and deplete the concentration of oxygen in the soil air. Soils on which crops are grown contain more CO_2 than fallow lands. The amount of CO_2 in usually much greater near the roots of plants than further away. It may be due to respiration by roots.

3. Microbial Activity : The micro-organisms in soil require oxygen for respiration and they take it from the soil air and thus deplete its concentration in the soil air. Decomposition of organic matter produces CO_2 because of increased microbial activity. Hence, soils rich in organic matter contain higher percentage of CO_2.

4. Seasonal Variation : The quantity of oxygen is usually higher in dry season than during the monsoon. Because soils are normally drier during the summer months, opportunity for gaseous exchange is greater during this period. This results in relatively high O_2 and low CO_2 levels. Temperature also influences the CO_2 content in the soil air. High temperature during summer season encourages microorganism activity, which results in higher production of CO_2.

Exchange of Gases between Soil and Atmosphere

The exchange of gases between the soil and the atmosphere is facilitated by two mechanisms :

1. Mass Flow : With every rain or irrigation, a part of the soil air moves out into the atmosphere as it is displaced by the incoming water. As and when moisture is lost by evaporation and transpiration, the atmospheric air enters the soil pores.

The variations in soil temperature cause changes in the temperature of soil air. As the soil air gets heated during the day, it expands, and the expanded air moves out into the atmosphere. On the other hand, when the soil begins to cool, the soil air contracts and the atmospheric air drawn in.

2 Diffusion : Most of the gaseous interchange in soils occurs by diffusion. Atmospheric and soil air contains a number of gases such as nitrogen, oxygen, carbon dioxide etc., each of which exerts its own partial pressure in proportion to its concentration. The movement of each gas is regulated by the partial pressure under which it exists. If the partial pressure on one of the gases (i.e. carbon dioxide) is greater in the soil air than in the atmospheric air, it (CO_2) moves out into the atmosphere. Hence, the concentration of CO_2 is more in soil air. On the other hand partial pressure of oxygen is low in the soil air, as oxygen present in soil air is consumed as a result of biological activities. The oxygen present in the atmospheric air (partial pressure of O_2 is greater), therefore, diffuses into the soil air till an equilibrium is established. Thus, diffusion allows extensive movement and continual change of gases between the soil air and the atmospheric air. Oxygen and carbon dioxide are the two important gases that take in diffusion.

Importance of Soil Aeration

The role of soil air in relation to fertility of soil and plant growth is given below :

1. Plant and Root Growth : Soil aeration is an important factor in the normal growth of plants. The supply of oxygen to roots in adequate quantities and the removal of CO_2 from the soil atmosphere are very essential for healthy plant growth. When the supply of oxygen is inadequate, the plant growth either retards or ceases completely as the accumulated CO_2 hampers the growth of plant roots.

The abnormal effect of insufficient aeration on root development is most noticeable on the root crops such as carrot and sugarbeets. Abnormally shaped roots of these plants are common on the compact and poorly aerated soils. The penetration and development of root are poor. Such undeveloped root system cannot absorb sufficient moisture and nutrients from the soil.

2. Microorganism Population and Activity : The micro-organisms living in the soil also require oxygen for respiration and metabolism. Some of the important microbial activities such as the decomposition of organic matter, nitrification, sulphur oxidation etc., depend upon oxygen present in the soil air. The deficiency of air (oxygen) in soil slows down the rate of microbial activity. For example, the decomposition of organic matter is retarded and nitrification arrested. The micro-organism population is also drastically affected by poor aeration.

3. Formation of Toxic Material : Poor aeration results in the development of toxin and other injurious substances such as ferrous oxide, H_2S gas, CO_2 gas etc. in the soil.

4. Water and Nutrient Absorption : A deficiency of oxygen has been found to check the nutrient and water absorption by plants. The energy of respiration is utilized in absorption of water and nutrients. Under poor aeration condition (this condition may arise when soil is waterlogged), plants exhibit water and nutrient deficiency.

5. Development of Plant Diseases : Insufficient aeration of the soil also lead to the development of diseases. For example, *wilt of arhar and gram, dieback of citrus and peach.*

SOIL TEMPERATURE

Agriculture is the exploitation of solar energy in presence of water and nutrients for plant growth. The solar energy is the main source of heat for soil, which determines the thermal regime of soil and growth of plants.

Sources of Soil Heat

The sources of soil heat are solar radiation, conduction, biological and chemical reactions and rain.

1. Solar Radiation : The main source of soil heat is the energy of sun's rays (radiant energy) that reach the earth after they pass through the atmosphere. The exposure of the earth to the heat of the sun warms the surface of the soil on which the rays fall.

2. Conduction : The interior of the earth is very hot hence, the conduction of this heat to the soil is very slow. Generally during night the surface soil becomes cooler than sub-surface soil (sub-soil). Thus heat flows from sub-soil (warmer layers) to surface soil (cooler layer).

3. Biological and Chemical Reaction : Some amount of heat is liberated during the chemical and biological process taking place in soil.

4. Rain : The occurrence of warm rain during the winter months may raise the temperature of the soil.

Absorption and Loss of Solar Energy

Solar energy is primary source of energy to heat soils. But clouds and dust particles intercept the sun's rays and absorb, scatter, or reflect most of their energy. Only about 35-40 % of the solar radiation actually reaches the earth in cloudy humid regions and 75% in cloud-free arid areas. The global average is about 50%.

Out of the total solar energy reaching the earth, most of it is primarily used to evaporate water from the soil or from the leaf surfaces or radiated or reflected back to the sky. Thus only about 10% is absorbed by the soil and can be used to warm it.

Factors affecting absorption of heat : In addition to solar radiation following factors influence the amount of energy absorbed by soil.

1. Colour : Dark coloured soils absorb more energy than lighter coloured soils. This does not mean that dark soils are always warmer. In fact, dark soil usually are rich in organic matter and hold large amount of water, which requires comparatively more energy to be warmed.

2. Slope : If the incoming path of the rays is perpendicular to the soil surface energy absorption is greater than to the sloping surface, receiving the rays.

3. Vegetative Cover : Bare soils warm up more quickly and cool off more rapidly than those covered with vegetation.

Loss of Soil Heat

1. Radiation : They quantity of heat so absorbed by the soil does not remain constant. A part is lost to the air by radiation.

2. Conduction : Some heat transmitted to lower layers of soil by conduction.

3. Evaporation : In the process of evaporation of soil water a large amount of heat is used. This results in a cooling effect especially at the surface.

4. Rain : During summer months, generally rain has a cooling action in soil, because rains usually have a lower temperature than soil.

Movement of Soil Heat and Temperature Changes

Movement : The movement or transfer of heat in soil takes place mainly by conduction. The heat absorbed by the surface soil penetrates into the lower layers and thus heats up the soil profile. During the day, the heat moves downwards as the temperature at the surface is greater than at the lower layers. At night it moves in the reverse direction, i.e., upward, towards the surface, as the surface soil is cooler than the lower layers. The changes in soil temperature are affected due to diurnal and seasonal variation

Diurnal Variation : The diurnal changes in soil temperature depends upon the intensity of solar radiation received at the surface, the loss of heat by radiation and convection, and the rapidity with which heat is conducted to lower layers. Heat moves downward during day time when the surface soil is more hot and upward to the surface at night when the lower layers are hotter. Thus, there is an alternate or diurnal rise and fall in soil temperature with the rising and setting of the sun.

Temperature variation is the greatest in the surface layer and the least at 20 cm depth. The lower layers do not suffer to a great variation as the surface soil that is directly exposed to the sun's radiation. The soil temperature remains practically constant throughout the 24 hours at a depth of about 1 meter.

Seasonal Variation : Temperature changes are associated with the seasonal variations in insulation and the moisture content of the soil.

There is a close similarity between the variation in soil temperature, more especially of the surface soil, and the variations in air temperature. During the cold months of December and January when the air temperatures are low, the soil temperatures are also low. There after soil temperature reaches its highest point in March and the night temperature in May. With the advent of the monsoon in June there is a rapid fall of temperature. It remains more or less constant at this low temperature throughout the rainy season.

The lowest layer of soil behaves differently at different seasons. The night temperatures at 15 cm And 30 cm. depth, as indicated by the morning readings are greater than those of the surface soil throughout the year.

Control of Soil Temperature

Regulation of soil temperature is possible up to a some extent, under field condition by following ways :

1. Moisture : The waterlogged soil has a low temperature. The only way to increase the temperature of such soils is to remove excess water by providing suitable drainage. The removal of excess water lowers its specific heat and thus increases the temperature. Increase in the air content of the soil also helps to increase the soil temperature by lowering the specific heat.

2. Colour : Altering the soil colour can modify the temperature of surface soil. A black substance like charcoal powder when spread on the surface of the soil increases its temperature as it allows less reflection and hence a greater absorption of heat.

3. Straw Mulch : Application of straw mulch can also regulate soil temperature. During the daytime, mulch keeps the surface soil cooler by intercepting sun rays. At night however, it keeps the soil warmer by cutting off the outgoing radiation.

4. Vegetation : Vegetation and mulch keep the soil temperatures low. The shade helps in protecting young seedlings and shallow rooted crops such as tea, coffee and tobacco etc., from the intense heat during summer.

5. Irrigation : Use of irrigation water also lowers the soil temperature and protects the crop from dry spells. Spreading a thin layer of a white substance like chalk lowers the temperature by reflecting much of the incoming radiant energy.

Factors Affecting Soil Temperature

1. Soil Texture : Sandy soils generally warm up quicker than clayey or fine-grained soils. A fine grained soils carry a large amount of water and for this reason also slow to warm. Soil moisture is the most vital controlling factor in soil temperature. Specific heat is the amount of heat required to raise the temperature of one gram of a substance by 1°C. The specific heat of dry soil is less than moist soil. Hence, moist soils are cooler than dry soils.

2. Soil Structure : Soil structure also affects soil temperature by controlling the pore space. Soils having good structure (granular or crumby) warm up more rapidly because there is no water logging.

3. Soil Composition : The soil is composed partly of mineral matter and partly organic. The specific heat of mineral substances is less than that of organic materials (specific heat of iron is 0.11 whereas of humus is 0.44). Hence, mineral soils get heated more readily than organic soils.

4. Soil Colour : Dark coloured soil usually warm up more readily than light coloured soils. As they possess a greater capacity for absorbing the sun's heat.

5. Soil Moisture : Specific heat of water is high than soil. Moist soils have a higher specific heat than dry soils. The evaporation of water rather helps to lower the temperature of a moist soil. Moist soil gets heated more slowly.

6. Slope of the Land : The topography of the land, more particularly the ground slope, also affects the temperature of the soil.

7. Vegetative Cover : Soils that are covered with vegetation absorb less heat than those that are bare. Vegetation acts as an interceptor and retards the warming of the soil surface.

On the other hand, plant cover prevents the soil from getting cool as it retards the loss of heat. Hence, soils carrying a dense plant cover are cooler in summer and warmer in winter than unprotected soils. Bare soils cool off more rapidly than those covered with vegetation.

8. Climate : Climate has a great effect on soil temperature. Soils in temperate (cool) regions are cooler than those in tropical (warm) regions

9. Season : Soil temperature varies with different seasons of the year. It is noticed that there is a close similarity between the variation in soil temperature, more especially of the surface soil and the variations in air temperature. During the cold months of December and January when the air temperatures are low, the soil temperature is also low. The temperature of the surface soil is always higher than the air temperature.

Effects of Soil Temperature on Soil and Plant Growth

The following effects of soil temperature on fertility of soil and plant growth are observed.

1. Soil Micro-organism : A certain amount of heat is necessary for the proper functioning of micro-organism in the soil. Soil temperature controls the rate of microbiological processes involved in mineralization of nitrogen, decomposition of organic matter, nitrogen-fixation etc. There is lowest microbiological activity where soil temperature is below 5°C and above 54°C. Optimum temperature for microbiological activity is in between 25-35°C.

2. Decomposition of Soil Organic Matter : Organic matter decomposition depends on microbial processes and micro-organism activity. Higher the temperature, more rapid is the decomposition.

3. Absorption of Soil Water : Very low and very high temperature affects the absorption of soil water by the roots of plant

4. Nutrient Availability : Soil temperature influences the various chemical reactions that take place in the soil. The solubility of food nutrients and their availability are considerably influenced by soil temperature.

5. Seed Germination : Soil temperature is one of the important factors that influence germination of seeds. The temperatures at which different seeds germinate are different. If the temperature is too low, the seed fails to germinate or germinate very slowly. If it is too high it may be injured.

6. Plant Growth : The growing plant requires a certain amount of heat right from the seed germination upto the stage where the plant reaches maturity. During plant growth physiological processes are influenced by temperature

7. Soil Formation : Process of weathering and soil development is accelerated where there is an increase in soil-temperature.

8. Physical Properties : Soil temperature indirectly influences soil structure.

9. Plant Diseases : Development of plant diseases are also related with soil temperature.

EXERCISE

Q.1 Select the appropriate word :

1. The soil air contains much greater proportion of ________ than atmospheric air.

(a) Nitrogen (b) Carbon dioxide

(c) Oxygen (d) Hydrogen

2. The concentration of CO_2 in subsoil is usually grater probably due to ________ in lower layers than in the surface soil.

(a) More sluggish aeration (b) Poor conduction

(c) Lower diffusion (d) Fast aeration

3. Decomposition of organic matter produces CO_2 because of increased ________.

(a) Root respiration (b) Microbial activity

(c) Supply of CO_2 from atmospheric Air (d) Diffusion of CO_2

4. ______________ allows extensive movement and continual change of gases between the soil air and the atmospheric air.
(a) Mass flow (b) Conduction
(c) Diffusion (d) Precipitation

5. Abnormally shaped roots of crops such as carrot and sugarbeets on the compact soil is due to ______________.
(a) Insufficient aeration (b) Inadequate water
(c) Poor texture (d) Poor structure

6. Poor aeration results in the development of injurious substances such as _____.
(a) O and CO_2 (b) O and H_2S
(c) H_2S and CO_2 (d) CO_2 and H

7. The interior of the heat flow from sub soil to surface soil is known as _________.
(a) Movement of heat (b) Conduction
(c) Diffusion (d) Transfer of heat

8. The global average of solar energy reaching the earth surface is ______
(a) 25% (b) 35%
(c) 50% (d) 65%

9. Dark coloured soils absorb more energy than lighter coloured soils. This ______ that they are always warmer.
(a) Does not mean (b) Does mean
(c) Will mean (d) Will not mean

10. If the path of the rays is perpendicular to the soil surface energy absorption is___ than to the sloping surface.
(a) Lower (b) Smaller
(c) Greater (d) Bigger

11. The movement of soil heat takes place mainly by _________
(a) Diffusion (b) Conduction
(c) Mass flow (d) Diurnal variation

12. There is an alternate ____________ in soil temperature with the rising and setting of the sun.
(a) Seasonal and diurnal (b) Rise and fall
(c) Diffusion (d) Alteration

13. The soil temperature remains practically constant throughout the 24hrs at a depth of about ___________ cm.
(a) 50 (b) 100
(c) 150 (d) 200

14. The soil temperature at a depth of about 30 cm is always _________ than surface soil throughout the year.
(a) Smaller (b) Bigger
(c) Greater (d) Lower

15. The removal of excess water from soil lowers its _________ and thus increases the soil temperature.
(a) Specific area (b) Specific temperature
(c) Specific heat (d) Specific flow

16. The specific heat of humus is ____________
(a) 0.11 (b) 0.22
(c) 0.33 (d) 0.44

17. Because of less specific heat of mineral substances ________ soils get heated more readily than organic soils,

(a) Organic (b) Peat
(c) Marshy (d) Mineral

Q.2 Define the following terms :

1. Mass flow
2. Soil aeration
3. Diffusion
4. Movement of heat.

Q.3 Write to the point :

1. Enlist the factors affecting composition of soil air.
2. Why the oxygen content in sub soil air is less than surface soil ?
3. Why the CO_2 content in the rhizosphere is higher than further away ?
4. Why the soils rich inorganic matter contain high CO_2 ?
5. In summer season, why the soil air contains more CO_2 ?
6. State the three microbial process retarded due to deficiency of air in soil?
7. Name the two plant diseases developed due to insufficient aeration.
8. What are the four sources of soil heat ?
9. What is the per cent of solar energy absorbed by the soil to warm ?
10. State the factors affecting absorption of heat .
11. Why dark coloured soils require comparatively more energy to be warmed ?
12. State the ways of losses of soil heat.
13. Enlist the ways controlling soil temperature.
14. How soil colour controls soil temperature ?
15. Enlist the factors affecting soil temperature.
16. Why fine grained soils are slow to warm ?

Q.4 Match the pairs :

1. Mulch
2. Waterlogged soil
3. White soil
4. Dry soil
5. Vegetative cover
6. Tropical region
7. Surface soil
8. Optimum temp. for microbial activity
9. Soil temperature
10. Conduction

1. Reflect much of the radiant energy
2. Higher temperature than atmosphere
3. Low specific heat
4. Soils are warmer
5. Controls the rate of microbial processes.
6. 25–35°C
7. Intercepts sunrays
8. Source of heat
9. Absorption of heat
10. High specific heat
11. 54°C
12. Absorb much of solar energy
13. Low temperature than atmosphere
14. Mass flow
15. Chemical and biological reactions.

10

Soil Colloids

Soil colloids, properties of soil colloids, types of soil colloids, structure and properties of silicate clay minerals, sesquioxide clay minerals, allophanes, humus.

The colloidal state refers to a two-phase system in which one material in a very finely divided state is dispersed through second phase. The examples are : Solid in liquid–Clay in water (dispersion of clay in water), Liquid in gas—Fog or clouds in atmosphere.

The clay fraction of the soil contains particles less than 0.002 mm in size. Particles less than 0.001 mm size possess colloidal properties and are known as **soil colloids.**

General Properties of Soil Colloids

1. Size : The most important common property of inorganic and organic colloids is their extremely small size. They are too small to be seen with an ordinary light microscope. Only with an electron microscope they can be photographed. Most are smaller than 2 micrometers in diameter.

2. Surface Area : Because of their small size, all soil colloids expose a large external surface per unit mass. The external surface area of 1 g of colloidal clay is at least 1000 times that of 1 g of coarse sand. Some colloids, especially certain silicate clays, have extensive internal surfaces as well. These internal surfaces occur 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.

3. Surface Charges : Soil colloidal surfaces, both external and internal, characteristically carry negative and/or positive charges. For most soil colloids, electronegative charges predominate. Soil colloids both organic and inorganic when suspended in water, carry a negative electric 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. The magnitude of the charge also known as *zeta potential*. Although some mineral colloids in very acid soils have a net electropositive charge. The presence and intensity of the particle charge influence the attraction and repulsion of the particles towards each other, thereby influencing both physical and chemical properties.

The negative electrical charge on clays comes from i) Ionizable hydrogen ions and ii) Isomorphous substitution.

(i) Ionizable Hydrogen Ions : Ionizable hydrogen ions are hydrogens from hydroxyl ions on clay surfaces. The –Al–OH or –Si–OH portion of the clay ionizes the H and leaves an unneutralized negative charge on the oxygen (–Al–O- or –Si–O-). The extent of ionized hydrogen depends on solution pH; more ionization occurs in more alkaline (basic) solutions.

(ii) Isomorphous Substitution : The second source of charge on clay particles, is due to the substitution of one ion for another of similar size and often with lower positive valence. In clay structures, certain ions fit into certain mineral lattice sites because of their convenient size and charge. Dominantly, clays have Si^{4+} in tetrahedral sites and Al^{3+} in octahedral sites. Other ions present in large amounts during clay crystallization can replace some of the Al^{3+} and Si^{4+} cations. Substitutions that are common are the Si^{4+} replaced by Al^{3+}, and even more extensive replacement of Al^{3+} by one or more of these : Fe^{3+}, Fe^{2+}, Mg^{2+}, or Zn^{2+}. Notice that most substitutions are by ions with lower charge (less positive) than the ones being replaced. Since the total negative charge from the anions (the oxygens) remains unchanged, the lower positive charge because of substitution results in an excess negative charge at that location in the structure.

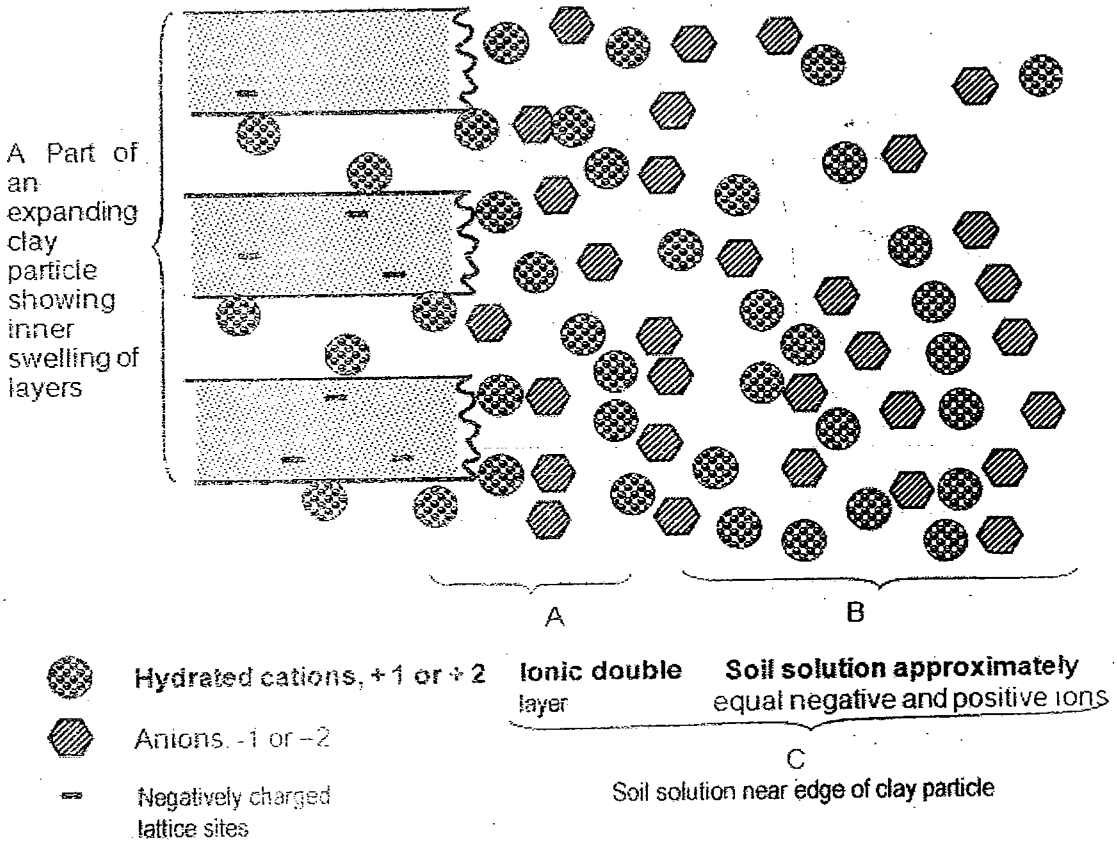


Fig. 10.1 : Illustration of the movement, mostly of cations, to the surfaces of outer and interlayer of clay particle.

4. Adsorption of Cations : As soil colloids possess negative charge they attract the ions of an opposite charge to the colloidal surfaces. They attract hundreds of positively charged ions or cation such as H^+, Al^{3+}, Ca^{2+}, and Mg^{2+}. This gives rise to an **ionic double layer** (Fig. 10.1).

The process, called isomorphous substitution and the colloidal particle constitutes the inner ionic layer, being essentially huge anions, with both, external and internal layers that are negative in charge. The outer layer is made up of a swarm of rather loosely held (adsorbed) cations attracted to the negatively charged surfaces. Thus a colloidal particle is accompanied by a swarm of cations that are adsorbed or held on the particle surfaces.

5. Adsorption of Water : In addition to the adsorbed cations, a large number of water molecules are associated with soil colloidal particles. Some are attracted to the adsorbed cations, each of which is hydrated. Others are held in the internal surfaces of the colloidal particles. These water molecules play a critical role in determining both the physical and chemical properties of soil.

6. Cohesion : Cohesion is the phenomenon of sticking together of colloidal particles that are of similar nature. Cohesion indicates the tendency of clay particles to stick together. This tendency is due primarily to the attraction of the clay particles for the water molecules held between them. When colloidal substances are wetted, water first adheres to the particles and then brings about cohesion between two or more adjacent colloidal particles. Hydrogen bonding between clay surfaces and water and also among water molecules is the attractive force responsible for the cohesion. It accounts for the presence of hard clods in some soils that resist being broken down even with repeated tillage.

7. Adhesion : Adhesion refers to the phenomenon of colloidal particles sticking to other substances. It is the sticking of colloidal materials to the surface of any other body or substance with which it comes in contact. When clay particles envelope sand particles or when they stick to the moldboard of a plough they do so under the force of adhesion.

8. Swelling and Shrinkage : Some clays (soil colloids) such as smectites swell when wet and shrink when dry. After a prolonged dry spell, soils high in smectites (e.g.. Vertisols) often are crises-crossed by wide, deep cracks, which at first allow rain to penetrate rapidly. Later, because of swelling, such soil is likely to close up and become much more impervious than one dominated by kaolinite, chlorite or fine-grained micas. Vermiculite is intermediate in its swelling and shrinking characteristics.

9. Dispersion and Flocculation : As long as the colloidal particles remain 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 flocs or loose aggregates, and settle out. This phenomenon of coalescence and formation of flocs is known as *flocculation*. The reverse process of the breaking up of flocs into individual particles is known as *deflocculation* 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. The smaller the particle, the more rapid is its movement. The Brownian movement is mainly responsible for the *coagulation or flocculation* of colloidal particles.

11. Non Permeability : Colloids, as opposed to crystalloid, 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.

Types of Soil Colloids

There are four major types of colloids present in soil

1. Layer silicate clays
2. Iron and aluminium oxide clays (sesquioxide clays)
3. Allophane and associated amorphous clays
4. Humus.

Layer silicate clays, iron and aluminium oxide clays, allophane and associated amorphous clays are *inorganic colloids* while humus is an organic colloid.

1. Layer Silicate clays : These are most important silicate clays and are known as *phyllosilicates* (Gr. Phyllon, leaf) because of their leaf-like or platelike structure. They are comprised of two kinds of horizontal sheets, one dominated by silicon and other by aluminium and/or magnesium. The basic structure of silica tretrahedron and aluminium octahedran is explained below.

Silica Tretrahedron : The basic building block for the silica-dominated sheet is a unit composed of one silicon atom surrounded by four oxygen atoms. It is called the silica tetrahedron because of its four-sided configuration (fig.10.2a). An interlocking array or a series of these silica tetrahedra tied together horizontally by shared oxygen anions gives a tetrahedral sheet.

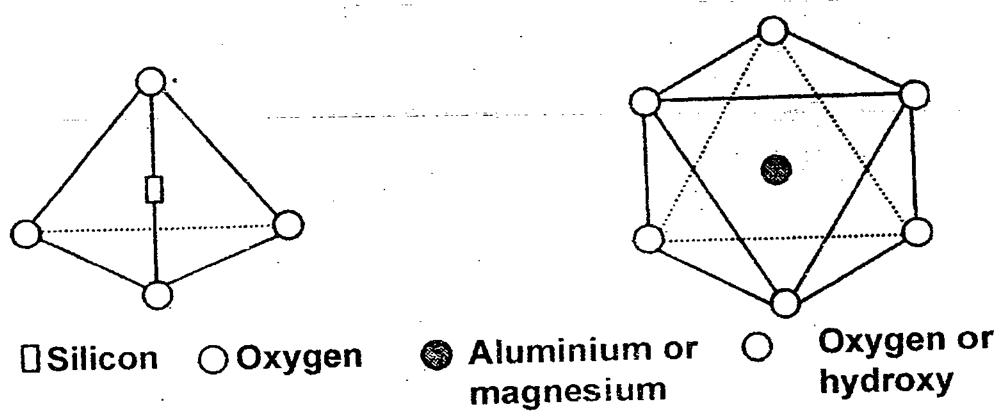


Fig. 10.2 (a) : Silica tetrahedron and (b) aluminium octahedron.

Alumina-Magnesia Octahedron : Aluminium and/or magnesium ions are the key cations in the second type of sheet. An aluminium (or magnesium) ion surrounded by six oxygen atoms or hydroxyl group gives an eight-sided building block termed octahedron (figure10.2b). Numerous Octahedra linked together horizontally comprise the octahedral sheet. An aluminium-dominated sheet is known as a *dioctahedral sheet,* whereas one dominated by magnesium is called a *trioctahedral sheet.* The distinction is due to the fact that two aluminium ions in a dioctahedral sheet satisfy the same negative charge from surrounding oxygen and hydroxyls as three magnesium ions in a trioctahedral sheet. As will be seen later, numerous intergrades occur where both cations are present.

The tetrahedral and octahedral sheets are the fundamental structural units of silicate clays. They, in turn, are bound together within the crystals by shared oxygen atoms into different layers. The specific nature and combination of sheets in these layers vary from one type of clay to another and largely control the physical and chemical properties of each clay. The relationship between sheets and layers shown in Figure 10.3 is important and should be well understood.

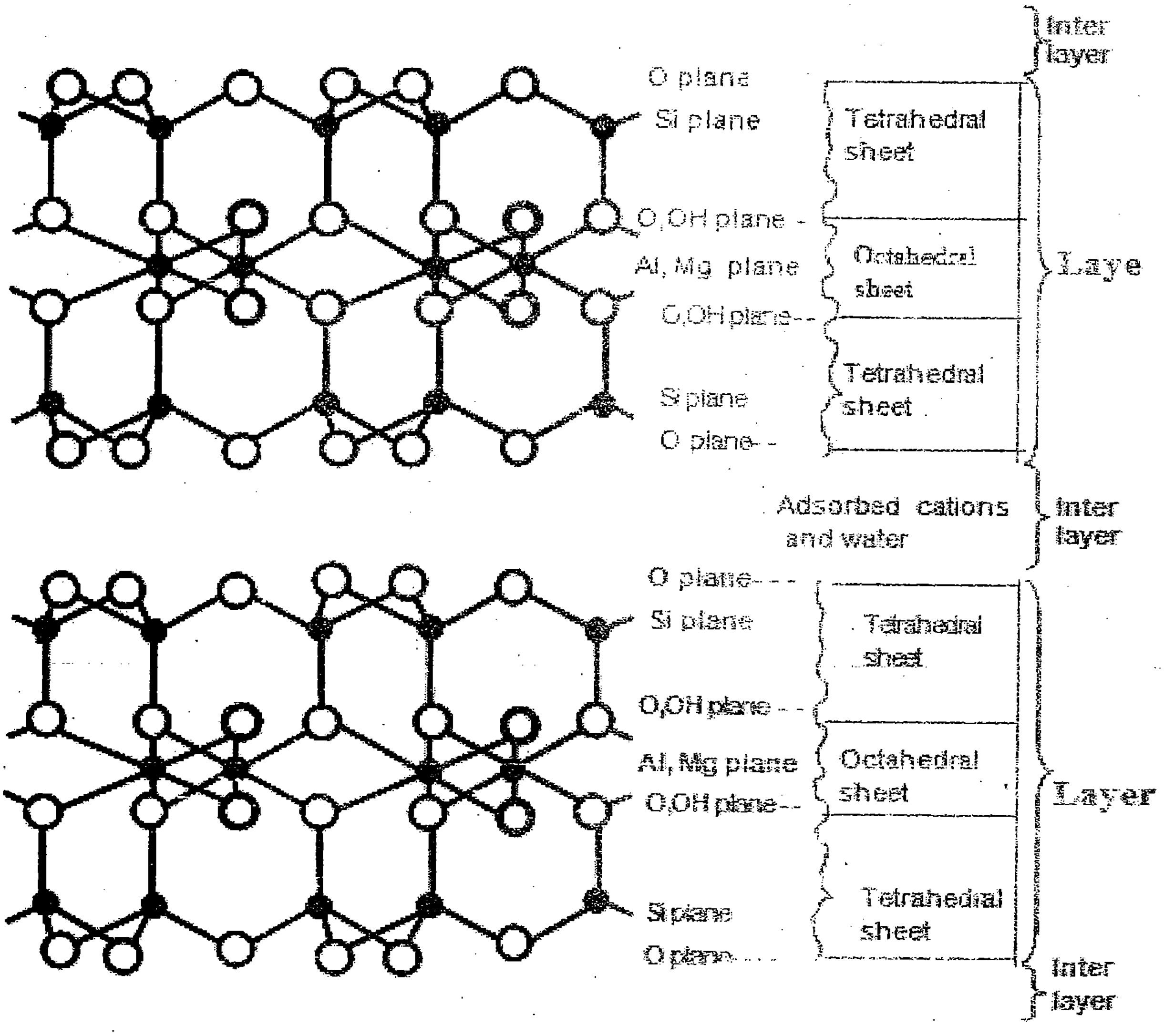


Fig. 10.3 : Basic molecular and structural components of silicate clays (crystal or micelle).

Types of Silicate Clay Minerals

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

1:1 Type clay minerals

2:1 Type clay minerals

2:1:1 Type clay minerals.

1:1 Type Minerals : The layers of the 1:1-type minerals are made up of one tetrahedral (silica) sheet combined with one octahedral (alumina) sheet-hence the terminology 1:1-type crystal (figure 10.4). In soils, kaolinite is the most prominent member of this group, which includes hallosite, nacrite and dickite.

The tetrahedral and octahedral sheets in a layer of a kaolinite crystal are held together tightly by oxygen atoms, 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 thus restricted to its outer faces or to its external surface area. Also, there is little isomorphous substitution in this 1:1-type mineral. Along with the relatively low surface area of kaolinite, this accounts for its low capacity to adsorb cations.

Kaolinite crystals usually are hexagonal in shape. In comparison with other clay particles, they are large in size, ranging from 0.10 to 5 mm across with the mejority falling within the 0.2 to 2 mm range. 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 (capability of being molded), cohesion, shrinkage, and swelling. Its restricted surface and limited adsorptive capacity for cations and water molecules suggest that kaolinite does not exhibit colloidal properties of a high order of intensity.

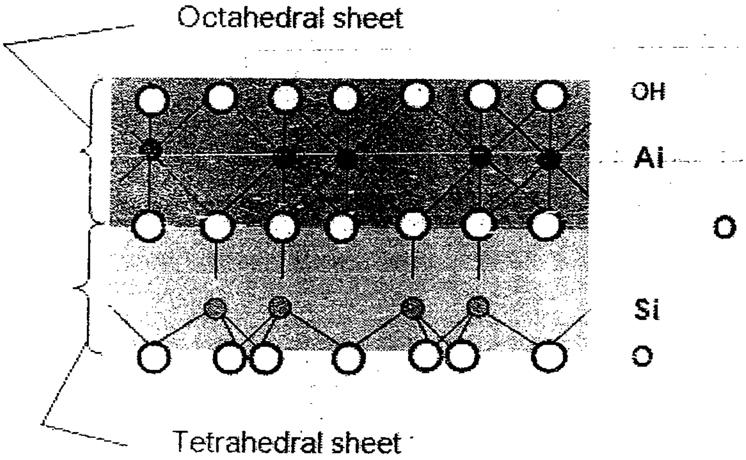


Fig. 10.4 : The 1 : 1 type clay kaolinite.

2:1. Type Minerals : 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, include *expanding-type* minerals, while the third, fine grained micas (illite), is relatively *non-expanding*.

Expanding Minerals : The smectite group is noted for interlayer expansion, which occurs by swelling when the minerals are wetted, the water entering the interlayer space and forcing the layers apart. *Montmorillonite* is the most prominent member of this group in soils, although beidellite, nontronite, and saponite are also found.

The flake-like crystals of smectites (e.g., Montmorillonite) are composed of a expanding lattice 2:1-type clay mineral. Each layer is made up of an octahedral sheet sandwiched between two tetrahedral (silica) sheets (figure10.5). There is little attraction between oxygen atoms in the bottom tetrahedral sheet of one unit and those in the top tetrahedral sheet of another. This permits a ready and variable space between layers, which is occupied by water and exchangeable cations. This internal surface far exceeds the surface around the outside of the crystal. In montmorillonite magnesium has replaced aluminium in some sites of the octahedral sheet. Likewise, some silicon atoms in the tetrahedral sheet may be replaced by aluminium. These substitutions give rise to a *negative charge*.

These minerals show high cation exchange capacity, marked swelling and shrinkage properties. Wide cracks commonly form as smectite-dominated soils (e.g., Vertisols) are dried. The dry aggregates or clods are very hard, making such soils difficult to till.

Vermiculites are also 2:1-type minerals in that an octahedral sheet occurs between two tetrahedral sheets. In most soils vermiculites, the octahedral sheet is aluminium-dominated (dioctahedral), although magnesium dominated (trioctahedral) vermiculites are also common. In the tetrahedral sheet of most vermiculites, considerable substitution of aluminium for silicon has taken place. This accounts for most of the very high net negative charge associated with these minerals.

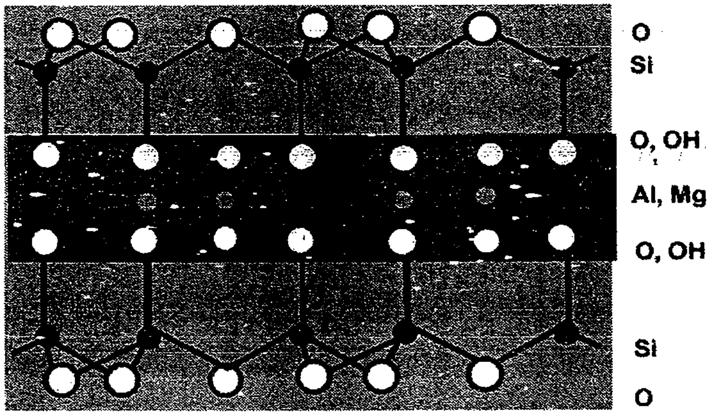


Fig. 10.5 : The 2 : 1 type clay mineral (montmorillonite)

Water molecules, along with magnesium and other ions, are strongly adsorbed in the interlayer space of vermiculites. However, they act primarily as bridges holding the units together rather than as wedges driving them apart. The degree of swelling is, therefore considerable less for vermiculites than for smectites. For this reason, vermiculites are considered *limited-expansion* clay minerals, expanding more than kaolinite but much less than the smectites.

The cation exchange capacity of vermiculites usually exceeds that of all other silicate clays, including montmorillonite and other smectites, because of the very high negative charge in the tetrahedral sheet. Vermiculite crystals are larger than those of the smectites but much smaller than those of kaolinite.

Non-expanding minerals : Micas are the type minerals in this group. Muscovite and biotite are examples of unweathered micas often found in the sand and silt separates. Weathered minerals similar in structure to these micas are found in the clay fraction of soils. They are called fine-grained micas.

Like smectites, fine-grained micas have a 2:1-type crystal. However, the particles are much larger than those of the smectites. Also, the major source of charge is in the tetrahedral sheet where aluminium atoms occupy about 20% of the silicon sites. This results in a high net negative charge in the tetrahedral sheet, even higher than that found in vermiculites. To satisfy this charge, potassium ions are strongly attracted in the interlayer space and are just the right size to fit snugly into certain spaces in the adjoining tetrahedral sheets. The potassium thereby acts as a binding agent, preventing expansion of the crystal. Hence, fine-grained micas are quite non- expansive.

The properties such as hydration, cation adsorption, swelling, shrinkage, and plasticity are much less intense in fine-grained micas than in smectites. The fine-grained micas exceed kaolinite with respect to these characteristics, but this may be due in part to the presence of interstratified layers of smectite or vermiculite. In size, too, fine-grained mica crystals are intermediate between the smectities and kaolinites. Their specific surface area varies from 70 to 100 m2/g, about one eighth that for the smectites.

2:1:1 Type Minerals : This silicate group is represented by chlorites, which are common in a variety of soils. Chlorites are basically iron-magnesium silicates with some aluminium present. In a typical chlorite clay crystal, 2:1 layers, such as are found in vermiculites, alternate with a magnesium-dominated trioctahedral sheet, giving a 2:1:1 ratio (figure10.6). Magnesium also dominates the trioctahedral sheet in the 2:1 layer of chlorites. Thus, the crystal unit contains two silica tetrahedral sheets and two magnesium-dominated trioctahedral sheets, giving rise to the term 2:1:1or 2:2-type structure.

The negative charge of chlorites is about the same as that of fine-grained micas and considerably less than that of the smectites or vermiculites. Like fine micas, chlorites may be interstratified with vermiculites or smectites in a single crystal. Particle size and surface area for chlorites are also about the same as for fine grained

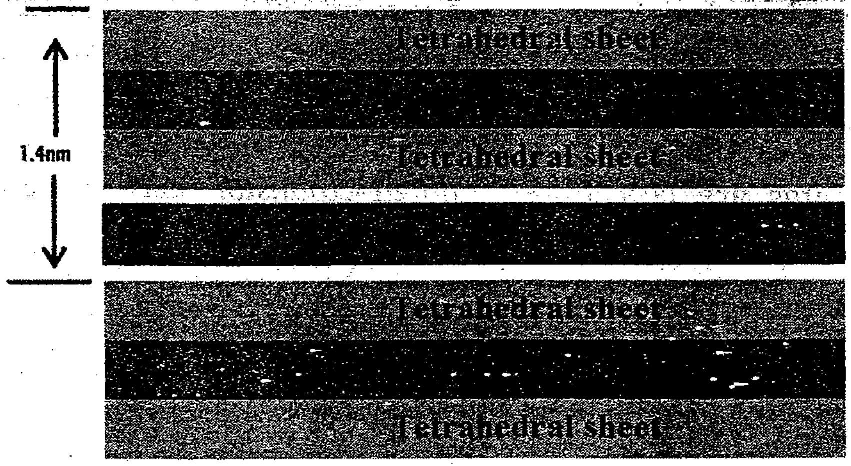


Fig. 10.6 : The 2 : 1 : 1 Type mineral, chlorite.

micas. There is no water adsorption between the chlorite crystal units, which accounts for the nonexpansive 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 of the well-defined minerals described. 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 "fine-grained mica-smectite" are used to describe mixed-layer minerals. In some soils, they are more common than single-structured minerals such as montmorillonite.

1. Iron and Aluminium oxide Clays (Sesquioxide Clays) : Under conditions of extensive leaching by rainfall and long time intensive weathering of minerals in humid warm climates, most of the silica and much of the alumina in primary minerals are dissolved and slowly leached away. The remnant materials, which have lower solubility, are sesquioxides. Sesquioxides (metal oxides) are mixtures of aluminium hydroxide, Al $(OH)_3$ and iron oxide, Fe_2O_3, or iron hydroxide, Fe $(OH)_3$. The Latin word sesqui means one and one-half times, meaning one and one-half times more oxygen than Al and Fe. These clays can grade from amorphous to crystalline. Examples of iron and aluminium oxides common in soils 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. These clays do not swell, not sticky and have high phosphorus adsorption capacity.

2. Allophane and other Amorphous Minerals : These silicate clays are mixtures of silica and alumina. They are amorphous in nature. Even mixture of other weathered oxides (iron oxide) may be a part of the mixture. Typically, these clays occur where large amount of weathered products existed. These clays are common in soils forming from volcanic ash (e.g., Allophane).

These clays have high anion exchange capacity or even high cation exchange capacity. Almost all of their charge is from accessible hydroxyl ions (OH^-), which can attract a positive ion or lose the H^+ attached. These clays have a variable charge that depends on H^+ in solution (the soil acidity).

3. Humus (Organic Colloid) : Humus is amorphous, dark brown to black, nearly insoluble in water, but mostly soluble in dilute alkali (NaOH or KOH) solutions. It is a temporary intermediate product left after considerable decomposition of plant and animal remains. They are temporary intermediate because the organic substances remain continue to decompose slowly. The humus is often referred to as an organic colloid and consists of various chains and loops of linked carbon atoms. The humus colloids are not crystalline. They are composed basically of carbon, hydrogen, and oxygen rather than of silicon, aluminium, iron, oxygen, and hydroxyl groups. The organic colloidal particles vary in size, but they may be at least as small as the silicate clay particles.

The negative charges of humus are associated with partially dissociated enolic (–OH), carboxyl (–COOH), and phenolic (–⌬–OH) groups; these groups in turn, are associated with central units of varying size and complexity. The relationship is illustrated in fig. 10.7.

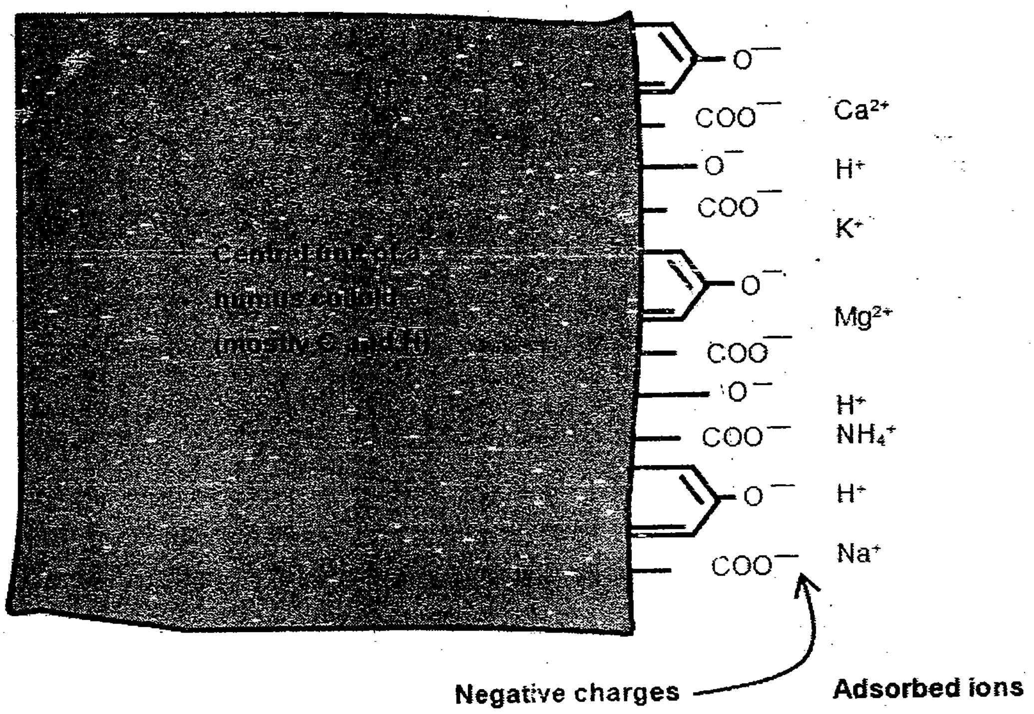


Fig. 10.7 : Adsorption of cation by humus colloids. (the phenolic hydroxy groups are attached to aromatic rings.)

It has cation exchange capacity on a dry weight basis many times greater than that of clay colloids. On a weight basis a few percent humus exerts much greater influence on cation exchange capacity than does several times more per cent clay.

EXERCISE

Q.1 Select the appropriate word :

1. ______ is a two phase system in which one material in a very finely divided state is dispersed through second phase :
(a) Physical state
(b) Chemical state
(c) Colloidal state
(d) Biological state

2. The particles less than ________ mm size possess colloidal properties and are known as soil colloids.
(a) 0.001
(b) 0.010
(c) 0.100
(d) 1.00

3. The total surface area of soil colloids with external and internal surfaces ranges from ___________ m^2/g.
(a) 1 to 8
(b) 10 to 80
(c) 10 to 800
(d) 100 to 800

4. Soil colloids when suspended in water carry a __________ electric change.
(a) Neutral
(b) Negative
(c) Positive
(d) No

5. The –Al-OH or Si-OH portion of the clay ionizes the ______ and leaves negative charge on the oxygen.
(a) Al
(b) Si
(c) H
(d) O

6. Dominantly, clays have ______ in tetrahedral and octahedral sites, respectively.
(a) Si^{4+} and Al^{3+}
(b) Al^{3+} and Si^{4+}
(c) Fe^{3+} and Fe^{2+}
(d) Fe^{2+} and Al^{3+}

7. In isomorphous substitutions, most substitutions are by ions with ________ than the ones being replaced.
(a) Higher charge
(b) Lower charge
(c) Same charge
(d) No charge

8. The adsorption of positively charged ion on colloidal surfaces gives rise to _____.
(a) Isomorphous substitution
(b) Ionic double layer
(c) Swelling and shrinkage
(d) Flocculation

9. The oscillation of colloidal particles in solution is due to the __________ of colloidal particles with those of the liquid.
(a) Cohesion
(b) Collision
(c) Adhesion
(d) Dispersion

10. _____________ has four sided configuration.
(a) Silica tetrahedron
(b) Alumina octahedron
(c) Alumina tetrahedron
(d) Silica octahedron

11. AN interlocking array of series of Al or Mg surrounded by six oxygen atoms or OH groups linked together horizontally gives a __________.
(a) Tetrahedral sheet
(b) Octahedral sheet
(c) Pentahedral sheet
(d) Hexahedral sheet

12. In kaolinite, the tetrahedral and octahedral sheets are held together by _____ atoms.
(a) Hydrogen
(b) Oxygen
(c) Silicon
(d) Aluminium

13. In tetrahedral sheets of fine grained mica Al atoms occupy about _____ of silicon sites.
(a) 10%
(b) 20%
(c) 30%
(d) 40%

14. Sesquioxides contain __________ more oxygen than Al and / or Fe.
(a) Two times (b) One and one half times
(c) Two and half times (d) Three times

15. Allophane and other amorphous silicate clays are mixture of ________.
(a) Fe and Al (b) Si and Al
(c) Mg and Al (d) Fe and Si

16. Allophane and other amorphous minerals have a variable charge that depends on ________ in solution.
(a) H ions (b) OH ions
(c) Si and Al ions (d) H and Al ions

17. ______________ is a temporary intermediate product left after considerable decomposition of plant and animal remains.
(a) Compost (b) Humus
(c) FYM (d) Amorphous clay

Q.2 Write the answers to the point :

1. Enlist the general properties of soil colloids.
2. State the surface area in the upper 15cm of a hectare of clay soil
3. What is zeta potential ?
4. State the sources of negative electrical charge on clay particles.
5. State the two components of ionic double layer.
6. State the forces responsible for the cohesion.
7. Why the soils dominated with montmorillonite are much more impervious than one dominated with kaolinite ?
8. What is Brownian movement ?
9. Enlist the different types of soil colloids.
10. What is silica tetrahedron sheet ?
11. What do you mean by dioctahedral and trioctahedral sheet ?
12. Name the different types of silicate clay minerals.
13. Why kaolinite clays have low CEC and water holding capacity ?
14. Why fine grained micas are quite non-expansive ?
15. What are mixed-layer mineral
16. Why allophane and other amorphous minerals have high anion and cation exchange capacity ?
17. Give the basic composition of humus.
18. State the dissociating functional groups on which negative charge of humus depends.
19. Which colloids have highest cation exchange capacity ?
20. What is deflocculation ?

Q.3 Define the following terms :

(1) Isomorphous substitution (2) Cohesion (3) Adhesion
(4) Flocculation (5) Interstratified minerals (6) Sesquioxides
(7) Humus

Q.4. Match the suitable pairs :

1. Tetrahedral and octahedral sheets	1. Oscillation of colloidal particles
2. Chloride	2. Iron and aluminium oxides
3. Humus	3. Smectite group
4. Limited expansion	4. Fine-grained micas
5. Allophane and other amorphous clay	5. Interstratified mineral

6. Phyllosilicates	6. Fundamental structural units of silicate clays.
7. Kaolinite	7. Oscillation of water molecules
8. Brownian movement	8. 2:1:1 – type mineral
9. Muscovite and Biotite	9. Organic colloid
10. Sesquioxides	10. Vermiculite
11. Montomorillonite	11. Comprised of two kinds of horizontal sheets
12. Chlorite – vermiculite	12. 1:1 type of clay
	13. Coarse grained mica
	14. High anion and cation exchange capacity
	15 Specific surface area
	16 Poor in phosphate ions.

□□□

11

Ion Exchange

Importance, cation and anion exchange phenomenon, mechanism of cation exchange, cation exchange capacity, factors affecting cation exchange capacity, base saturation and significance in agriculture.

As soils are formed during the weathering processes, some minerals and organic matter are broken down to extremely small particles. Chemical changes further reduce these particles until they cannot be seen with the naked eye. The very smallest particles are called colloids (see chapter 10, Soil colloids). Scientists have learned that mineral clay colloids are plate-like in structure and crystalline in nature. In most soils, clay colloids exceed organic colloids in amount. Colloids are primarily responsible for the chemical reactivity in soils. The kind of parent material and the degree of weathering determine the kinds of clays present in the soil. Since, soil colloids are derived from these clays, their reactivity is also influenced by parent material and weathering.

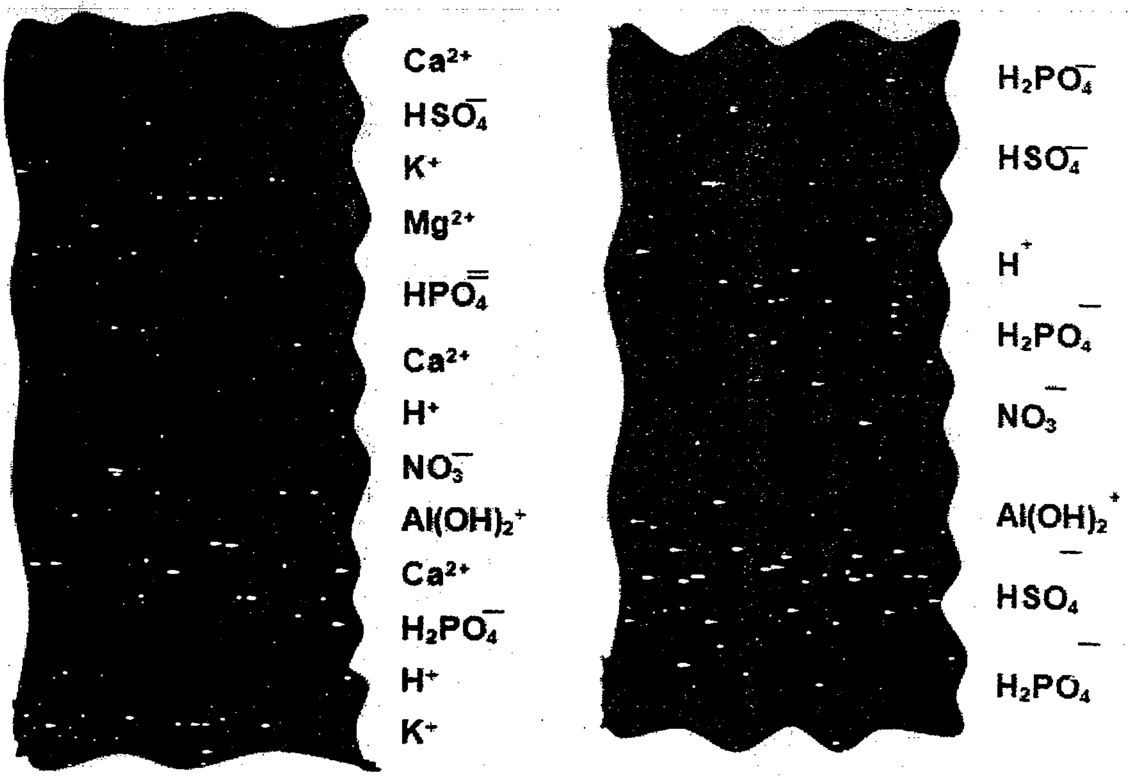
Each colloid (inorganic and organic) has a net negative (–) charge developed during the formation process. This means it can attract and hold positively (+) charged particles, as unlike poles of a magnet attract each other. Colloids repel other negatively charged particles, again as like poles of a magnet repel each other.

An element with an electrical charge is called an ion. Potassium, sodium (Na), hydrogen (H), Ca and Mg all have positive charges. They are called cations and ions with negative charges, such as nitrate and sulfate, are called anions. They are written in ionic form as shown in the table below (Table 11.1). Note that some cations and anions have more than one charge.

Table 11.1: Common cations and anions with their chemical symbols and ionic forms in soil.

Cation	Chemical Symbol	Ionic form	Anions	Chemical symbol	Ionic form
Potassium	K	K^+	Chloride	Cl	Cl^-
Sodium	Na	Na^+	Nitrate	N	NO_3^-
Hydrogen	H	H^+	Sulphate	S	SO_4^-
Calcium	Ca	Ca^{++}	Phosphate	P	H_2PO^{4-}
Magnesium	Mg	Mg^{++}			

Negatively charged colloids attract cations and hold them like a magnet holds small pieces of metal. This characteristic explains why nitrate-N is more easily leached from the soil than ammonium-N. Nitrate has a negative charge, like soil colloids. So, NO_3^- is not held by the soils, but remains as a free ion in soil water to be leached through the soil profile in some soils and under some rainfall conditions.



a) 1:1 Silicate clay b) Fe/Al oxide particle

Fig. 11.1 : Schematic diagram showing cation and anion adsorption.

CATION AND ANION ADSORPTION

The charges associated with soil particles attract simple and complex ions of opposite charge. Thus, a given colloidal mixture may exhibit not only a maze of positive and negative surface charges but also an equally complex complement of simple cations and anions such as Ca^{2+} and SO_4^{2-} that are attracted by the particle charges.

Fig. 11.1 illustrates how soil colloids attract the mineral elements so important for plant growth. The adsorbed anions are commonly present in smaller quantities than the cations because the negative charges generally predominate on the soil colloid, especially in soils of temperate regions. Consideration now will be given to the exchange of ions between micelles and the soil solution, starting first with cation exchange.

Mechanism of Cation Exchange

The exchange of cations has been explained on the basis of the electrokinetic theory of ion exchange. According to this theory, the adsorbed cations forming the outer shell of the ionic double layer are supposed to be in a state of oscillation, when suspended in water, forming a diffuse double layer (See Fig. 10.1). Due to these oscillations, some of the cations move away from the surface of the clay micelle. In the presence of the solution of an electrolyte, a cation of the added electrolyte slips in between the inner negative layer and the outer oscillating positive ion. The electrolyte cation is now adsorbed on the micelle and the surface cation remains in solution as an exchanged ion. Thus, the exchange of cations takes place.

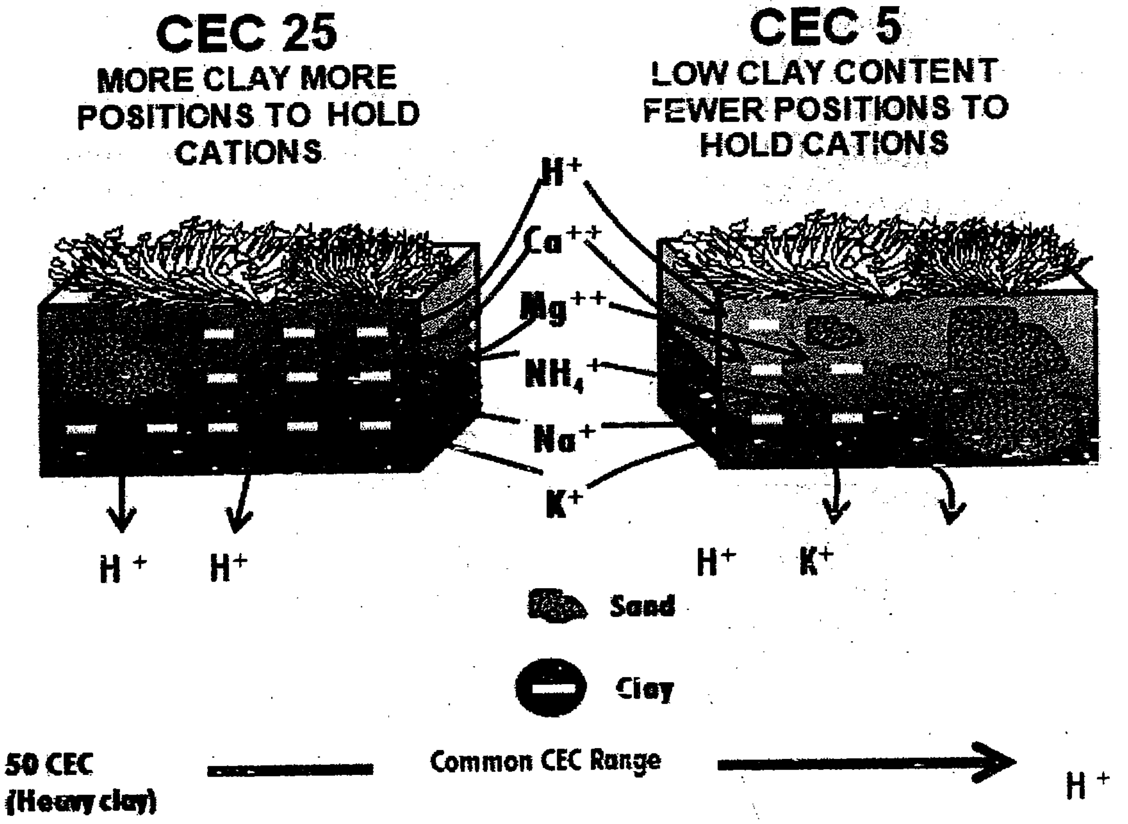


Fig. 11.2 : A Schematic Look at Cation Exchange.

Cations are positively charged nutrient ions and molecules. While, clay particles are negatively charged constituents of soils. These negatively charged particles (clay) attract, hold and release positively charged nutrient ions (cations). Organic matter particles also have a negative charge to attract cations. Sand particles carry little or no charge and do not react. Cations held by soils can be replaced by other cations. This means they are exchangeable. For example, Ca^{++} can be exchanged for H^+ and /or K^+ and vice versa (See Fig. 11.2).

Cation Exchange Capacity (CEC)

The CEC is the capacity of soil to hold and exchange cations. The cation exchange capacity is defined simply as 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 K^+ and other cations. The CEC depends on amount and kinds of clay and organic matter present. A high-clay soil can hold more exchangeable cations than a low-clay soil (Fig. 11.2). CEC also increases as organic matter increases. Clay minerals usually range from 10 to 150 meq/100 g in CEC values. Organic matter ranges from 200 to 400 meq/100 g. So, the kind and amount of clay and organic matter content greatly influence the CEC of soils.

If soils are highly weathered and organic matter levels are low, CEC values are low. Where less weathering has occurred and organic matter levels are usually higher, CEC values can be quite high. Clay soils with high CEC can retain large amounts of cations against potential loss by leaching. Sandy soils, with low CEC, retain smaller quantities. This makes timing and application rates important in planning a fertilizer programme. For example, it may not be wise to apply K on very sandy soils in the middle of a monsoon, where rainfall can be high and intense. Fertilizer application should be split to prevent leaching and losses through erosion, especially in the humid tropics. Also, splitting N applications to meet peak crop demand are important to reduce the potential for nitrate leaching on sands as well as finer-textured soils.

Means of Expression

The cation exchange capacity is expressed in terms of equivalents or more specifically, as milliequivalents per 100 gram and is written as meq/100g The term equivalent is defined as one gram of atomic weight of hydrogen (or the amount of any other ion) that will combine with or displace this amount of hydrogen for monovalent ions such as Na+, K+, NH4+ and Cl-, the equivalent weight and atomic weight are same, since they can replace one H ion. Divalent cations such as Ca++ and Mg++ can take the place of two H+ ions.

The milliequivalent weight of a substance is one thousandth of its atomic weight. Since the atomic weight of hydrogen is about 1 gram, the term milliequivalent (meq.) may be defined as 1 milligram of hydrogen .

It indicates that other ions also may be expressed in terms of milliequivalent. e.g. calcium has an atomic weight of 40, compared to 1 for H . Each Ca++ ion has two charges and thus is equivalent to two H+ ions. Therefore, the amount of calcium required to displace 1 mg. of hydrogen is 40/2 =20 mg(atomic weight is divided by its positive valence to obtain the equivalent weight). This is the weight of 1 meq. of calcium.

If 100 g of certain clay is capable of exchanging a total of 250 meq. of calcium, the cation exchange capacity is 250/20 = 12.5 meq. per 100 g. of soil.

This unit of exchangeable cations i.e. milliequivalent per 100 g of soil (meq/100g) was used prior to 1982. In the newer metric system the term equivalent is not used, however, now moles are the accepted chemical unit. All the calculation and concepts of "equivalents" are still mentally used but the notation must be written differently. The old "equivalent " is represented by moles (+) or mole, which indicates a monovalent ion portion. For example, to write 12.5 meq/100 g in the newer metric system, it can be written as: 12.5 cmol (+) kg^{-1} of soil (centimoles) or 125 mmol (+) kg-1 of soil (millimoles). Also the solidus (/) can be used in place of "-1". Such as writing the frist one above as 12.5 cmol (+) /kg or second one as 125 mmol(+)/kg soil. Thus it may also be expressed as centimoles of positive charge per kilogram of soil (Cmol(P^+)/kg), which are numerically equal to meq/100 g.

Replacing Power of Cation : The replacing power of cations varies with the type of ion, its size and degree of hydration, its valence and concentration, and the kind of clay mineral involved. As it is controlled by number of factors no single order of replacement can be given. All other factors being equal, the replacing power of monovalent cations increases in the following order : Li < Na < K < Rb < Cs < H and for divalent cations : Mg< ca<Sr<Ba. In case of mixture of monovalent and divalent cations as they exist in normal soils the replacing power increases in the following order : Na < K < NH_4 < Mg < Ca < H. This means Na is more easily replaced than K and K more easily than NH_4 and so on.

Percent Base Saturation : The per cent of total CEC occupied by the major cations has been used in the past to develop fertilizer programs. The idea is that certain nutrient ratios or 'balances' are needed to ensure proper uptake by the crop for optimum yields. Research has shown, however, that cation saturation ranges and ratios have little or no utility in a vast majority of agricultural soils. Under field conditions, ranges of nutrients can vary widely with no detrimental effects, so long as individual nutrients are present in sufficient levels in the soil to support optimum plant growth.

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. In fact, the usual "soil test' to predict a soil's ability to furnish potassium to the plant is a measure of its exchangeable potassium content. Cation exchange is very important in soils because of the following relationships :

1. The exchangeable K is a major source of plant K.
2. The exchangeable Mg is often a major source of plant Mg.
3. The amount of lime required to raise the pH of an acidic soil is greater as the CEC is greater.
4. Cation exchange sites hold Ca^{2+}, Mg^{2+}, K^+, Na^+ and NH^{4+} ions and slow down their losses by leaching .
5. Cation exchange sites hold fertilizer K^+ and NH^{4+} and greatly reduce their mobility in soils.
6. 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

Anion adsorption: Adsorption of negative ion (anions) e.g. Cl^-, NO_3^-, $SO_4^=$, and $H_2PO_4^-$ on positively charged sites of clay and organic matter is known as anion adsorption.

Source of Positive Charge

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

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

$$\underset{\substack{\text{No change}\\\text{(Soil solids)}}}{Al-OH} \quad + \quad \underset{\text{(Soil solution)}}{H^+} \rightleftharpoons \underset{\substack{\text{Positive charge}\\\text{(Soil solids)}}}{Al-OH_2^+}$$

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

$$\underset{\text{No charge}}{Al(OH)_3 + H^+} \longrightarrow \underset{\text{Positive charge}}{Al(OH)_2^+} + H_2O$$

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

Anion Exchange : The basic principles of cation exchange apply as well to anion exchange, except that the charges on the colloids are positive and the exchange is among negatively charged anions. A simple example of an anion exchange reaction is

$$\underset{\text{(soil solid)}}{\text{Micelle}}\ \ \underset{\text{(in sil solution)}}{NO_3^- + Cl^-} \rightleftharpoons \underset{\text{(soil solid)}}{\text{Micelle}\ \ Cl^-} + \underset{\text{(in soil solution)}}{NO_3^-}$$

Just as in cation exchange, equivalent quantities of NO_3^- and Cl^- are exchanged, the reaction can be reversed, and plant nutrients can be released for plant absorption.

Although simple reactions such as this are common, the adsorption and exchange of some anions including phosphates, molybdates, and sulphates are somewhat complex. The complexity is owing to specific reactions between the anions and soil constituents. For example, the H_2PO_4 ion may react with the protonated hydroxy group rather than remain as an easily exchanged anion

$$\underset{\text{(soil solid)}}{>Al-OH_2^+} + \underset{\text{(in soil solution)}}{H_2PO_4^-} \longrightarrow \underset{\text{(soil solid)}}{>Al-H_2PO_4} + \underset{\text{(in soil solution)}}{H_2O}$$

Also H_2PO_4 is held very tightly by the soil solids and is not readily available for plant uptake.

Despite these complexities 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 promptly.

Anion Exchange Capacity : The sum total of exchangeable anions that a soil can adsorb is known as *anion exchange capacity* and is expressed as Cmol /kg or m.e./100 g soil. The capacity of adsorption and exchange of anions varies with the type of clay mineral, soil reaction, and the nature of anion. Kaolinitic minerals have a greater anion adsorbing and exchange capacity than montmorillonitic and illitic clays. The exchange capacity for anions is less in the case of montmorillonite and illite because the exchange is located at only a few broken bonds.

The capacity for holding anions increases with the increase in acidity. The lower the pH the greater is the adsorption. All anions are not adsorbed equally readily. 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 exchange is brought about mainly by the replacement of OH ions of the clay mineral. The reaction is very similar to cation exchange.

$$OH - Clay + H_2PO_4^- \rightleftharpoons H_2PO_4 - Clay + OH^-$$

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. Hence the fixation is temporary. The whole of the phosphate adsorbed by clay is, however, not exchangeable, as even at pH, 7.0 and above. So, substantial quantities of phosphate ions are still retained by clay particles.

The OH ions originate not only from silicate clay minerals but also from hydrous oxides of iron and aluminium present in the soil. The phosphate ions, therefore, react with the hydrous oxides also and get fixed as in the case of silicate clay, forming insoluble hydroxy – phosphates of iron and aluminium.

$$\underset{\text{(soluble)}}{Al(OH)_3 + H_2PO_4^-} \rightleftharpoons \underset{\text{(insoluble)}}{Al(OH)_2.H_2PO_4} + OH^-$$

If the reaction takes place under conditions of slight acidity it is reversible, and soluble phosphate is again liberated when hydroxy phosphate comes in contact with ions. If the reaction takes place at a low pH under strongly acid conditions, the phosphate (ions) are irreversibly fixed and are totally unavailable for the use of plants.

EXERCISE

Q.1. Select the appropriate word :

1. ______________ are primarily responsible for the chemical reactivity in soil.

12

Soil Reaction

Definition, concept of H ion concentration, active and potential acidity, buffering capacity, significance of soil reaction in plant nutrition, factors controlling soil reaction

Concept of H ion Concentration

The acidity or alkalinity of a solution can be expressed on the scale of acidity and alkalinity in the same way as temperature is expressed on a thermometer scale. The scale of acidity or alkalinity is called *pH scale*. The unit of this scale is called pH value. This scale runs from 0 to 14 values. The neutral point in this scale is at pH 7.0. All the values above pH 7.0 represent alkalinity and below 7.0 denote acidity. The degree of alkalinity increases as values go above pH 7.0 and the degree of acidity increases as the pH decreases below 7.0 (Fig. 12.1).

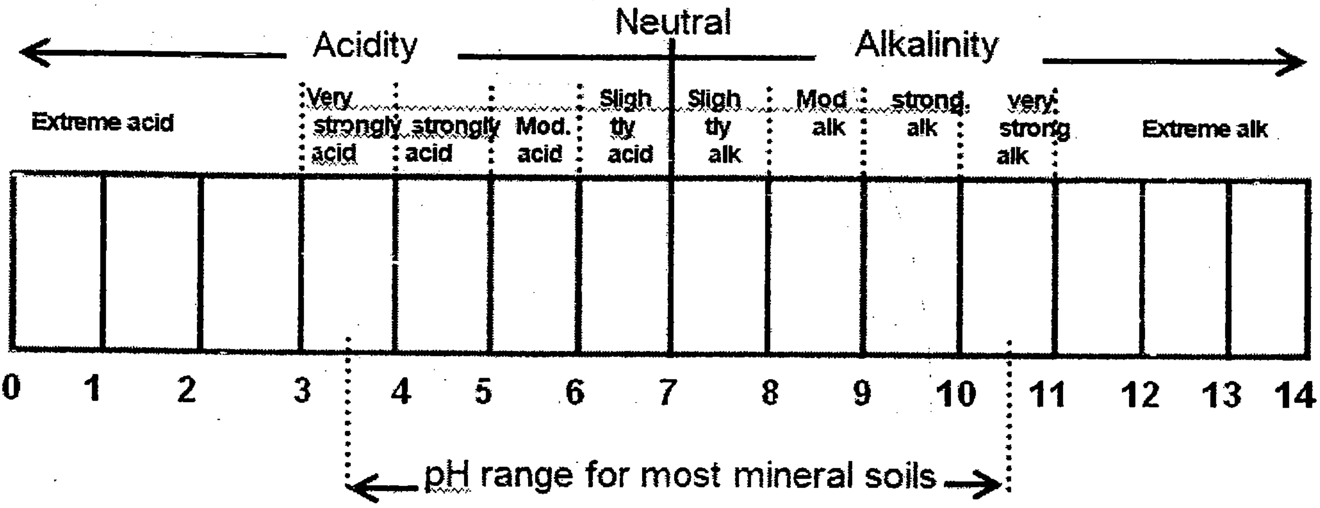


Fig. 12.1 : pH scale and ranges in soil pH.

According to the *theory of electrolytic dissociation* when liquids have number o H ions just equal the number of OH ions, the solution is neutral. While, H ions exceed OH ions the solution is acidic. Conversely, if OH ions are in excess the solution is alkaline.

Pure water ionises to a very small degree, though to a measurable extent, according to the following equation :

$$H_2O \longrightarrow H^+ + OH^-$$

According to the law of mass action

$$\frac{\text{Concentration of H ions} \times \text{concentration of OH ions}}{\text{Concentration of undissociated } H_2O} = \text{KW (A constant)}$$

$$\text{Or}\quad \frac{[H^+][OH^-]}{H_2O} = KW$$

Since, the amount of undissociated water is extremely large (as only one molecule in about 10 million ionises), it can be taken as unity and the above equation, therefore becomes.

$$[H^+][OH] = KW$$

This ionic product of water has been measured by electrical conductivity measurements and is found to be of the order of 1×10^{-14} ions per litre at 22°C. Since in pure water, the number of H ions is equal to the number of OH ions, the concentration of each ion type must be 1×10^{-7} g ions per litre. If the concentration of H ions is more than 10^{-7}, the solution is acidic ; if less solution is alkaline.

This method of expressing the H ions concentration is very inconvenient and therefore **Sorenson (1969)** suggested that H ions concentration be generally expressed as the numerical value of the negative power to which 10 must be raised in order to express the required concentration and this value be designated by the symbol pH.

Thus, technically pH is the negative logarithm of the H ion concentration or the logarithm to the base ten of the reciprocal of hydrogen ion concentration i.e.

$$H^+ = 10^{-pH}$$

$$\log [H^+] = -\,pH \log 10$$

$$-\,pH = \frac{\log [H^+]}{\log 10}$$

$$pH = -\,\frac{\log [H^+]}{\log 10}$$

Since $\log 10 = 1$,

therefore $$pH = -\log [H^+]$$

Or

$$pH = \log \frac{1}{[H^+]}$$

Soil Recation

Soil reaction is one of the most important physiological characteristics of the soil solution. The presence and development of micro-organisms and higher plants depend upon the chemical environment of soil. Therefore study of soil reaction is important in soil science. There are three types of soil reactions :

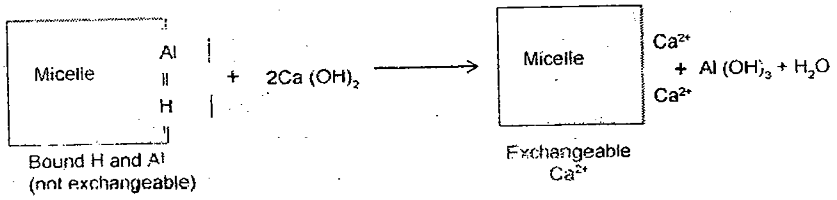
1. Acidic 2. Alkaline and 3. Neutral

1. Acidic : It is common in region where precipitation is high. The high precipitation leaches appreciable amounts of exchangeable bases from the surface intermediate for vermiculites, and lowest for kaolinite. In any case, however, it accounts for only a small portion of the total soil acidity as the next section will verify.

(iii) Residual Acidity : Residual acidity is that which remains in the soil after active and exchange acidity has been neutralized. Residual acidity is generally associated with aluminium hydroxy ions and with hydrogen and aluminium atoms that are bound in non exchangeable forms by organic matter and silicate clays. If lime is added to a soil, the pH increases and the aluminium hydroxy ions are changed to uncharged gibbsite as follows.

$$Al(OH)^{2+} \xrightarrow{OH^-} Al(OH)_2^+ \xrightarrow{OH^-} Al(OH)_3$$

In addition, as the pH increases bound hydrogen and aluminium can be released by calcium and magnesium in the lime materials [$Ca(OH)_2$ is used as an example of the reactive calcium liming material].



The residual acidity is commonly far greater than either the active or salt replaceable acidity. Conservative estimates suggest that the residual acidity may be 1000 times greater than the soil solution or active acidity in a sandy soil and 50000 or even 100000 times greater in a clayey soil high in organic matter. The amount of ground limestone recommended to at least partly neutralize residual acidity is commonly 4-8 metric tons (Mg) per hectare furrow slice (1.8-3.6 tons/AFS). It is obvious that the pH of the soil solution is only "the tip of the iceberg" in determining how much lime is needed.

Buffering and Soil Reaction

Buffer Action : Buffering refers to resistance to a change in pH. If 1 ml HCl (of 0.1N) is added to one liter of pure distilled water of pH 7.0, the resulting solution would have a pH of about 5.0. If on the other hand, the same amount of acid is added to a liter of soil suspension the resulting change in pH would be very small. There is, a distinct resistance to change in pH . This power to resist a change in pH is called *buffer action. A buffer solution* is one which contains reserve acidity and alkalinity and does not change pH with small additions of acids or alkalies.

Buffer capacity : 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. Buffer capacity of the soil varies with its cation exchange capacity (C.E.C.). The greater the C.E.C. the greater will be its buffer capacity. 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.

Importance of Buffering to Agriculture : Changes in soil reaction (pH) have a direct influence on the plants and it also affects the availability of plant nutrients. Deficiency of certain plant nutrients and excess availability of others in toxic amounts would seriously upset the nutritional balance in the soil. Buffering prevents sudden changes and fluctuation in soil pH, so it regulates the availability of nutrients and also checks direct toxic effect to plants.

Factors Controlling Soil Reactions : Soil reaction varies due to following factors :

1. Nature of Soil Colloids : The colloidal particles of the soil influence soil reaction to a very greatest extent. When hydrogen (H^+) ion forms the predominant adsorbed cations on clay colloids, the soil reaction becomes acid.

2. Soil Solution : The soil solution carries a number of salts dissolved in capillary water. The cations of the salts intermingle with those of the diffuse double layer of the clay particle and increase the concentration. The concentration of cations in bulk of the solution is more or less (or nearly) the same as that near the particle surfaces. For an unsaturated soil (Clay). The more compact the layer the greater is the number of hydrogen ions dissociating into the solution. This increases the acidity of the soil solution or lowers its pH.

Under field conditions, the concentration of salts varies with the moisture content of the soil. 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. This principle of increasing the concentration of CO_2 in soil air is also used in the reclamation of alkali soils.

3. 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).

4. Soil Management : Cultural operations in general tend to increase soil acidity. They make an acid soil more acidic and an alkaline soil less alkaline. As a result of constant cultivation, basic elements are lost from the soil through leaching and crop removal. This leads to change the soil reaction to the acid side.

5. Parent Material : Soils developed from parent material of basic rocks generally have higher pH than those formed from acid rocks (e.g. granite). The influence of parent material is not very important as it is completely masked by the climatic conditions under which the soil is developed.

6. Precipitation : As water from rainfall passes through the soil, basic nutrients such as calcium (Ca) and magnesium (Mg) are leached. They are replaced by acidic elements including Al, H, and manganese (Mn). Therefore, soils formed under high rainfall conditions are more acid than those formed under arid conditions.

7. Decomposition of Organic Matter : Soil organic matter is continuously being decomposed by micro-organisms into organic acids, carbon dioxide (CO2) and water, forming carbonic acid. Carbonic acid, in turn, reacts with the Ca and Mg carbonates in the soil to form more soluble bicarbonates, which are leached away, leaving the soil more acid.

8. Native Vegetation : 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. Calcium and Mg contents also vary according to the portion (s) of the plant harvested. Many legumes release H^+ ions into their rhizosphere when actively fixing atmospheric N_2. The acidity generated can vary from 0.2 to 0.7 pH units per mole of fixed N.

9. Soil Depth : Except in low rainfall areas, acidity generally increases with depth, so the loss of topsoil by erosion can lead to a more acid pH in the plow layer. The reason is that more subsoil is included in the plow layer as topsoil is lost. There are areas, however, where subsoil pH is higher than that of the topsoil.

10. 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.

11. 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. Consequently, liming is of little value in flooded rice production. Further, it can induce deficiencies of micronutrients such as zinc (Zn).

Influence of Soil Reaction on Availability of Nutrients

The main effect of soil reaction is on the availability of plant nutrients in the soil (Fig. 12.3). The unproductiveness of acid and alkali soils is very often due to the lack of available plant nutrients. In highly acid soils (low pH), the availability of some of the nutrients such as aluminium, iron, manganese etc., is increased to a point to become toxic to the plant. At the same time the supplies of available calcium, nitrogen, phosphorus etc., are reduced to starvation level (become unavailable). The same is the case at high pH (alkaline conditions), plant growth suffers due to the unavailability of nutrients like nitrogen, phosphorus and some minor elements (e.g., iron, manganese, boron etc).

Another indirect effect occurs through the activity of microorganisms. Most micro-organisms function at their best within a pH range 6.0 to 7.5. If soil reaction is changed beyond this range, the micro-organisms become functionless. Consequently, the supply of some of the essential plant nutrients like nitrogen is considerably reduced.

1. Nitrogen : Plant absorbs most of their nitrogen in the form of nitrate of which availability depends on the activity of nitrifying bacteria. The micro-organisms responsible for nitrification are most active when the pH is between 6.5 and 7.5. They are adversely affected if the pH falls below 5.5 and rises above 9.0. Nitrogen fixing bacteria (like Azotobacter) also fail to function below pH 6.0. The decomposition of organic matter which is the primary source of nitrogen is also slowed down under acidic condition.

2. Phosphorus : Its availability is at its highest when the reaction is between 6.5 and 7.5. When the reaction is above or below this range, availability is reduced. In the strongly acidic soil (pH 5.0 or less), iron, aluminium, manganese and other bases are present in a soluble state and in more quantity. The phosphates of these elements are formed and become unavailable. Example :

$$Al^{+++} + \underset{\text{(Soluble)}}{H_2PO_4^-} + 2H_2O \rightleftarrows 2H^+ + \underset{\text{(Insoluble)}}{Al(OH)_2.H_2PO_4}$$

The phosphates react with hydrated oxides of iron and aluminium and forms insoluble hydroxy – phosphates of iron and aluminium. Unavailability of phosphorus is called *phosphorus fixation.*

Fixation of phosphates takes place even when the soil is alkaline (high pH). Phosphate ion combines with calcium ion and calcium (or magnesium) carbonates and form insoluble calcium (or magnesium) phosphate. The reaction is as follows :

$$\text{(i)}\quad \underset{\text{(Soluble)}}{Ca(H_2PO_4)_2} + \underset{\text{(adsorbed)}}{2Ca^{++}} \rightleftarrows \underset{\text{(Insoluble)}}{Ca_3\,(PO_4)_2} + 4H^+$$

$$\text{(ii)}\quad \underset{\text{(Soluble)}}{Ca(H_2PO_4)_2} + 2CaCO_3 \rightleftarrows \underset{\text{(Insoluble)}}{Ca_3(PO_4)_2} + 2CO_2 + 2H_2O$$

The availability of phosphorus at different pH is linked with the ionic form in which it is present in soil solution. The monovalent H_2PO_4 ions predominate in highly acid (at pH 4.0–5.0) solutions. With decreasing acidity, the divalent HPO_4 ions begin to appear. In alkaline soil the trivalent PO_4 ions are present in extremely small quantity. At pH 9.0 and above PO_4 is available to plants.

The ionic form has a large influence on the availability of phosphorus to plants. The H_2PO_4 and HPO_4 ions are considered to be more available than PO_4 ions. The plants depend for their phosphorus requirement on these two ionic forms to a much greater extent than PO_4 ions; H_2PO_4 at neutrality and below (acid range) and HPO_4 at neutrality and above (alkaline range).

In the pH range 6.0 to 7.0, phosphate fixation is very slight. Consequently, at this pH range phosphorus availability is highest. At this pH range only 20 – 30 % phosphorus is actually assimilated by the growing plant, if soluble phosphorus is added in the soil as fertilizer. It is believed that the presence of calcium hinders the absorption of phosphate by plant. In acid soil (low pH), phosphorus become available by anion exchange. Part of the phosphate, which has reacted with iron and aluminium compounds, is subject to replacement by other anions, such as the hydroxyl ion (OH-). Such replacement is called anion exchange. It is the reverse reaction of phosphate fixation in acid soil given above :

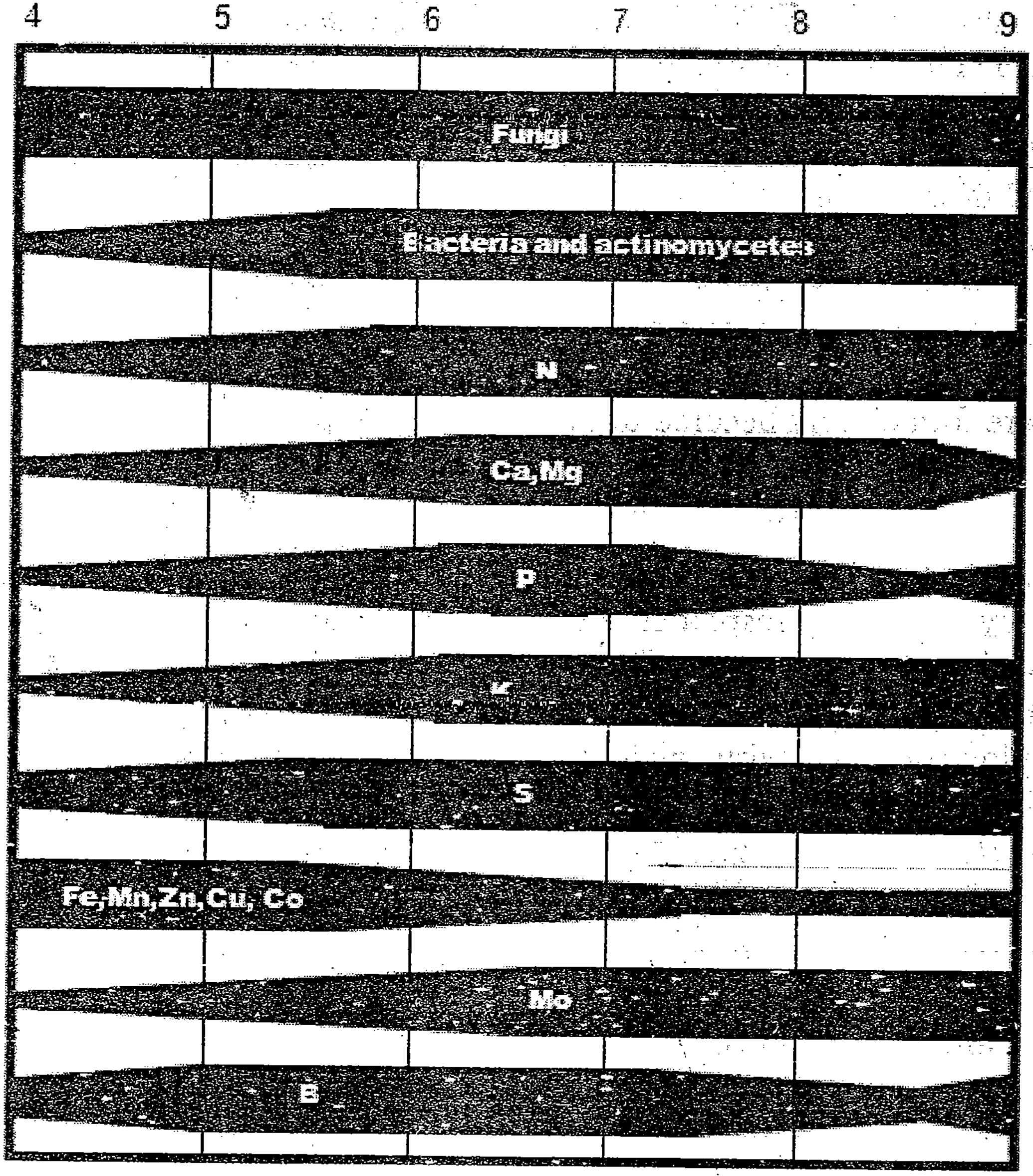


Fig. 12.3 : Relationship between soil pH and nutrient availability.

$$\underset{\text{(Soluble)}}{Al(OH)_2.+H_2PO_4} + OH^- \rightleftharpoons \underset{\text{(Soluble)}}{Al(OH)_2 + H_2PO_4^-}$$

One anion (OH^-) has been exchanged for another $(H_2PO_4^-)$. Phosphorus $(H_2PO_4^-)$ becomes available after liming in the acid soil.

3. Potassium : The availability of potassium does not influence by soil reaction to any great extent. In acid soil potassium is lost through leaching. The unavailability of K is due to the conversion of exchangeable to non-exchangeable potassium in alkaline soil. Particularly if the alkalinity is due to $CaCO_3$ (brought about by over liming in acid soil), the solubility of soil potassium is depressed.

4. Calcium and Magnesium : Acid soils (base unsaturated) are poor in available calcium and magnesium. In alkaline soil (pH not exceeding 8.5) availability of Ca and Mg nutrients always high. When the pH is above 8.5, the availability of these nutrients again decreases.

5. Iron, Aluminium and Manganese : When the pH is low the solubility of iron, aluminium and manganese compounds are increased and hence, they are readily available in acid soils. At the pH range 5.5 to 7.0, iron and manganese are present in the soluble ferrous (Fe^{++}) and manganous (Mn^{++}) forms. At pH below 5.5, the solubility of these compounds considerably increased with the result that they have a toxic influence on plant growth.

Under neutral and alkaline conditions, iron and manganese are usually present in ferric (Fe^{--}) and manganic (Mn^{++++}) states. Hence in soils with pH 7.5 and above, they become unavailable and sometimes produce deficiency diseases like chlorosis in plants.

6. Sulphur : The availability of sulphur is not affected by soil reaction as sulphur compounds are soluble in the whole pH range. However, it is more soluble in acid soil and lost in leaching. Acid conditions, which retard the decomposition of organic matter, therefore, retard the release of available sulphur. The availability of sulphur present in organic matter depends upon the decomposition of organic matter.

7. Micronutrients : In general, the availability of boron, copper and zinc is reduced in alkaline soils and that of molybdenum in acid soils. The availability of these nutrients progressively decreases as the soil pH increases. Their availability also decreases under highly acid condition when the pH is below 5.0.

Zinc availability in alkaline soils from insoluble zinc salts (calcium zincate) is reduced. Zinc and copper are adsorbed on the clay colloids and not easily displaced and hence not available for plant growth.

The availability of molybdenum, is reduced under acid soils. It is more available in neutral and alkaline soils.

EXERCISE

Q.1 Select the correct answer :

1. The degree of alkalinity and acidity increases as the pH values goes __________ 7.0, respectively.

(a) Below and above (b) Above and below

(c) Increasing above (d) Decreasing below

2. ______ suggest that the H ions concentration be expressed as the numerical value of the negative power to which 10 must be raised to express required concentration.

(a) Sorenson (1869) (b) Pearson (1969)

(c) Sorenson (1969) (d) Jackson (1969)

3. The high precipitation leaches appreciable amounts of ______ from the surface soil, so that the exchange complex is dominated by H ion.

(a) Exchangeable bases (b) Exchangeable ions

(c) Exchangeable Ca (d) Exchangeable Mg

4. According to the theory of dissociation, the activity is due to the ________ of compounds.

(a) Deflocculation (b) Ionization

(c) Aggregation (d) Solubility

5. Equivalent quantities of acids and alkalis when dissolved in water they ionize to __________.

(a) Different extent (b) Same extent
(c) Same level (d) Give varying ions.

6. 10 ml of 1N strong HCl and 10 ml of 1N weak carbonic acid will require ________ sodium hydroxide to neutralize separately.
(a) 15 and 10 ml of 1N (b) 15 ml of 1N
(c) 10 ml of 1N (d) 10 and 15 ml of 1N

7. Exchangeable acidity is primarily associated with _______ that are present in largest quantities in very acid soils.
(a) Exchangeable Fe and Al (b) Exchangeable Al and Mg
(c) Exchangeable Al and H (d) Exchangeable Fe and H.

8. The limestone needed to neutralize the exchangeable acidity is commonly _________ times more than that needed for active acidity.
(a) 10 (b) 50
(c) 100 (d) 200

9. If lime is added to an acid soil, the pH increases and the aluminium hydroxy ions are changed to uncharged _________.
(a) Calcite (b) Dolomite
(c) Lignite (d) Gibbsite

10. A buffer solution is one which contains ______ and does not change the pH with small additions of acids and alkalis.
(a) Active acidity (b) Exchange acidity
(c) Reserve acidity (d) Reserve acidity and alkalinity

11. As a result of constant cultivation,______ are lost from the soil through leaching and crop removal which leads to lower down the pH.
(a) Organic acids (b) Basic elements
(c) Essential nutrients (d) Organic elements

12. The acidity generated during fixation of Nitrogen can vary from _____pH units per mole of fixed N.
(a) 0.1 to 0.5 (b) 0.2 to 0.7
(c) 0.3 to 0.9 (d) 0.4 to 1.1

13. Regardless of original pH values, most soils reach pH of _______ within one month after flooding.
(a) 5.5 to 6.5 (b) 6.5 to 7.2
(c) 7.2 to 8.2 (d) 7.0 to 8.0

14. The unproductiveness of acid and alkali soils is very often due to ____
(a) Disturbed soil reaction (b) Lack of nutrient balance
(c) Lack of aeration (d) Unavailability of plant nutrients

15. If the microorganisms become functionless in soil, the availability of ______ is considerably reduced.
(a) Nitrogen (b) Phosphorus
(c) Sulphur (d) Hydrogen

16. The activity of bacteria is adversely affected if the pH falls below or rises above _________ respectively.
(a) 4.5 and 7.0 (b) 5.5 and 9.0
(c) 6.5 and 7.5 (d) 7.5 and 9.5

17. In acidic soils, phosphorus is fixed as ___________.
(a) Iron phosphate (b) Aluminium phosphate
(c) Ammonium phosphomolybdate (d) Iron and aluminium phosphate

18. The availability of ________ is linked with the ionic form in which it is present in soil solution at varying pH.

(a) Nitrogen (b) Phosphorus
(c) Sulphur (d) Iron

. In acid soils phosphorus becomes available by ________.
(a) Adsorption (b) Cation exchange
(c) Anion exchange (d) Adhesion

20. In soils with pH 7.5 and above, Fe and Mn become unavailable and sometime produce __________ in plant.
(a) Mitosis (b) Meiosis
(c) Chlorosis (d) Chlorotic

Q.2 Write the answer to the point :

What is pH scale ?
2. State the dissociation of water molecules, according to law of mass action.
What is the concentration of undissociated water molecules in solution ?
4. Why study of soil reaction is important in soil science ?
State the different types of soil reaction.
6. Why acid soils occur widely in humid region ?
Why equal amounts of strong and weak acids require same amount of alkali to neutralize?
What is the pH of a solution having aH+ = 4.2 x 10-6 g ions/lit.
9. State different types of soil acidity.
Though the concentration of H ions owing to active acidity is extremely small, why it is important ?
Name the clay minerals having highest and lowest exchangeable acidity.
12. State the reaction indicating the removal of H and Al by liming material.
What is common recommendation of limestone to at least partly neutralization of residual acidity in a hectare furrow slice?
Name four factors on which buffering capacity of soil depends.
15. Enlist the factors controlling soil reaction.
How plant roots and organisms affect soil pH ?
17. Why the effect of parent material is not much important in soil reaction ?
Which elements are likely to become toxic due to high solubility in very acid soils ?
19. Name the major and minor elements which are unavailable at high pH range.
What is the suitable pH range for activity of nitrifying bacteria ?
21. Explain P fixation in acid soils.
How phosphorous is fixed in alkaline soils ?
23. State the more available ionic forms of phosphorous.
Name the micronutrients which are soluble in acid pH range.
25. Which is the only micronutrient available in neutral to alkaline pH range ?

Q.3 Define the following terms :

1. pH 2. Active acidity 3. Exchangeable acidity
4. Residual acidity 5. Buffering 6. Buffering capacity of soil
7. Phosphorus fixation

Q.4 Match the suitable pairs :

1. Arid and semi-arid region	1. Measure of H ion activity in soil solution at a given time.
2. Soils developed from granite	2. Heavy textured clay soils.
3. Decomposition of organic matter	3. 1 x 10-14 ions /lit at 22OC

4. Theory of electrolytic dissolution
5. Residual acidity
6. N fertilization
7. Ionization of acid or alkali
8. High buffering capacity of soil
9. Legumes
10. Ionic product of water
    acidity development in soil.
11. Soil pH tends to drop
    in neutral solution.
12. Active acidity

4. Leave basicity in soil.
5. Soil gets progressively dry
6. Generally have low pH
7. 1×10^{-7} ions/lit at 20OC
8. Alkaline soils
9. Leaves acidity in soil
10. Speeds up the rate of
11. H and OH ions are just equal
12. Leave acidity in rhizosphere
13. Content of free H and OH ions
14. 100 times greater than soil solution
15. Acidity in sandy soils
16. Increase basicity in rhizosphore.

❑❑❑

13

Soil Solution

Definition, composition, concentration, factors affecting, importance.

Water exists in the soil partly as combined and bound water (water of constitution and hygroscopic water), and partly as free water in the form of films surrounding the soil particles (capillary water). The soluble products that are liberated as a result of the process of weathering and soil formation are dissolved in the free water. The free water also contains a part of organic matter that is soluble in water. Some of the soil gases like oxygen and carbon dioxide are also dissolved in this water. In a cultivated soil, some of the products of excretion and secretion of plant roots and of the activities of micro-organisms are also dissolved in soil moisture. The free water carrying these various substances and gases in solution is known as soil solution.

The soil solution contains small but significant quantities of soluble inorganic and organic compounds, some of which contain elements that, are essential for plant growth. The soil solids, and particularly the fine organic and inorganic particles, release these elements to the soil solution from which they are taken up by growing plants. Such exchanges, which are critical for higher plants, are dependent on both soil water and the fine soil solids.

One other critical property of the soil solution is its acidity or alkalinity. Many chemical and biological reactions are dependent on the levels of hydrogen ions (H^+) and hydroxide ions (OH^-) in the soil. These levels influence the solubility, and in turn the availability of several essential nutrient elements such as iron, manganese, phosphorus, zinc, and molybdenum to plants.

Composition of Soil Solution

Soil solution contains a number of salts. The salts are present in both ionic and molecular forms. When the solution is dilute as is often the case in cultivated soils, a greater proportion of the salts is present in ionic state. Molecules appear only when the solution gets concentrated, e.g., during dry spell, in dry season, or in arid regions. Of all the cations, calcium, magnesium, sodium, and potassium are present to the greatest extent. In normal soils calcium forms the predominant cation, which in saline soils, sodium constitutes the largest quantity. In acid soil, the soil solution usually contains a preponderance of hydrogen ions. Among the anions, bicarbonate, sulphate and chloride ions are commonly present in soil solution in large quantities. Of these, the bicarbonate ions are usually present in greater quantities than the other two, except in saline soils where sulphate and chloride ions are in preponderance. In case of alkaline soils, hydroxyl ions are generally present in larg quantities. Calcium and potassium ions vary considerably not only from soil to soil but also in the same soil at different times.

Ionic forms of elements present in soil solution

Element	Cations	Element	Anions
Sodium	Na^+	Nitrogen	NO_2^-, NO_3^-,
Potassium	K^+	Chlorine	Cl^-
Calcium	Ca^{2+}	Sulphur	SO_3^{2-}, SO_4^{2-}
Magnesium	Mg^{2+}	Carbon	HCO_3^-, CO_3^{2-}
Iron	Fe^{2+}, Fe^{3+}	Phosphorus	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}
Aluminium	Al^{3+}	Boron	$H_2BO_3^-$
Hydrogn	H^+	Molybdenum	MoO_4^{2-}
Manganes	Mn^{2+}, Mn^{3+}		
Copper	Cu^{2+}		
Zinc	Zn^{2+}		
Nitrogen	NH_4^+		

Factors Affecting Composition and Concentration of Soil Solution

The factors that are mainly responsible for the variation in composition and concentration of soil solution are.

1. Type of soil
2. Moisture content
3. Action of growing plants
4. Action of soil micro-organisms.
5. Adsorption by colloidal complex
6. Leaching effect
7. Season
8. Cultivation.

1. Type of Soil : No two soil types have the same composition and concentration of soil solution. Saline soils differ markedly from non-saline soils in both composition and concentration of their soil solution. Soils formed in arid a semi-arid regions, or under restricted drainage usually have more concentrated soi solution than those formed in temperate and moist tropical regions or those hav free drainage. The soil solution of the former soil types is usually more rich i monovalent cations while that of the latter in divalent cations. The former is a richer in sulphate and chloride anions than the latter.

2. Moisture Content : The greater the amount of moisture in a soil, th more dilute is the soil solution. The rate of evaporation, which governs the amo of soil moisture, controls the concentration of soil solution. In arid and semi-arid regions where evaporation is high, the soil solution is usually more concentrated than in temperate and cool humid regions. Even in a given soil, soil solution is more dilute soon after rainfall or irrigation than a few days later. Its concentration is gradually increased as the soil moisture content is reduced.

3. Action of Growing Plants : The growing plants, which absorb nutrients from the soil, changes the concentration as well as the composition of the soil solution. Plants exert considerable selection in the absorption of nutrients. Some ions like, nitrates are absorbed almost completely in preference to others, while some ions are not absorbed at all or to a much lesser extent. The selective absorption of ions changes the composition of soil solution considerably. On the other hand, the action of carbon dioxide and other acidic substances excreted by plant roots brings some of the insoluble soil constituents into solution thereby changing its concentration and composition. Even plant transpiration affects its concentration. On all these accounts, the concentration of the soil solution is always lower in cropped soil than in the same soil that is not cropped. It is usually higher in the beginning of the growing season than at its end.

4. The Action of Soil Micro-organisms : Soil micro-organisms help to increase the concentration of soil solution. Their activities lead to an increase of certain ions, chiefly the anions, in solution. The anions so produced are nitrates, sulphates and bicarbonates. They also bring the bases like calcium and magnesium in solution. The microorganisms utilise some of the salts from soil solution for their own nutrition, some of which are liberated again and brought into solution when the micro- organisms die and decompose.

5. Adsorption by Colloidal Complex : The rate at which the colloidal complex adsorbs ions from soil solution, changes its concentration as well as composition. Most of the ions present in soil solution, except those which are not adsorbed by colloids, e.g., nitrate and chloride, are in equilibrium with those present in the adsorbed form i.e. the exchangeable cations and anions. Anything that disturbs this equilibrium brings about a change in the character of soil solution.

6. Leaching Effect : The continuous removal through leaching of certain ions that are not adsorbed by colloids or those that are in excess of what can be adsorbed and retained in soil, also affects the nature of soil solution. For instance, nitrate and chloride ions, if they are not utilised by the growing crop, continuously lost in drainage water. Similarly, calcium, magnesium and sodium ions which are present in excess of the absorbing capacity of the colloidal complex or the requirement of the growing crop are removed through leaching.

7. Season : Seasonal variations, especially temperature and rainfall, also bring about a change in the concentration of soil solution. A rise in temperature brings some of the soil constituents into solution, thereby increasing its concentration. Rainfall, on the other hand, tries to dilute it. The composition of soil solution is also changed by seasonal variations due to the adjustments in equilibrium taking place.

8. Cultivation : Cultural operations help to increase the solubility of soil constituents, thereby increasing the concentration of soil solution. The addition of mannures, fertilizers and soil amendments also changes its concentration and composition.

Importance of Soil Solution

The main function of soil solution is to supply mineral nutrients to the growing plant. The nutrients in soil solution are replenished continuously as plants absorb them during their growth. The crop production capacity of soil is therefore, linked with its nutrient supplying power.

Other things being normal, good fertile soils usually contain a more concentrated soil solution than poor soils. There is, however, a limit to the concentration of soil solution that can be tolerated by plants. When the concentration exceeds the critical value plant growth suffers, and when the osmotic pressure approaches that of the sap of root cells (20 to 25 atm), plant growth ceases almost completely.

Nature and proportion of the ions present in soil solution also influences crop production. Among the cations, the proportion of Ca and Na ions present in soil solution plays a very important role in influencing soil fertility. Fertile soils usually have a Ca : Na ratio greater than one. When proportion of Na ion increases to reduce the ratio to less than 1, the soil becomes less productive. The same is case with Ca: Mg ratio. Among the anions, the nitrate ions are most important. A soil supplying greater amount of nitrate ions during the crop growing period is usually more productive. The same is the case with phosphate ions.

EXERCISE

Q.1. Select the appropriate word :

1. The soil solution contains small but significant quantities of soluble _____ compounds.

(a) Inorganic (b) Organic

(c) Mineral (d) Inorganic and organic

2. The levels of __________ ions in soil solution influence the solubility and in tur availability of several nutrients to plants.

(a) N and P (b) P and K

(c) H and OH (d) N, P, K and H

3. The soil solution of cultivated soils contains a greater proportion of salts i ______________ state.

(a) Ionic (b) Molecular

(c) Dissolved (d) Suspended

4. Among all the cations ____________ cations are present in soil solution to the great extent.

(a) Ca, Mg, Na, K (b) Ca, Mg, Na

(c) Ca and Mg (d) N, P, K and S.

5. In solution of normal soils ____________ forms the predominant cation.

(a) Na (b) K

(c) Ca (d) Mg

6. In normal soil solution __________ anions are present in greater quantities than others.
(a) Carbonates (b) Bicarbonates
(c) Sulphates (d) Chlorides

7. In saline soils __________ ions are in preponderance .
(a) Carbonates and bicarbonates (b) Sulphates and chlorides
(c) Carbonates and sulphates (d) Bicarbonates and chlorides

8. Soils in arid and semi-arid regions have more __________ soil solution than those in temperate and moist tropical regions.
(a) Concentrated (b) Dilute
(c) Saturated (d) Unsaturated

9. The ions like __________ are absorbed almost completely by plants in preference to others.
(a) Carbonates (b) Nitrate
(c) Phosphate (d) Sulphate

10. The bases like ________ are brought in solution due to microorganisms.
(a) Ca and Mg (b) Ca and Na
(c) Mg and Na (d) Na and K

Q.2 Write to the point.

1. Name the predominant cation present in saline soil.
2. State the anions which are commonly present in soil solution in large quantities.
3. Which ion is dominant in acid soil solution ?
4. Enlist the factors affecting composition and concentration of soil solution.
5. How the roots of growing plant change the concentration and composition of soil solution.
6. Name the anions increased in soil solution due to microorganisms activity.

Q.3 Match the pairs.

1. Soil solution of arid soils	1. Lower concentration of solution
2. Soil microorganisms	2. Rich in divalent cations
3. Leaching	3. Nutrient supplying power
4. concentration of solution exceeds critical value	4. Ca : N Ratio > 1
5. Soil solution of temperate soils	5. Rich in monovalent cations
6. Crop production capacity of soils	6. Poor in nitrate ions
7. Cropped soils	7. Ions not adsorbed by colloids
8. Fertile soil	8. Increase the concentration of soil solution
	9. Plant growth suffers
	10. Ca : Mg ratio < 1
	11. Poor in phosphate ions.

□□□

14

Soil Organic Matter

Sources, factors affecting, composition, decomposition, role, humus formation, properties, clay-humus complex, C:N ratio

Soil organic matter comprises an accumulation of partially disintegrated and decomposed plant and animal residues and other organic compounds synthesized by the soil microbes as the decay occurs. Such material is continually being broken down and resynthesized by soil micro-organisms. Consequently, organic matter is a rather transitory soil constituent, lasting from a few hours to several hundred years. This constituent requires maintenance by the regular addition of plant and/or animal residues to the soil.

The organic matter content of a typically well drained mineral soil is low varying from 1 to 6% by weight in the topsoil and even less in the subsoils. The influence of organic matter on soil properties, and consequently, on plant growth is far greater even though the percentage of organic matter is less in the soil.

Sources of Soil Organic Matter

The primary sources of soil organic matter is plant tissue are :

- The tops and roots of trees
- Shrubs
- Grasses
- Remains of harvested crops
- Soil organisms
- Animals usually are considered as secondary source of organic matter.
- Waste products of animals
- Remains of animals after completion of life cycle.

Factors Affecting Soil Organic Matter

The important factors that affect the soils organic matter are :

1. Climate
2. Natural vegetation
3. Texture
4. Drainage
5. Cropping and tillage

6. Rotations, residues and plant nutrients

These factor are described below :

1. Climate : Climatic conditions, especially temperature and rainfall, exert a dominant influence on the amounts of nitrogen and organic matter found in soils.

Temperature : As one moves from warmer to cooler areas, the organic matter and nitrogen of comparable soils tend to increase. At the same time, the C/N ratio increases somewhat. In general, the decomposition of organic matter is accelerated in warm climates; a lower rate of decay is the rule in cool regions. Within belts of uniform moisture conditions and comparable vegetation, the average total organic matter and nitrogen increase by two to three times for each 10°C decline in mean annual temperature.

Rainfall : It is generally observed that there is an increase in organic matter with an increase in rainfall. Although a correlation of increasing organic matter with rainfall exists, remember that the level of organic matter in any one soil is influenced by temperature and other factors as well as by precipitation. Climate influences never work independently. Moisture also exerts a positive influence on the accumulation of organic matter and nitrogen in soils. Ordinarily, under comparable conditions, the nitrogen and organic matter increase as the effective moisture becomes greater. The C/N ratio also increases, especially in grassland areas.

2. Natural Vegetation : Grasslands generally dominate the subhumid and semiarid areas, whereas trees are dominant in humid regions. In climatic zones where the natural vegetation includes both forests and grasslands, the total organic matter is higher in soils developed under grasslands than those under forests.

3. Texture : The texture of the soil, other factors being constant, influences the percentage of humus and nitrogen present. Soils high in clay and silt are generally higher in organic matter than coarser-textured soils.

4. Drainage : Poorly drained soils, because of their high moisture content and relatively poor aeration, are generally much higher in organic matter and nitrogen than their better drained equivalents.

5. Cropping and Tillage : The cropped land has much lower nitrogen and organic matter than comparable virgin soils. Modern conservation tillage practices helps maintain high surface soil organic matter levels. Compared to conventional tillage, these practices leave a higher proportion of the residues on or near the soil surface. This technique protects the soil from erosion and also discourages the rapid decay of the crop residues.

6. Rotations, Residues and Plant Nutrients : A rotation of corn, oats, and clovers results in a higher soil organic matter level than did continuous corn. The nitrogen fixed by the clover and the higher crop residues from this rotation likely accounted for the higher level of organic matter. The application of manure, lime, and phosphorus help to maintain much higher organic matter levels, especially where a rotation of crops is followed.

Composition of Plant Residues

The number of organic substances is immense, and they are as variable in composition as they are numerous. Organic matter is composed of about half carbon with lesser amounts of oxygen and hydrogen plus small quantities of nitrogen, phosphorus, sulfur, and many other elements. Carbon atoms joined together into carbon chains of many lengths and linkage are the basic "skeleton" of organic compounds. The remaining elements fill out the skeletons to make different groups of organic matter substances called proteins, lignins, carbohydrates, oils, fats , waxes, and many other materials.

The moisture content of plant residues is high, varying from 60-90%, with 75% a representative figure. On a weight basis, the dry matter is mostly carbon and oxygen, with less than 10% each of hydrogen and inorganic elements (ash). However, on an elemental basis (number of atoms of the elements), hydrogen predominates. In a representative plant residues there are 8 hydrogen atoms for every 3.7 carbon atoms and 2.5 oxygen atoms. These three elements dominate the bulk of organic tissue in the soil.

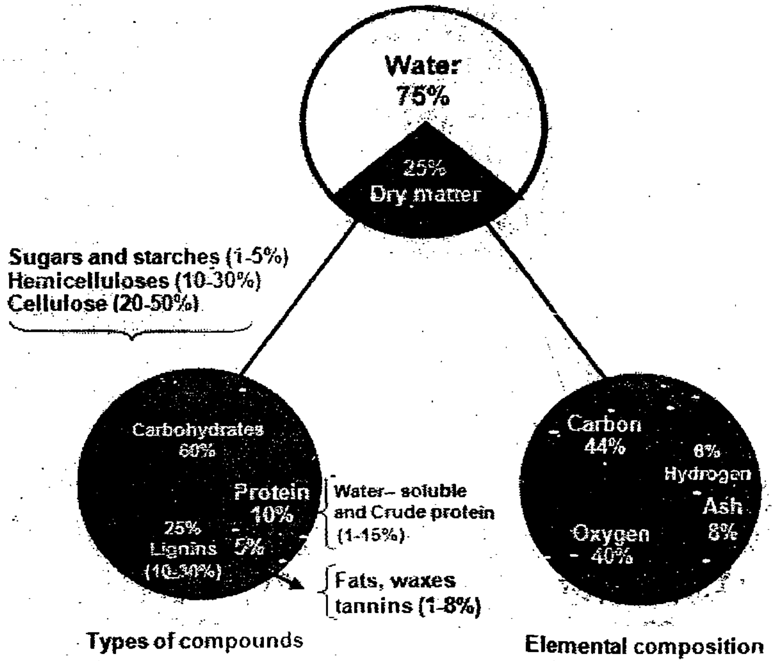


Fig. 14.1: Composition of representative green plant materials.

The general composition of representative green plant materials added to the soils can be looked into figure 14.1. Note that all inorganic elements, including nitrogen, are represented in the ash. Common ranges in the percentages of compounds present are shown in parentheses.

Decomposition of Soil Organic Matter

The organic materials (plant and animal residues) incorporated in the soil do not remain as such very long. They are at once attacked by a great variety of micro-organisms, worms and insects present in the soil especially if the soil is moist. The micro-organism for obtaining their food, break up the various constituents of which the organic residues are composed and convert them into new substances. Some of these substances are very simple in composition and others highly complex. The whole of the organic residues is not decomposed all at once or as a whole. Some of the constituents are decomposed very rapidly, some less readily and others very slowly. They may be listed in terms of ease of decomposition as follows :

1. Sugars, starches and simple proteins Rapid decomposition
2. Crude proteins
3. Hemicelluloses
4. Cellulose
5. Fats, waxes resins
6. Lignins Very slow decomposition

The organic matter is also classified on the basis of their rate of decomposition as given below :

Rapidly decomposed : Sugars, starches, proteins etc.
Less rapidly decomposed : Hemicelluloses, celluloses etc.
Very slowly decomposed : Fats, waxes, resins, lignins etc.
Simple decomposition products : Aerobic – CO_2, H_2O, NO_3, SO_4, PO_4 etc.
Anaerobic – CH_4, H_2, N_2O, N_2 etc.

When organic material is added to soil, three general reactions take place.

1. The bulk of the material undergoes enzymatic oxidation with carbon dioxide, water, energy, and heat as the major products.

2. The essential elements such as nitrogen, phosphorus and sulphur are released and/or immobilized by a series of specific reactions relatively unique for each element.

3. Compounds very resistant to microbial action are formed either through modification of compounds in the original plant tissue or by microbial synthesis.

A. Decomposition of Soluble Substances : Sugars and water-soluble nitrogenous compounds are the first to be decomposed as they offer a very readily available source of carbon, nitrogen and energy for the micro-organisms. Thus, when glucose is decomposed under aerobic conditions the reaction is as under :

$$\text{Sugar} + \text{Oxygen} \longrightarrow \text{Carbon dioxide} + \text{Water}$$

When the nutrient or oxygen supplies are restricted, partially oxidized different compounds are formed :

$$\text{Sugar} + \text{Oxygen} \longrightarrow \text{Aliphatic acids (Acetic, formic etc.)}$$

Or

Hydroxy acids (Citric, lactic etc.)

Or

Alcohols (Ethyl alcohol etc.)

Some of the reactions involved may be represented as under :

$$C_6H_{12}O_6 + 2O_2 \longrightarrow \underset{\text{(acetic acid)}}{2CH_3.COOH} + 2CO_2 + 2H_2O$$

$$2C_6H_{12}O_6 + 3O_2 \longrightarrow \underset{\text{(citric acid)}}{2C_6H_6O_7} + 4H_2O$$

$$C_6H_{12}O_6 + 2O_2 \longrightarrow \underset{\text{(ethyl alcohol)}}{2C_2H_5OH} + 2CO_2$$

(i) Ammonification : Soluble nitrogenous compounds, viz., amino acids, amides, ammonium compounds, nitrates etc., are also attacked by the micro-organisms. The transformation of organic nitrogenous compounds into ammonia is called *ammonification*. During the course of action under aerobic conditions by heterotrophic organisms, oxygen is taken up and carbon dioxide is released. Ammonification process involves a gradual simplification of complex compounds.

Protein → Polypeptides → amino acids → ammonia or ammonium salt

Or

$$\text{Organic nitrogen} \longrightarrow NH_3$$

The ammonification occurs as a result of action of enzymes produced by micro-organisms. Their action is chiefly hydrolytic and oxidative (in presence of air).

(ii) Nitrification : The process of conversion of ammonia to nitrites (NO_2) and then to nitrate (NO_3) is known as *nitrification*. The production of nitrate is more rapid than that of nitrite, while the formation of ammonia is the slowest process. That is why soil usually contains more nitrate nitrogen than nitrite at any time. Nitrification is an aerobic process involving the production of nitrates from ammonium salts. It is the work of autotrophic bacteria :

$$\underset{\text{Ammonia}}{NH_3} \xrightarrow{\text{Nitrosomonas}} \underset{\text{Nitrite}}{NO_2} \xrightarrow{\text{Nitrobacter}} \underset{\text{Nitrate}}{NO_3}$$

The net reactions are as follows :

$$NH_4^+ + O_2 \longrightarrow NO_2^- + 2H^+ + H_2O + \text{energy (66 k cal)}$$

$$NO_2^- + O_2 \longrightarrow NO_3^- + \text{energy (18 k cal)}$$

The process, which involves conversion of soil nitrate into gaseous nitrogen o nitrous oxide, is called *denitrification*.

$$\text{Nitrate} \xrightarrow{\text{pseudomonas / Bacillus}} \text{Nitrogen gas}$$

Water logging (e.g. Rice field) and high pH will increase nitrogen loss by denitrification.

B. Decomposition of Insoluble Substances

(i) Breakdown of Protein : Proteins are complex organic substance containing nitrogen, sulphur, and sometimes phosphorus, in addition to carbon, hydrogen and oxygen. During the course of decomposition of plant materials, th proteins are first hydrolyzed to a number of intermediate products, e.g., proteoses, peptones, peptides, etc., collectively known as polypeptides. The changes may be represented as under :

$$\underbrace{\text{Proteins} \xrightarrow{\text{hydrolysis}} \begin{pmatrix}\text{Proteoses}\\ \text{Peptones}\\ \text{Peptides}\end{pmatrix}}_{\text{Aminization}} \longrightarrow \underbrace{\begin{pmatrix}\text{Amino}\\ \text{acids}\\ \text{Amides}\end{pmatrix} \longrightarrow \text{Ammonia}}_{\text{Ammonification}}$$

The process of conversion of proteins to amino acids is known as aminization and the conversion of amino acids and amides to ammonia is known as ammonification.

(ii) Breakdown of Cellulose : Cellulose is the most abundant carbohydrate present in plant residues. The micro-organisms break up cellulose into cellobiose and glucose. Glucose is further attacked by organisms and converted into organic acids :

The decomposition of cellulose in acid soils proceeds more slowly than in neutral and alkaline soils. It is quite rapid in well aerated soils and comparatively slow in those poorly aerated.

(iii) Breakdown of Hemicellulose : When subjected to microbial decomposition, hemicelluloses are first hydrolysed to their components sugars and uronic acids. The sugars are further attacked by micro-organisms. They are converted to organic acids, alcohols, carbon dioxide and water. The uronic acids are broken down to pentose and carbon dioxide. The newly synthesised hemicelluloses thus form a part of the humus. Hemicelluloses decompose faster than cellulose.

(iv) Breakdown of Starch : Chemically it is glucose polymer. It is first hydrolysed to maltose by the action of enzymes (amylases). Maltose is next converted to glucose by another enzyme (Maltase). Glucose being soluble in water is utilized for growth and other metabolic activities. The process may be represented as under :

$$(C_6H_{10}O_5)_n + nH_2O \longrightarrow n(C_6H_{12}O_6)$$

C. Decomposition of Ether Soluble Substances. Fats are first broken down by micro-organisms through the agency of enzymes lipase into glycerol and fatty acids. Glycerol is further oxidised to organic acids which along with the other fatty acids are finally oxidised to carbon dioxide and water.

$$\text{Fats} \xrightarrow{\text{lipase}} \text{glycerol} + \text{fatty acids}$$

$$\text{Glycerol} \xrightarrow{\text{oxidation}} \text{corbon dioxide} + \text{water}$$

D. Decomposition of Lignin : Lignin is deposited on the cell wall to impart strength to the skeleton framework of plant. Lignin decomposes slowly, much slower than cellulose. Complete oxidation of lignin gives rise to carbon dioxide and water.

Simple Decomposition Products

As the enzymic changes of the soil organic matter proceed, simple products begin to manifest themselves. Some of these, especially carbon dioxide and water, appear immediately. Others, such as nitrate nitrogen, accumulate only after the peak of the vigorous decomposition is over. The more common simple products resulting from the activity of the soil micro organisms are as follows :

Carbon : CO_2, CO_3—, HCO_3^- , elemental carbon
Nitrogen : NH^{4+}, NO^{2-} , NO^{3-} gaseous nitrogen
Sulphur : S, H_2S, SO_3—, SO_4— , CS_2
Phosphorus : H_2PO^{4-} , HPO_4 —
Others : H_2O , O_2 , H_2 , H^+ , OH^- , K^+ , Ca^{++} , Mg^{++} etc.

(i) Mineralization of Organic Sulphur : Many organic compounds, especially those of a nitrogenous nature, carry sulphur. Heterotrophic bacteria simplify the complex organic compounds, then autotrophic bacteria (sulphur bacteria) oxidise it into sulphate form.

$$\underset{\text{Sulphur}}{S} + 2O_2 \xrightarrow[\text{Oxidation}]{\text{Enzymic}} \underset{\text{Sulphate}}{SO_4^-}$$

(ii) Mineralization of Organic Phosphorus : A large proportion of the soil phosphorus is carried in organic combinations. Upon attack by micro-organisms the organic phosphorus compounds are mineralized; that is they are changed to inorganic combinations. It depends upon soil pH. As the pH goes up from 5.5 to 7.5 the available phosphorus changes from H2PO4 to HPO4=. Both of these forms are available to higher plants.

Factors Affecting Decomposition : The most important factors that alter the rate of decomposition of organic matter are :

1. Temperature : Cold periods retard plant growth and organic matter decomposition. If temperatueres are warm enough to produce considerable vegetation during the growing season, but are cold for long periods at other times of the year, organic matter accumulation in and on the soil will be high. Continuous cold temperatures lower soil humus because of less plant material is grown. Warm summers may permit plant growth and humus accumulation. Continuous warm temperatures not only aid high plant production, but also promote faster decomposition.

2. Soil Moisture : Both plant grrowth and organic matter decomposition require moisture; near or slightly wetter than field capacity moisture conditions are most favourable for both processes. Extremes of both arid (dry) and anaerobic (waterlogged) conditions reduce plant growth and microbial decomposition. (Water weeds and rice are common exceptions to this guide of growth inhibition in anaerobic conditions). Poorly drained soils with growing vegetation usually have relatively high humus contents; such conditions have been the cause of formation of some organic soils.

3. Nutrients : Lack of nutrients, particularly nitrogen, usually reduces plant growth more than it slows decomposition because micro-organisms use the nutrients in the dead organic material before plant roots can absorb it.

4. Soil pH : Most common microorganisms grow best at pH 6-8, but are severely inhibited below pH 4.5 and above pH 8.5. Strontly acid soils are even more inhibiting to microbe growth than are strongly alkaline ones. (Plants tolerate pH extremes more readily than do microbes.)

5. Soil Texture : Soils higher in clays tend to retain larger amounts of humus, other conditions being equal. Most organic substances adsorb to mineral surfaces by many kinds of bonds, particularly to clays. The many active bonding sites of minerals and humus include the = O, —OH, —Al—OH, —Fe—OH, and cation exchange sites of minerals, and the $-NH^{3+}$, —SH, —OH, and –COOH portions of organic materials. When oily or waxy molecules (such as caome from conifer needles) are adsorbed, the soil may become water repelent as these materials coat soil solids.

6. Other factors : Other decomposition inhibitors include toxic levels of elements (aluminum, manganese, boron, selenium, chloride), excessive soluble salts, shade, and organic phytotoxins (toxic to plants) in plant materials. The type of plant is also important, as legumes are more readily decomposed than grasses.

Role of Organic Matter

The effects of organic matter on soil fertility are as follows :

1. Organic matter binds soil particles into structural units called aggregates. These aggregaes help to maintain a loose, open, granular condition. Water infiltrate and percolate more readily. The granular condition of soil maintains favourable condition of aeration and permeability.

2. Water holdong capacity of soil is increased by organic matter. Organic matter definitely increases the amount of available water in sandy and loamy soils. Further, the granular soil resulting from organic matter additions, supplies more water than sticky and impervious soil.

3. Surface runoff and erosion are reduced by organic matter as there is good infiltration.

4. Organic matter on the soil surface reduces losses of soil by wind erosion.

5. Surface mulching with coarse organic matter, lowers soil temperatures in the summer and keep the soil warmer in winter.

6. The organic matter serves as a source of energy for the growth of soil micro-organisms.

7. Organic matter serves as a reservoir of chemical elements that are essential for plant growoth. Most of the soil nitrogen occurs in organic combination. Also a considerable quantity of phosphorus and sulphur exist in organic forms. Upon decomposition, organic matter supplies the nutrients as well as many hormones and antibiotics needed by growing plants.

8. Fresh organic matter has a special function in making soil phosphorus more readily available in acid soils.

9. Organic acids released from decomposing organic matter help to reduce alkalinity in soils.

10. Fresh organic matter supplies food for such soil life such as earthworms, ants and rodents. These micro-organisms improve drainage and aeration. Earth worms can flourish only in soils that is well provided with organic matter.

11. Organic matter upon decomposition produces organic acids and carbon dioxide which helps to dissolve minerals such as potassium and make them more available to growing plants.

12. Humus (highly decomposed organic matter) provides a storehouse for the exchangeable and available cations – potassium and magnesium. Ammonium fertilizers are also prevented from leaching because humus holds ammonium in an exchangeable and available form.

13. It acts as a buffering agent. Buffering checks rapid chemical changes in pH and in soil reaction.

HUMUS

Humus is a mixture of complex compounds, not a single material and the compounds that make up humus have been synthesized by micro-organisms in the soil from products of the breakdown or alteration of the original plant tissue. These two facts lead to the following definition.

Humus is a complex and rather resistat mixture of brown or dark brown amorphous and colloidal organic substance that results from microbial decomposition and synthesis and has chemical and physical properties of great significane to soils and plants.

Humus Formation

The humus compounds have resulted from two general types of biochemical reactions : decomposition and synthesis.

1. Decomposition : Decomposition occurs as chemicals in the plant residues are broken down or drastically modified by soil organisms. Even lignin is split and degraded, many of its structural units being destroyed. Other simple organic compounds that also result from the breakdown may take part immediately in the second of the humus-forming processes, biochemical synthesis. These simple chemicals are metabolized into new compounds in the body tissue of the soil micro-organisms. The new compounds are subject to further modification and synthesis as the microbial tissue is subsequently attacked by other soil micro-organisms.

2. Synthesis : Synthetic reactions involve such breakdown products of lignin as the phenols and quinones. These decomposition products, present initially as separate molecules called monomers, are enzymatically stimulated to join togethe into polymers. By this process of polymerization (linkage) *polyphenols* and *polyquinones* are formed. These high molecular weight compounds interact with nitrogen-containing amino compounds and give rise to a significant component of resistant humus. The formation of these polymers is encouraged by the presence of colloidal clays. Studies suggest that there are two general groups of compounds that collectively make up humus, the humic group and the nonhumic group.

Humic Group : The humic substances make up about 60 – 80% of the soil organic matter. They are comprised of the most complex material, which are also the most resistant to microbial attack. These are characterized by aeromatic, ring-type structures. *e.g.*, Polyphenols and polyquinones, which are even more complex. They are amorphous, dark in colour and have high to very high molecular weights.

Nonhumic Group : The nonhumic group comprises about 20-30% of the organic matter in soils. Nonhumic substances are less complex and less resistant to microbial attack than those of the humic group. E.g. Polysaccharides, polyuronides.

The approximate proportions of organic carbon from plant residues that are found in humic and non-humic compound 1 year ofter the residues were added to the soil are shown in fig. 14.2. Much of the carbon returns to the atmosphere as carbon dioxide, but nearly one third remains in the soil either as living organisms (5%) or as humus (25%).

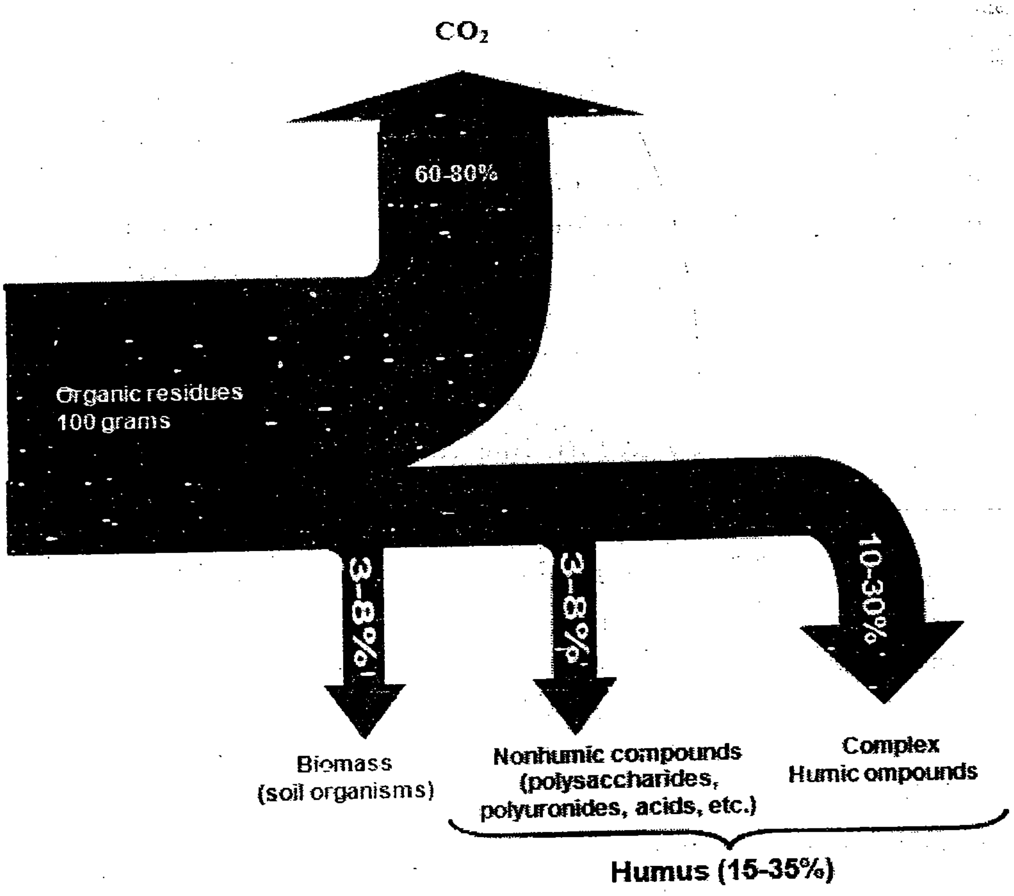


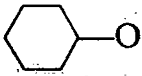
Fig. 14.2. Disposition of organic residuce 1 year after incorporation in soil.

Properties of Humus

The following are the major characteristics of humus :

1. The tiny colloidal humus particles (micelles) are composed of carbon, hydrogen, and oxygen (probably in the form of polyphenols, polyqunonoes, polyuronides, and polysaccharides).

2.The surface area of humus colloids per unit mass is very high, generally exceeding that of silicate clays.

3. The colloidal surfaces of humus are negatively charged, the source of the charge being hydroxy (—OH), carboxylic (—COOH), or phenolic (—OH) groups. The extent of the negative charge is pH dependent (high at high pH values).

4. At high pH values the cation exchange capacity of humus on a mass basis (150-300 cmol./kg) far exceeds that of most silicate clays.

5. The water-holding capacity of humus on mass basis is 4-5 times that of the silicate clays.

6. Humus has a very favourable effect on aggregate formation and stability.

7. The black color of humus tends to distinguish it from most of the other colloidal constituents in soils.

8. Cation exchange reactions with humus are qualitatively similar to those occurring with silicate clays.

Clay-Humus Complex

Humus and clay, one organic and the other inorganic, together form the soil colloidal complex. Though both are colloidal in nature, clay is crystalline while humus is amorphous having no definite shape or form. Both are extremely active and form important sources of plant nutrients. Clay supplies chiefly the basic nutrient ions. While humus supplies both basic and acidic ions. Both perform a number of other functions in soil economy and plant nutrition. Clay is more or less stable, while humus is transitory and ultimately disappears from the soil.

It is believed that humus and clay exist in the soil as a clay-humus complex, the two being held together, by cations like calcium, iron, etc. Depending upon the nature of cation binding the two colloidal particles, two different types of clay—humus complex have been recognised. In one, the colloidal particles of clay and humus are *held together by calcium ions*. The colloidal complex so formed is more stable and is responsible for the favourable physical condition of the soil, particularly its structure. In the other type of colloidal complex, *iron acts as the binding agent* holding the clay and humus particles together. The poor physical condition of some soils as in the case of podzols is attributed to this type of soil colloidal complex.

Carbon Nitrogen (C:N) Ratio

The ratio of the weight of organic carbon (C) to the weight of total nitrogen (N) in a soil (or organic material), is known as C : N ratio. When fresh plant residues are added to the soil, they are rich in carbon and poor in nitrogen. The content of carbohydrates is high. This results in wide carbon nitrogen ratio which may be 40 to 1. Upon decomposition the organic matter of soils changes to humus and has an approximate C : N ratio of 10 :1.

The ratio of carbon to nitrogen in the arable (cultivated) soils (organic matter) commonly ranges from 8 : 1 to 15 : 1. The carbon nitrogen ratio in plant material is variable, ranging from 20 : 1 to 30 : 1 in legumes and farm yard manure, to 100:1 in certain strawy residues. It is as high as 400:1 in saw dust. The C:N ratio of the body of moicro-organisms ordinarily ranges between 4:1 and 9:1. Low ratios of carbon to nitrogen (10 : 1) in soil organic matter generally indicate an average stage of decomposition and resistance to further micro-biological decomposition. A wide ratio of C : N (35 : 1) indicates little or no decomposition, susceptibility to further and rapid decomposition and slow nitrification.

Significance of C : N Ratio : The C:N ratio of soil organic matter is important for two major reasons :

1. Keen competition among micro-organisms for available nitrogen when organic residues (with high C : N ratio) are added to soils. When organic residues with a wide C/N ratio (50 :1) are incorporated in the soil, decomposition quickly occurs. Carbon dioxide is produced in large quantities. Under these conditions, nitrate- nitrogen disappears from the soil because of the insistent microbial demand for this element, and for the time being, little (or no) nitrogen is available to plants, consequently plant growth affected. As decay (decomposition) occurs, the C/N of the plant material decreases since carbon is being lost and nitrogen conserved. Nitrates (nitrogen) again appear in quantity in the soil, thus increases plant growth. (Fig. 14.3).

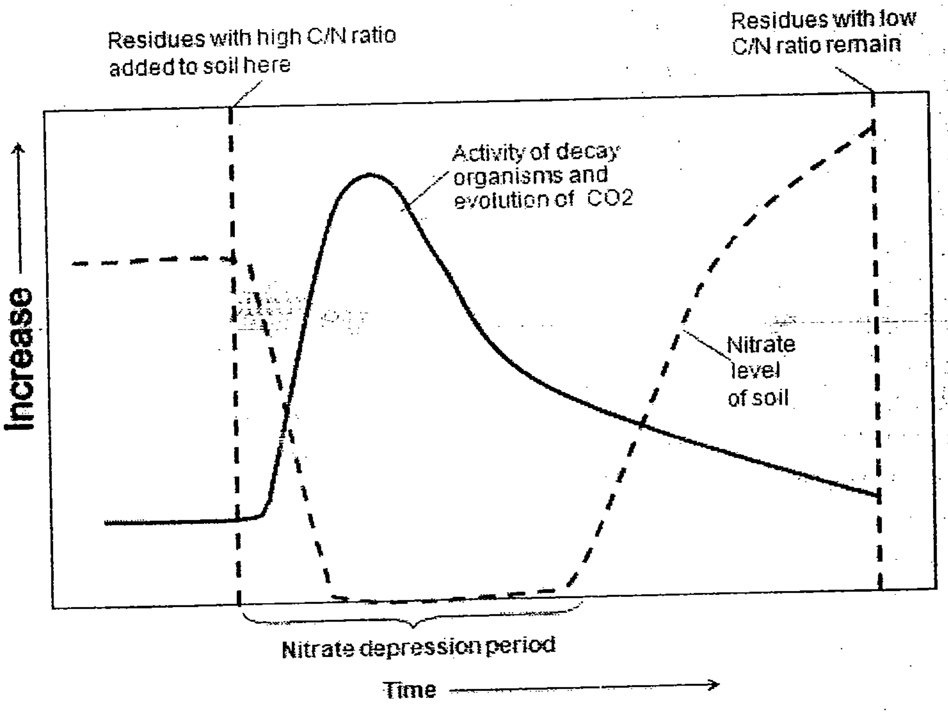


Fig. 14.3. Relationship between stage of decay of organic residues and presence of nitrate nitrogen in soil.

2. Consistency of C : N Ratio : As the decomposition processes continue, both carbon and nitrogen are lost—the carbon as carbon dioxide and the nitroen as nitrates which are leached or absorbed by plants. In time the percentatage of total nitrogen being removed equals the percentage of the total carbon being lost. At this point carbon-nitrogen ratio, becomes more or less constant, generally stablizes at 10:1 or 12:1.

It has always been considered profitable to mix the highly carbonaceous material like straw with a small quanitity of ammonium sulphate. With this available source of nitrogen from ammonium sulphate, the decomposition of fresh organic material is hastened and thus, the release of available nitrogen is affected in a shorter period of time.

EXERCISE

Q.1. Select the appropriate word :

1. As ____________ comprises of partially decomposed plant and animal residues, which is continuously being broken down and resynthesized and thus it is a transitory soil constituent.

(a) Humus (b) Organic matter
(c) Soil colloids (d) Silicate clay

2. The organic matter content is generally high in ____________.

(a) Subsoil of forest (b) Top soil of forest
(c) Subsoil in arid region (d) Top soil in arid region

3. Among the climate factor __________ exert a dominant influence on the amounts of nitrogen and organic matter in soil.

(a) Temperature and humidity (b) Humidity and rainfall
(c) Rainfall and its intensity (d) Temperature and rainfall

4. Within uniform moisture conditions and comparable vegetation, the average total lorganic matter and nitrogen increase by two to three times for each ________ decline in mean annual temperature.

(a) 20°C (b) 15°C
(c) 10°C (d) 5°C

5. Soils having better drainage contain generally ________ organic matter than poorly drained equivalent soil.

(a) Higher (b) Lower
(c) Maximum (d) Minimum

6. Carbon atoms joined together into carbon chain and linkage are the basic _____ of organic compounds.

(a) Requirement (b) Principle
(c) Skeleton (d) Numbers

7. In a representative plant residues, there are 8 hydrogen atoms for every ____________ carbon and oxygen atoms, respectively.

(a) 3.5 and 2.7 (b) 3.7 and 2.5
(c) 2.7 and 3.5 (d) 2.5 and 3.7

8. The compounds very resistant to microbial action are formed either through the modification of compounds in original plant tissue or by __________ synthesis.

(a) Physical (b) Chemical
(c) Biochemical (d) Microbial

9. During ammonification process of proteins, firstly ____ are formed from proteins.
(a) Amino acid (b) Plypeptides
(c) Ammonium salts (d) Ammonia

10. In microbial processes, the production of ________ is more rapid among all the forms of nitrogen.
(a) Ammonia (b) Nitrite
(c) Nitrate (d) Ammonium salts.

11. ________ is the slowest microbial process.
(a) Ammonification (b) Nitrification
(c) Denitrification (d) Desintegration

12. ____ bacteria are involved in conversion of nitrate-N into gaseous nitrogen or nitrous oxide.
(a) Heterotrophic (b) Autotrophic
(b) Pseudomonas (d) P-solubilizing

13. During decomposition of plant materials, the proteins are first hydrolyzed to a number of intermediate products which collectively known as ____.
(a) Proteoses (b) Peptones
(c) Peptides (d) Polypeptides

14. When subjected to microbial decomposition, hemicelluloses are first hydrolyzed to their components namely ________.
(a) Sugars and uronic acid (b) Sugars and galacturonic acid
(c) Sugars and celluloses (d) Celluloses and cellobioses

15. In presence of lipase enzymes, fats are first broken down into ________.
(a) Glucose and maltose (b) Glycerol and uronic acid
(c) Glucose and galacturonic acid (d) Glycerol and fatty acids

16. Sulphur is oxidized by ________.
(a) Antotrophic bacteria (b) Heterotrophic bacteria
(c) Pseudomonas bacteria (d) Bacillus–bacteria

17. As the soil pH goes up from 5.5 to 7.5 the available phosphorus changes from __ form.
(a) PO_4 to HPO_4 (b) H_2PO_4 to HPO_4
(c) HPO_4 to H_2PO_4 (d) H_2PO_4 to PO_4

18. Arid and anaerobic conditions reduce both plant growth and ____.
(a) Microbial decomposition (b) Adsorption
(c) Sugar decomposition (d) Enzyme activity

19. The toxic, level of ____ elements inhibit the decomposition of organic matter.
(a) Al, Mn, Cl and B (b) Al, Mn, Fe and Cu
(c) Al, Mn, Na and Zn (d) Al, Mn, Fe and S

20. Upon decomposition organic matter supplies the nutrients as well as many ________ needed by plants.
(a) Hormones (b) Antibiotics
(c) Hormones and antibiotic (d) Antibiotics and enzymes

Q.2. Answer to the point :

1. State the primary sources of soil organic matter.
2. What are the secondary sources of organic matter ?
3. Enlist the factors affecting soil organic matter.
4. Why poorly drained soils are high in organic matter content ?
5. How cropping and tillage practices influence on soil organic matter ?
6. Give the elemental composition of plant residues.
7. Name the three elements dominating in soil organic matter.

8. State the different compounds present in representative green plant material.

9. List the constituents of organic residues in terms of ease of decomposition.

10. State the three general changes taking place in soil after addition of organic matter.

11. Why the sugar and water soluble N compounds are decomposed rapidly?

12. Name two aliphatic acids and two hydroxy acids formed during decomposition of sugar under restricted oxygen supply.

13. Why the soils usually contain higher $NO_3 - N$ than $NO_2 - N$?

14. Name the major process of nitrogen loss from waterlogged soils having high pH.

15. Name the enzymes taking part in breakdown of starch.

16. List the simple decomposition products of sulphur and carbon.

17. Name the factors affecting decomposition of organic matter.

18. State the active bonding sites of minerals and humus.

19. How organic matter improves aeration in soil ?

20. How organic matter increases availability of potassium.

Q.3. Define the following terms.

1. Ammonification
2. Nitrification
3. Aminization
4. Organic matter
5. Decomposition
6. Humus

Q.4. Match the suitable pairs :

1. Cellulose	1. Very slow decomposition
2. Lipase	2. Rapidly decomposed
3. pH below 4.5 and above 8.5	3. Low in organic matter content
4. Grass land soils	4. Proteoses, peptones and peptides
5. Starch	5. Formation of NO3-N
6. Lignins	6. Very slow decomposition.
7. Sugars, starches and proteins	7. Rapidly decomposed
8. Humic group	8. Cellobiose, glucose and organic acid
9. Polypeptides	9. Not resistant to microbial attack
10. Course textured soils	10. Decomposition of fat
11. Complete oxidation of lignin	11. High organic matter content than forest soils.
12. Sugars, starch and proteins	12. Microbial activity severely inhibited
	13. Glucose polymer
	14. Most resistant to microbial attack

Q.5. Answer to the following questions :

1. State the role of organic matter in soil.
2. Discuss the two types of biochemical reactions of humus formation.
3. Write the properties of humus.
4. Explain the significance of C: N ratio with diagram.

Q.6. Write short notes on :

1. Humic and nonhumic groups.
2. Clay humus complex
3. C : N ratio.

□□□

15

Soil Water

Soil moisture, importance, factors affecting, maximum water holding capacity, field capacity, wilting point, available water capacity, pF, soil water movement: Saturated and unsaturated, water vapour movement, infiltration, percolation, permeability

Water contained in soil is called soil moisture. The water is hold within the soil pores. Soil water is the major component of the soil in relation to plant growth. If the moisture content of a soil is optimum for plant growth, plants can readily absorb soil water. Not all the water, held in soil, is available to plants. Much of water remains in the soil as a thin film. Soil water dissolves salts and makes up the soil solution, which is important as medium for supply of nutrients to growing plants.

Importance of Soil Water

1. Soil water serves as a solvent and carrier of food nutrients for growth of plant.
2. Yield of crop is more often determined by the amount of water available rather than the deficiency of other food nutrients.
3. Soil water acts as a nutrient itself
4. Soil water regulates soil temperature.
5. Soil forming processes and weathering depend on water.
6. Micro-organisms require water for their metabolic activities.
7. Soil water helps in chemical and biological activities of soil.
8. It is a principal constituent of the growing plant.
9. Water is essential for photosynthesis.

Retention of Water by Soil

The soils hold water (moisture) due to their colloidal properties and aggregation qualities. The water is hold on the surface of the colloids and other particles and in the pores. The forces responsible for retention of water in the soil after the drainage has stopped are due to surface tension and surface attraction and are called surface moisture tension. This refers to the energy concept in moisture retention relationships. The force with which water is hold is also termed as suction. The water retained in the soil by following ways :

1. Cohesion and Adhesion Forces. These two basic forces are responsible for water retention in the soil. One is the attraction of molecules for each other i.e., cohesion. The other is the attraction of water molecules for the solid surface of soil i.e. adhesion. By adhesion, solids (soil) hold water molecules rigidly at their soil – water interfaces. These water molecules in turn hold by cohesion. Together, these forces make it possible for the soil solids to retain water.

2. Surface Tension. This phenomenon is commonly evidenced at water-air interfaces. Water behaves as if its surface is covered with a stretched elastic membrane. At the surface, the attraction of the air for the water molecules is much less than that of water molecules for each other. Consequently, there is a net downward force on the surface molecules, resulting in sort of a compressed film (membrane) at the surface. This phenomenon is called surface tension.

3. Polarity or Dipole Character. The retention of water molecules on the surface of clay micelle is based on the dipole character of the molecule of water. The water molecules are held by electrostatic force that exists on the surface of colloidal particles. By virtue of their dipole character and under the influence of electrostatic forces, the molecules of water get oriented (arranged) on the surface of the clay particles in a particular manner. Each water molecule carries both negative and positive charges. The clay particle is negatively charged. The positive end of water molecule gets attached to the negatively charged surface of clay and leaving its negative end outward. The water molecules attached to the clay surface in this way present a layer of negative charges to which another layer of oriented water molecules is attached (fig.15.1). The number of successive molecular layers goes on increasing as long as the water molecules oriented. As the molecular layer gets thicker, orientation becomes weaker, and at a certain distance from the particle surface the water molecules cease to orientate and capillary water (liquid water) begins to appear.

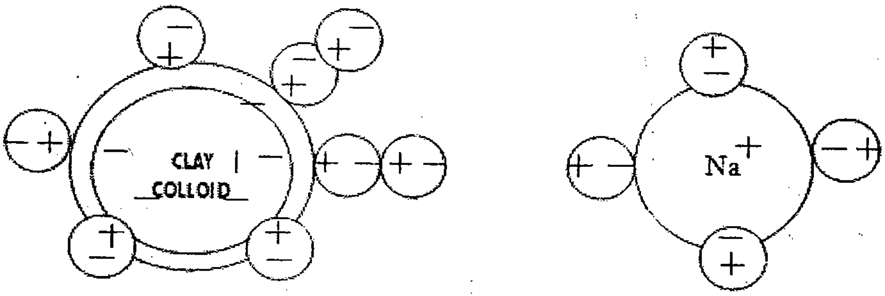


Fig. 15.1. Orientation of water molecules on the surface of clay micelle and cation.

Due to the forces of adsorption (attraction) exerted by the surface of soil particles, water gets attached on the soil surface. The force of gravity also acts simultaneously, which tries to pull it downwards. The surface force is far greater than the force of gravity so water may remain attached to the soil particle. The water remains attached to the soil particle or move downward into the lower layers, depending on the magnitude of the resultant force.

Factors Affecting Soil Water

Following factors affect the soil moisture content of the soil :

1. Texture : Finer the texture, more is the pore space and also surface area, greater is the retention of water.

2. Structure : Well-aggregated porous structure favours better porosity, which in turn enhance water retention.

3. Organic Matter : Higher the organic matter more is the water retention in the soil.

4. Density of soil : Higher the density of soil, lower is the moisture content.

5. Temperature : Cooler the temperature, higher is the moisture retention.

6. Salt content : More the salt content in the soil, less is the water available to the plant.

7. Depth of Soil : More the depth of soil, more is the water available to the plant.

8. Type of Clay : The 2:1 type of clay increases the water retention in the soil.

Soil Water Potential

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 *soil water energy concept.* Free energy of soil solids for water is affected by :

(i) *Matric (solid) force* i.e., the attraction of the soil solids for water (adsorption) which markedly reduces the free energy (movement) of the adsorbed water molecules.

(ii) *Osmotic force* i.e., the attraction of ions and other solutes for water to reduce 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.*

(iii) *Force of gravity,* acts on soil water, the attraction is towards the earth's center, which tends to pull the water downward. This force is always positive.

The difference between the energy states of soil water and pure free water is known as soil water potential. Total water potential (Pt) is the sum of the contributions of gravitation potential (Pg), matric potential (Pm) and the Osmotic potential or solute potential (Po).

$$Pt = Pg + Pm + Po$$

Potential represents the difference in free energy levels of pure water and of soil water. The soil water is affected by the force of gravity, presence of soil solid (matric) and of solutes.

Methods of Expressing Suctions

There are two units to express differences in energy levels of soil water.

(i) pF Scale : The free energy is measured in terms of the height of a column of water required to produce necessary suction or pressure difference at a particular soil moisture level. The pF, therefore, represents the logarithm of the height of a water column (cm.) to give the necessary suction. If water is allowed to be withdrawn from a wet soil under suction, the pressure below the layer of wet soil is less than above it. The difference between these two pressures determines the amount of water retained in the soil.

(ii) Atmospheres or Bars : It is the another common mean of expressing suction. Atmosphere is the average air pressure at sea level.

If the suction is very low, as occurs in the case of a wet soil containing the maximum amount of water that it can hold, the pressure difference is of the order of about 0.01 atmosphere or 1.0 pF equivalent to a column of water 10 cm in height. Similarly, if the pressure difference is 0.1 atmosphere the pF will be 2.0 (Table 15.1). Soil moisture constants can be expressed in term of pF values. A soil that is saturated with water has pF O, while an oven dry soil has a pF, 7.0. The maximum water holding capacity occurs at pF 1.0 and field capacity at pF 3.2 (fig. 15.5).

Table 15.1. pF values related to pressure and height of column of water.

Height of Column of Water (cm)	Pressure (atmosphere)	pF Value
1	0.001	0
10	0.01	1
10^2	0.1	2
10^3	1.0	3
10^4	10.0	4
10^5	100.0	5
10^6	1000.0	6
10^7	10,000.0	7

Measuring Soil Moisture

Two general types of measurements relating to soil water are ordinarily used.

(i) By some methods the moisture content is measured directly or indirectly and

(ii) Techniques are used to determine the soil moisture potential (tension or suction).

A. Measuring Soil Moisture Content in Laboratory

1. Gravimetric Method : This consists of obtaining a moist sample, drying it in an oven at 105°C until it loses no more weight, and then determining the percentage of moisture as follows :

$$\% \text{ Moisture} = \frac{\text{Loss in weight of soil}}{\text{Oven} - \text{dry weight of soil}} \times 100$$

Thus, if 100 grams of moist soil (soil and water) when dried loses 20 grams of water, the 80 grams of dry soil is used as a basis for the percentage calculation.

Therefore, $\% \text{ moisture} = \frac{20}{80} \times 100 = 25\%$

The gravimetric method is time consuming and involves laborious processes of sampling, weighing and drying in laboratory.

2. Electrical Conductivity Method : This method is based upon the changes in electrical conductivity with changes in soil moisture. Gypsum blocks inside of which are two electrodes at a definite distance apart, used in this method. These blocks require previous calibration for uniformity. The blocks are buried in the soil at desired depths and the conductivity across the electrodes measured with a modified wheatstone bridge. With proper calibrations, the percentage of moisture from the field capacity to the wilting percentage can be readily determined. These electrical measurements are affected by salt concentration in the soil solution and are not very helpful in soils with high salt contents.

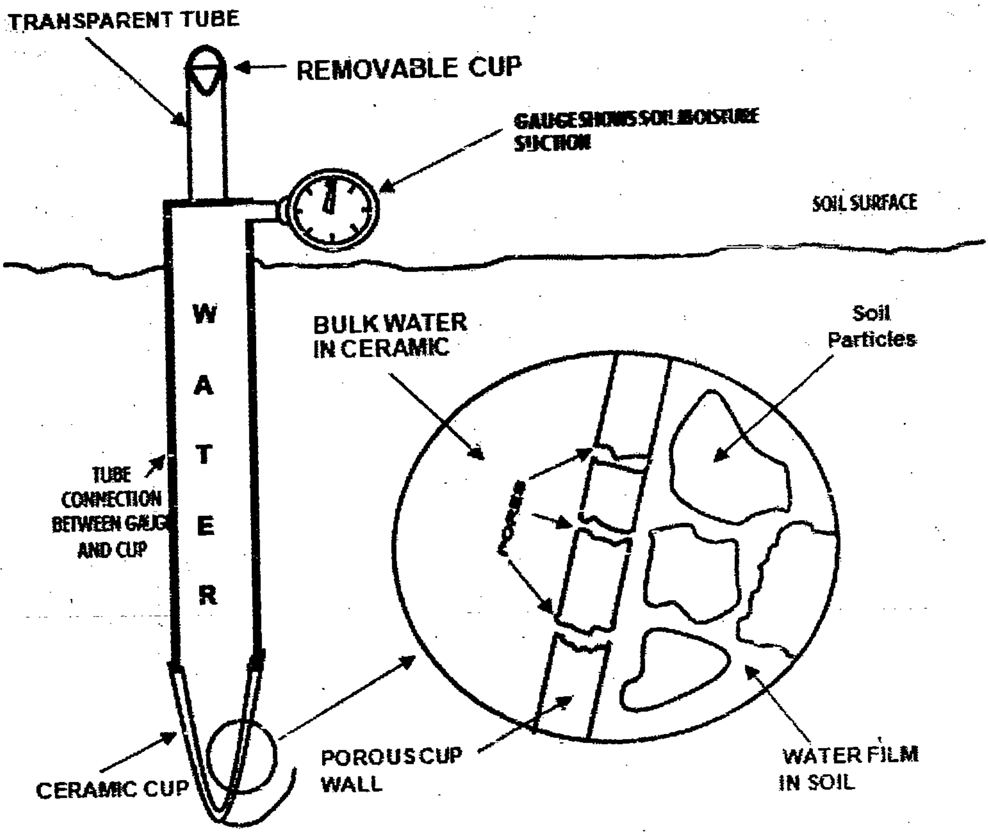


Fig. 15.2. Enlarged Section of Ceramic Cup showing Soil Particles.

3. Measuring Soil Moisture Potential in situ (field)

Suction methods or equilibrium tension methods : Field tensiometers measure the tension with which water is held in soils. They are used porous cup into the soil until equilibrium is established. These tension readings in the manometer, expressed in terms of cm or atmosphere, measures the tension or suction of the soil. If the soil is drier, water moves through the porous cup, setting up a negative tension (or greater is the suction). The tensiometers are more useful for measuring moisture in sandy soils than in fine textured soils. Once the air gets entrapped into the tensiometer, the reliability of readings is questionable.

Soil Moisture Tension Curves or Soil Characteristic Curves :

The suction curves for soils of different textural classes are shown in fig. 15.3. The curves bring out clearly the relation between tension and the moisture content of the soil, and the relationship of the various soil moisture constants to each other. It will be noticed that when the soil is perfectly dry it develops a tremendous suction or negative pressure approaching 10,000 atmospheres or pF 7. When the soil has absorbed the maximum amount of hygroscopic water the tension falls to about 30 atmospheres. In other words, it requires tremendous suction or energy to deprive a soil completely of its adsorbed or hygroscopic water. On the other hand, in the case of a saturated soil, a very slight suction is sufficient to remove excess or gravitational water from 0.01 to 0.03 atm. Between these

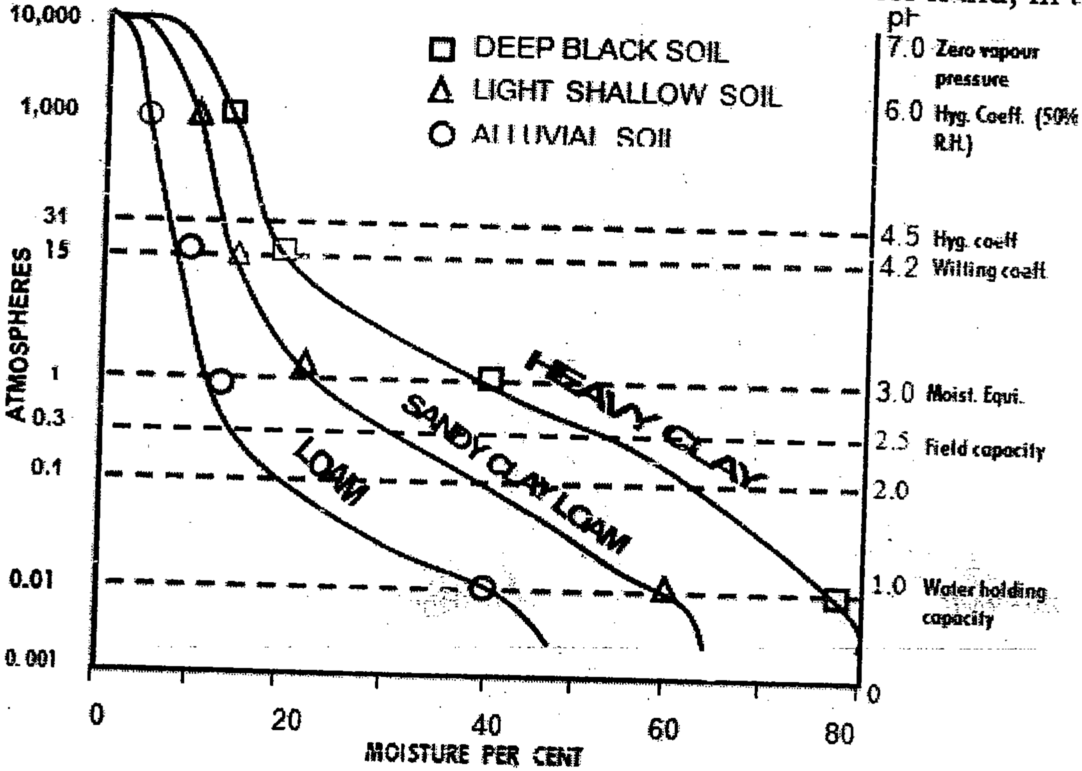


Fig. 15.3. Soil moisture tension curves for soils of different textures.

stage, then to the wilting stage, and further to the hygroscopic coefficient stage.

There is a rapid drop in tension as the moisture content increases. Note the initial lag in tension drop in the case of heavy soils.

The curves also bring out the relation between soil texture and soil moisture. As already explained that finer the texture, the greater are the hygroscopic coefficient, wilting coefficient, moisture equivalent and water holding capacity.

CLASSIFICATION OF SOIL WATER

Soil water has been classified from a physical and biological point of view as: Physical classification of soil water, and biological classification of soil water.

A. Physical classification of soil water

From a physical point of view the terms gravitational, capillary and hygroscopic waters are identified.The forms of soil moisture are discussed below :

1. Gravitational Water : Gravitational water occupies the larger soil pores (macro pores) and moves down readily under the force of gravity. Water in excess of the field capacity is termed gravitational water. Gravitational water is of no use to plants because it occupies the larger pores. It reduces aeration in the soil. Thus, its removal from soil is a requisite for optimum plant growth. Soil moisture tension at gravitational state is zero or less than 1/3 atmosphere.

Factors affecting gravitational water :

(i) **Texture** plays a great role in controlling the rate of movement of gravitational water. The flow of water is proportional to the size of particles. The bigger the particle, the more rapid is the flow or movement. Because of the larger size of pore (tube), water percolates more easily and rapidly in sandy soils than in clay soils.

(ii) **Structure** also affects gravitational water. In platy structure movement of gravitational water is slow and water stagnates in the soil. Granular and crumby structure help to improve gravitational water movement. In clay soils having single – grain structure, the gravitational water, percolates more slowly. If clay soils form aggregates (granular structure), the movement of gravitational water improves.

2. Capillary Water : Capillary water is held in the capillary pores (micro pores). Capillary water is retained on the soil particles by surface forces (fig.15.4). It is held so strongly that gravity cannot remove it from the soil particles. The molecules of capillary water are free and mobile and are present in a liquid state. Due to this reason it evaporates easily at ordinary temperature. Though it is hold firmly by the soil particle, plant roots are able to absorb it. Capillary water is, therefore, known as available water. The capillary water is held between 1/3 and 31 atmosphere pressure.

Factors affecting Capillary Water : The amount of capillary water that a soil is able to hold varies considerably. The following factors are responsible for variation in the amount of capillary water.

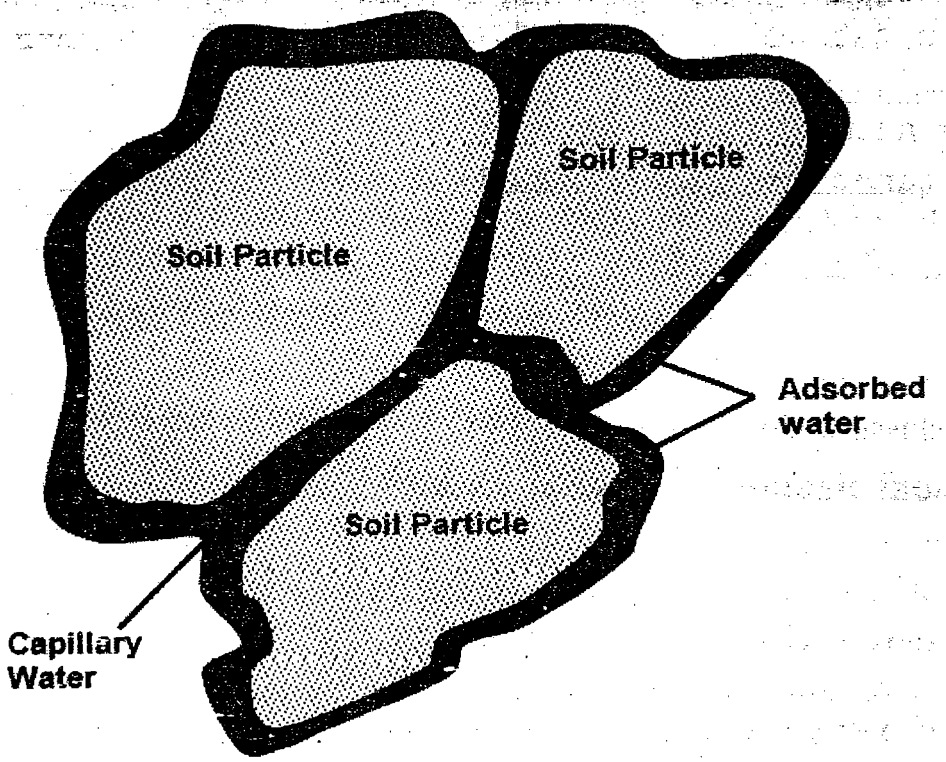


Fig. 15.4. Two "Forms" of water that together give rise to matric potential (adsorbed and capillary). The soil solids tightly adsorb water. (adsorbed and capillary).

(i) Surface tension : An increase in surface tension increases the amount of capillary water.

(ii) Soil texture : The finer the texture of a soil, greater is the amount of capillary water holds. This is mainly due to the greater surface area and a greater number of micro pores.

(iii) Soil structure : Platy structure contains more water than granular structure.

(iv) Organic matter : The presence of organic matter helps to increase the capillary capacity of a soil. Organic matter itself has a great capillary capacity. Undecomposed organic matter is generally porous having a large surface area, which helps to hold more capillary water. The humus that is formed on decomposition has a great capacity for absorbing and holding water. Hence, the presence of organic matter in soil increases the amount of capillary water in soil.

3. Hygroscopic Water : The water that held tightly on the surface of soil colloidal particle is known as *hygroscopic water*. It is essentially non-liquid and moves primarily in the vapour form. Hygroscopic water held so tenaciously (31 to 10, 000 atmosphere) by soil particles that plants can not absorb it. Some micro-organism may utilize hygroscopic water. As hygroscopic water is held tenaciously by surface forces its removal from the soil requires a certain amount of energy. Unlike capillary water which evaporates easily at atmospheric temperature (it requires very little energy for its removal), hygroscopic water cannot be separated from the soil unless it is heated (Fig.15.5).

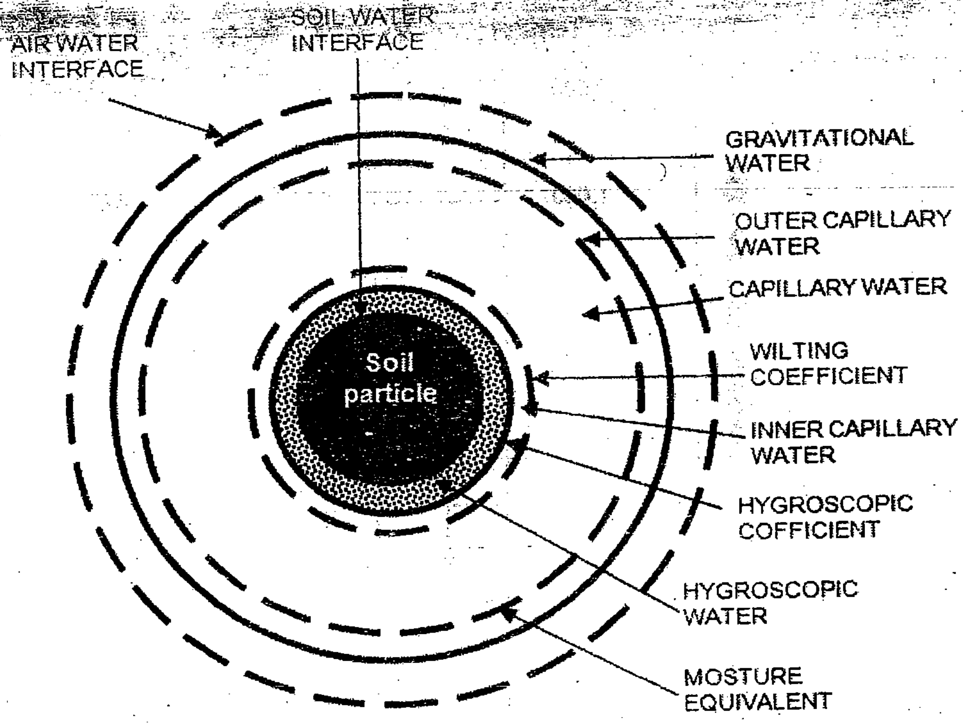


Fig. 15.5. Diagrammatic representation of different forms of soil water.

Factors Affecting Hygroscopic Water

Hygroscopic water is held on the surface of colloidal particles by the dipole orientation of water molecules. The amount of hygroscopic water varies inversely with the size of soil particles. The smaller the particle, the greater is the amount of hygroscopic water it adsorbs. Fine texture soils like clay contain more hygroscopic water than coarse-texture soils.

Not only the amount of clay but also its nature influences the amount of hygroscopic water. Clay minerals of the montmorillonite type with their large surface area adsorb more water than those of the kaolinite type. While illite minerals are intermediate.

B. Biological Classification of Soil Water

There is a definite relationship between moisture retention and its utilization by plants. This classification based on the availability of water to the plant. Soil moisture can be divided into three parts as shown in fig 15.6 :

1. Available Water. The available water is that water which lies between wilting coefficient and field capacity.It is obtained by subtracting wilting coefficient from moisture equivalent.

2. Unavailable Water. The unavailable water includes the whole of the hygroscopic water plus a part of the capillary water below the wilting point.

3. Super available or Superfluous Water. The water beyond the field capacity stage is said to be super available. It includes gravitational water plus a part of the capillary water removed from larger interstices. This water is unavailable for the use of plants. The presence of super-available water in a soil for any extended period is harmful to plant growth because of the lack of air.

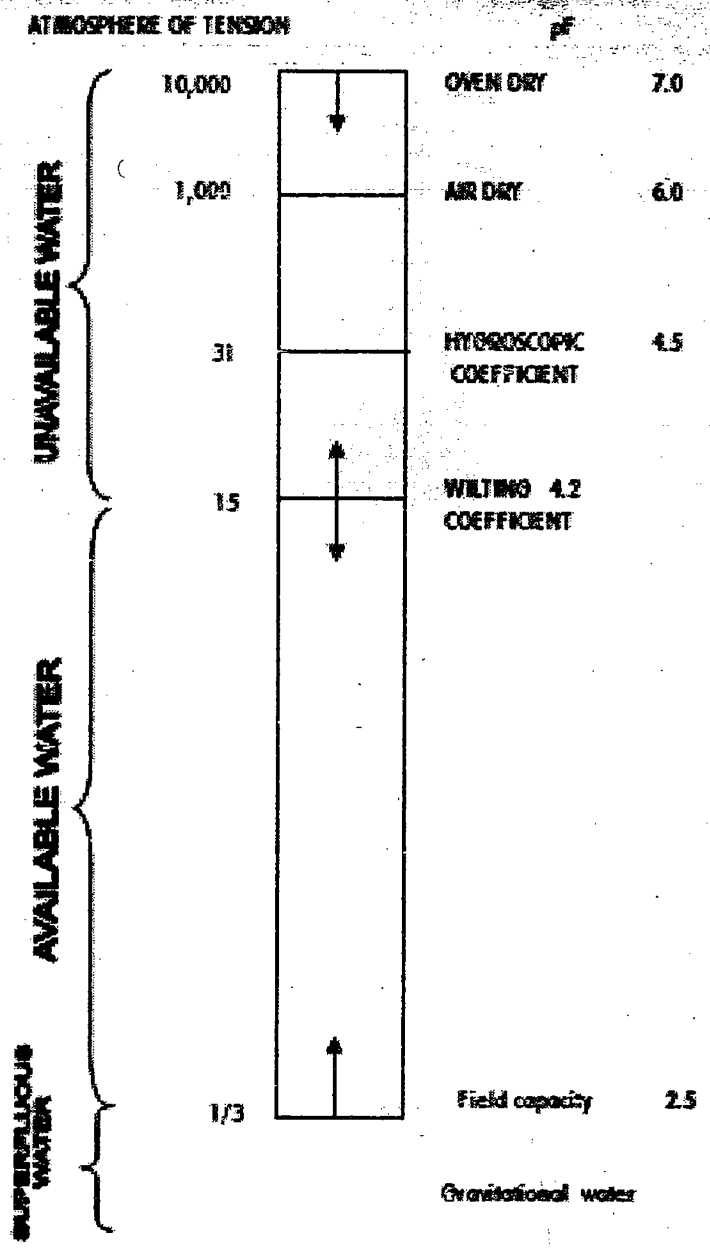


Fig. 15.6. The soil moisture constants.

Soil Moisture Constants

Earlier classification divided soil water into gravitational, capillary and hygroscopic water. The hygroscopic and capillary waters are in equilibrium with the soil under given condition. The hygroscopic coefficient and the maximum capillary capacity are the two equilibrium points when the soil contains the maximum amount of hygroscopic and capillary waters, respectively. The amount of water that a soil contains at each of these equilibrium points is known as a *soil moisture constant*. The soil moisture constant, therefore, represents definite soil moisture relationship and retention of soil moisture in the field.

The three classes of water (gravitational, capillary and hygroscopic) are however, very broad and do not represent accurately the soil – water relationships that exists under field conditions. Though the maximum capillary capacity represents the maximum amount of capillary water that a soil holds, the whole of capillary water is not available for the use of the plants. A part of it, at its lower limit approaching the hygroscopic coefficient, is not utilized by the plants. Similarly a part of the capillary water at its upper limit is also not available for the use of plants. Hence two more soil constants, viz., field capacity and wilting coefficient, have been introduced to express the soil-plant-water relationships as it is found to exist under field conditions. Following are the soil moisture constants.

1. Field Capacity : Assume that water is applied to the surface of a soil. With the downward movement of water all macro and micro pores are filled up. The soil is said to be saturated with respect to water and is at maximum water holding capacity or maximum retentive capacity. It is the amount of water held in the soil when all pores are filled.

Sometimes, after application of water in the soil all the gravitational water is drained away, 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* or *normal moisture 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 micropores or capillary pores are filled with water and plants absorb water for their use. At field capacity water is held with a force of 1/3 atmosphere. Water at field capacity is readily available to plants and micro-organism (Fig. 15.6).

2. Wilting Coefficient : As the moisture content falls, a point is reached when the water is so firmly held by the soil particles that plant roots are unable to draw it. 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*. It represents the point at which the soil is unable to supply water to the plant. Water at wilting coefficient is held with a force of 15 atmosphere.

3. Hygroscopic Coefficient : The hygroscopic coefficient is the maximum amount of hygroscopic water absorbed by 100 gm of dry soil under standard conditions of humidity (50% relative humidity) and temperature (15oC). This tension is equal to a force of 31 atmospheres. Water at this tension is not available to plant but may be available to certain bacteria.

4. Available Water Capacity : The amount of water required to apply to a soil at the wilting point to reach the field capacity is called the "available " water. The water supplying power of soils is related to the amount of available water a soil can hold. The available water is the difference in the amount of water at field capacity (-30 kPa or –0.3 bar) and the amount of water at the permanent wilting point (-1500 kPa or –15 bars).

5. Maximum Water holding Capacity : It is also known as *maximum retentive capacity*. It is the amount of moisture in a soil when its pore spaces both micro and macro capillary are completely filled with water. It is a rough measure of total pore space of soil. Soil moisture tension is very low between 1/100th to 1/1000th of an atmosphere or pF 1 to 0.

6. Sticky Point Moisture : It represents the moisture content of soil at which it no longer sticks to a foreign object. The sticky point represents the maximum moisture content at which a soil remains friable. Sticky point moisture values vary nearly approximate to the moisture equivalent of soils. Summary of the soil moisture constants, type of water and force with which it is held are given in following table.

Table 15.2: Soil moisture constants and range of tension and pF.

Sr. No.	Moisture class	Range of tension in atmosphere	Equivalent pF range
1.	Chemically combined	Very high	—
2.	Water vapour	Held at saturation point in the soil air	—
3.	Hygroscopic	31 to 10,000 (-3100 kPa to–100 MPa)*	4.5 to 7
4.	Hygroscopic coefficient	31 (-3100 kPa)*	4.5
5.	Wilting point	15 (-1500 kPa)*	4.2
6.	Capillary	1/3 to 31 (-33 to –3100 kPa)*	2.54 to 4.5
7.	Moisture equivalent	1/3 to 1 (-33 to 100 kPa)*	2.7 to 3.0
8.	Field capacity	1/3 (-33 kPa)*	2.54
9.	Sticky point	1/3 (-33 kPa)* (more or less)	2.54
10.	Gravitational	Zero or less than 1/3 (0 or > -33 kPa)*	< 2.54
11.	Maximum water, holding capacity	Almost zero	—

* Water potential (- 1 MPa = - 1000 kPa)

Entry of Water into Soil

The water obtained by soil, or water moves in soil by following ways :

(i) Infiltration : Infiltration refers to the downward entry or movement of water into the soil surface. Infiltration is affected by many factors. Infiltration is a surface characteristic so primarily influenced by the condition of the surface of soil. Soil surface with vegetative cover has more infiltration rate than bare soils. Warm soils absorb more water than cold one. Coarse surface texture (Sandy), granular structure and high organic matter content in surface soil, all help to increase infiltration. Infiltration rate is comparatively lower in wet soils than dry soils.

Factors Affecting Infiltration

1. Clay minerals : If the soil is dominant in montmorillonitic clay mineral, the pores will decrease on swelling, thereby lowering the infiltration rate.

2. Soil texture : Coarse textured have usually high infiltration rate.

3. Soil structure : Infiltration rate is higher when soil is well aggregated.

4. Moisture content : Dry soil condition is conducive to rapid infiltration.

5. Vegetative covers : Vegetative cover helps infiltration while the presence of somewhat impervious subsoil layer reduce it.

6. Topography : If the land is sloping the rate of infiltration is slow.

(ii) Percolation : The movement of water through a column of soil is called percolation. Percolation is important for two reasons. First, percolating waters are the only source of recharge of ground water, which can again be used through wells for irrigation. Second, percolating waters carry plant nutrients down and often out of reach of plant roots (leaching). Percolation is dependent on rainfall. In dry region, percolation is negligible but in region of high rainfall, percolation is usually high. Sandy soils permit greater percolation in comparison to clayey soils. Vegetation and high water table reduce the percolation losses.

(iii) Permeability : Permeability indicates the relative ease of movement of water within the soil. The characteristics that determine how fast air and water move through the soil is known as permeability. The term hydraulic conductivity is also used which refers to the readiness with which a soil transmits fluids through it.

SOIL WATER MOVEMENT

Three types of soil water movements are observed in soil. These are :

A. Saturated flow B. Unsaturated flow and C. Vapour moment. These different types of soil water movements are described below space.

A. Saturated Flow. Saturated flow takes place when the soil pores are completely filled with water. This water moves at water potentials larger (less negative) than –33 kPa. Saturated flow is water flow caused by gravity's pull. It begins with water *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.* The direction of flow is from a zone of higher moisture potential to lower moisture potential. Generally, water percolates down (vertically) into the lower layers. But horizontal flow also occurs with very less rapidity in comparison to vertical flow. The flow of water under saturated conditions is determined by two major factors: the *hydraulic force* i.e. *hydraulic gradient* driving the water through the soil (commonly gravity) and the *hydraulic conductivity,* or the ease with which the soil pores permit water movement. Hydraulic gradient is change in hydraulic head per unit distance in the direction of flow. While hydraulic conductivity is the rate at which a liquid will flow through soil mass under a given hydraulic head. Hydraulic conductivity can be expressed mathematically as :

$$V = Kf$$

Where, V is the total volume of water moved per unit time.

f is the water moving force and

K is the hydraulic conductivity of soil.

Hydraulic head is the energy stored in a hydraulic system expressed as height to which water rises above a fixed datum.

Hydraulic Head = Pressure head + Gravity head

$$H = H(P) + H(g)$$

Factors Affecting Movement of Water

The factors that control the rate of water movement into the soil are :

1. Texture : The flow of water is proportional to the size of the particles. The bigger the particle, more rapid is the flow of movement. Therefore water percolates more easily and rapidly in sandy soils than in clay soils.

2. Structure : In clay soils having single–grain structure (structureless), the gravitational water percolates more slowly than in those having an aggregate structure. In platy structure, saturated flow is poor in comparison to granular structure.

3. Amount of organic matter in the soil : The greater the amount of organic matter and the coarser it is, the more water that enters the soil. Organic surface mulches are especially helpful in keeping infiltration high because they protect soil aggregates from breakdown by reducing the impact of raindrops and by continuing to supply the cementing agents for aggregates, such as gums, as they decompose.

4. Depth of the soil to hardpan : Shallow soils do not permit as much water to enter as do deep soils, if they are similar in other respects, such as texture and structure.

5. Amount of water in the soil: Wet soils do not have as high as infiltration rate as do moist or dry soils. This is partly because pores or cracks are fewer or smaller because clays have already wetted and swelled.

6. Temperature : High soil temperature helps the water flow down.

7. Pressure : The movement of gravitation water is also influenced by the resistance offered by the entrapped soil air. As a result of pockets of air, the soil air pressure is increased and percolation decreased. This is more especially the case in lower layers.

Vertical water flow: The most common mathematical expression for the vertical water flow rate through soil is called Darcy's Law. The law states that the rate of flow of liquid or flux through a porous medium is proportional to the hydraulic gradient in the direction of flow of the liquid.

$$Qw = -K \frac{\frac{dw}{d} - At}{ds}$$

Where, Qw = Quantity of water in cm^3

K = Rate constant, cm/s

dw = Water height (head), cm

A = Soil area, cm^2

t = Time (any time-units may be used as long as units are given)

ds = Soil depth used, cm.

Problem : Under steady state condition, the water is flowing through a saturated vertisol soil column 20 cm in height, cross sectional area of soil column is 100 cm^2. It's constant water level above soil column is 10 cm. and water out flow in one hour is 360 cm^3, what is the hydraulic conductivity ?

$$360 \ m^3 = \frac{K \times 30 \times 100 \ cm^2 \times 1 \ hour}{10}$$

$$K = 1.2 \ cm / hour$$

B. Unsaturated Flow. In saturated soils, the relatively rapid water movement is through the large and continuous pores. But in unsaturated soils, (Soil pores contain some air as well as water) these macropores are filled with air, leaving only the finer pores to accommodate water movement, which, as would be expected is slow.

Unsaturated flow is the flow of water held with water potentials lower (more negative) than about –20 to –33 kPa. Water will move toward the region of lower potential (toward the greater "pulling" force). The rate of flow is greater as the water potentialy gradient (the difference in potential between wet and dry) increases and as the size of the water filled pores also increases. The water movement under these conditions is very slow compared to that occurring when the soil is saturated.

C. Water Vapour Movement : There are two types of water movement : (a) Internal movement, the change from the liquid to the vapour state takes place within the soil, that is, in the soil pores, and (b) External movement, the phenomenon occurs at the land surface and the resulting vapour is lost to the atmosphere by diffusion and convection (surface evaporation). The diffusion of water vapour from one area to another in soils does occur. Water vapour moves from high vapour pressure (generally in moist soil) to low pressure (generally in dry soil).

EXERCISE

Q.1 Select the appropriate word :

1. The force responsible for retention of water in the soil after the drainage has stopped is called ____________.
   (a) Cohesion (b) Adhesion
   (c) Surface moisture tension (d) Water potential
2. The retention of water molecules on the surface of the clay micelle is based on the ____________.
   (a) Negative charge on the clay micelle
   (b) Dipole character of the molecule of water
   (c) Water retention characteristics of soil.
   (d) Structure of clay in the soil.

3. The water molecules are held by __________ that exists on the surface of colloidal particles.
(a) Electrical force (b) Electrostatic force
(c) Adhesive force (d) Suction force

4. In soil water gets attached on the soil surface because __________.
(a) The surface force is far greater than gravitational force
(b) Gravitation force is greater than surface force
(c) Surface force and gravitational force are just equal
(d) All the air spaces are filled.

5. Potentials are negative and reduce the free energy level of soil water.
(a) Matric gravitational (b) Osmotic and gravitational
(c) Matric and osmatic (d) Osmotic and adhesive

6. If 100 g, which soil dried in oven loses it weight by 25 g, which means that the soil contains __________ moisture.
(a) 25.0 % (b) 28.50%
(c) 33.33% (d) 44.44 %

7. The hygroscopic water in soil is held with __________ atmospheres.
(a) 10,000 (b) 1,000
(c) 31 (d) 15

8. There is a rapid as the moisture content in soil increases.
(a) Drop in tension (b) Rise in tension
(c) Drop in force (d) Rise in force

9. The movement of gravitational water is rapid with __________ of soil.
(a) Clay texture (b) Platy structure
(c) Granular and crumby structure (d) Sandy texture

10. The amount of hygroscopic water varies inversely with the __________.
(a) Size of soil particle (b) Moisture content in soil.
(c) Structure of soil (d) Chemical composition of clay

11. The __________ is the difference in the amount of water at field capacity and permanent wilting point.
(a) Moisture constant (b) Hygroscopic water
(c) Available water (d) Sticky point moisture

12. The flow of water under saturated condition is determined largely by __________.
(a) Hydraulic gradient
(b) Hydraulic conductivity
(c) Hydraulic gradient and hydraulic conductivity
(d) Infiltration and percolation

13. The Darcy's law states that the rate of flow of liquid through a __________ medium is proportional to the hydraulic gradient in the direction of flow of the liquid.
(a) Solid (b) Liquid
(c) Gaseous (d) Porous

14. The movement of water through a column of soil is called as '__________.
(a) Saturated flow (b) Percolation
(c) Infiltration (d) Permeability

15. __________ indicates the relative ease of movement of water within the soil.
(a) Permeability (b) Unsaturated flow
(c) Vapour movement (d) Leaching

Q.2. Answer the following questions :

1. State the importance of Soil water.

2. Enlist the factors affecting Soil water.
3. What are the pF values for saturated and oven dry soils ?
4. How moisture content in soil is determined by gravimetric method ?
5. Why the electrical measurement of soil moisture is not helpful in salty soils ?
6. Why the tensiometers are more useful in determining the moisture content in sandy soils than clayey soils ?
7. Why the removal of soil moisture at field capacity is easier than at wilting point.
8. Enlist the factors affecting capillary water.
9. Why fine textured soil hold greater amount of capillary water ?
10. How organic matter increases capillary water in soil ?
11. Why superfluous water is harmful to plant growth ?
12. What are different types of soil water movement ?
13. What is hydraulic gradient ?
14. State the factors controlling water movement in soil.
15. Why the movement of water is slow in unsaturated flow compared to saturated flow?
16. State the types of water vapour movements ?
17. Enlist the factors affecting infiltration ?
18. Write the importance of percolation.

Q.3. Define the following terms :-

1. Soil water energy concept
2. Soil water potential
3. PF
4. Bar
5. Soil moisture constant
6. Field capacity
7. Wilting coefficient
8. Hygroscopic coefficient
9. Available water capacity
10. Maximum water holding capacity
11. Sticky point moisture
12. Infiltration
13. Percolation
14. Permeability

Q.4 Match the correct pairs :

1. Available water	1. Less water available to plant
2. Field capacity	2. Evaporates easily at ordinary temperature
3. Wheat stone bridge in sandy soils.	3. More useful in measuring moisture content
4. Superfluous water	4. Increase acidity in soil
5. Wilting coefficient	5. Held with 31 to 10,000 atm. Pressure
6. Gravitational water	6. Conductivity bridge
7. Maximum water holding capacity	7. Measuring soil moisture content
8. More salt content in soil	8. Useful in measuring hygroscopic water
9. Capillary water	9. The water beyond field capacity
10. Tensiometer	10. Retain water against downward pull of gravity.
11. Hygroscopic water	11. Held with less than 0.33 bar
	12. Plants do not show wilting
	13. Held between 1/3 and 31 atmosphere pressure.
	14. Both macro and micro pores are filled with water.
	15. Water is held with 15 atmospheres.

□□□

16

Salt Affected Soils

Saline, saline-alkali, alkaline soils, their formation and reclamation, calcareous soils, their formation and management.

Soils affected by salts like carbonates, bicarbonates, chlorides and sulphates have been given descriptive and even colourful names like white alkali, black alkali, slic spots and summer snow. For agricultural purpose such soils are regarded as class of problem soils that require special remedial measures and management practices for satisfactory crop production. At present, in India nearly 8.1 million hectares of soil is badly affected due to excess salts. Therefore, this chapter devotes to such problem soils of India.

Salted soils are classified on the basis of two criteria one is on the basis of total soluble salt content, and another is exchangeable sodium percentage or more recently sodium adsorption ratio. Because ions in water conduct electrical current, electrical conductivity (EC) is a fast, simple method of estimating the amount of total soluble salts in a soil sample. To measure a soils conductivity, a weighed soil sample is mixed with water to form a saturated paste; the liquid is then removed by pressure or suction filtration and the conductivity of this extract is measured in decisiemens per meter.

Saline and alkaline soils are those that have an alkaline reaction or whose pH is greater than 7.0. This is due to the presence of an excess of sodium salts or to the predominance of sodium among exchangeable bases. Saline and alkali soils occur most commonly under arid climate.

NATURE AND CLASSIFICATION

On the basis of the presence an excess of sodium salts and the predominance of sodium in the exchangeable complex the soils are divided into two main groups 1. *Saline soils* and 2. *Alkaline soils.*

1. Saline Soils : Saline soils contain an excess of sodium salts, but its colloidal material is not yet sodiumised.

2. Alkali Soils : In case of alkali soils, the exchange complex contains appreciable quantities of exchangeable sodium. Such soils may or may not contain excess salts. Alkali soils may be divided into following groups :

(a) Saline Alkali Soils : When they contain soluble salts in excess they are known as saline alkali soils.

(b) Non-saline Alkali : When they do not contain soluble salts, are called non-saline alkali soils.

(c) Degraded Alkali Soils : Under certain circumstance the clay complex of some alkali soils is broken down to give rise to degraded alkali soils.

The various types of salt affected soil with their differentiating characteristics are given in table below :

Table 16.1: Characteristics of salt affected soils.

Name of soil	pH	ECe (Decisiemens meter^{-1})	Sodium Adsorption Ratio(SAR)	Exchangeable Sodium Percentage (ESP)
Saline soils	~8.5	>4.0	<13	<15
Alkali or Sodic soils	>8.5	<4.0	>13	>15
Saline – Alkali soils	~8.5	>4.0	>13	>15
Degraded alkali soils	>8.5	>4.0	>13	>15

CHARACTERISTICS OF SALT AFFECTED SOILS

1. Saline Soils

When the soil contains excess of sodium salts and clay complex still contains exchangeable calcium, the soils is known as saline soils or white alkali or brown alkali soil. The process of accumulation of salts leading to the formation of saline soils is known as salinization.

(i) Saline soils contain usually chloride, sulphate, bicarbonates and some time nitrates of sodium. The presence of chloride and sulphate of sodium gives a white colour on the soil surface. When nitrates are in excess they give a brown colour to the soil.

(ii) Exchangeable sodium percentage (ESP) is very low. Being less than 15% of the total cation exchange capacity (C.E.C.)

(iii) As a consequence of ESP, generally pH varies between 7.5 and 8.5.

(iv) Total soluble salt content is more than 0.1%. It is high enough to interfere with normal growth of most plant species.

(v) Electrical conductivity (E.C) of solution extract (saturated soil) is 4 or more than 4 dSm-1.

(vi) Saline soils remain in a flocculated condition (granulated). These are permeable to water and air.

(vii) Saline soils usually have a surface crust of white salts, especially in the dry season when the net movement of soil moisture is upward. Salts dissolved in the soil water move to the surface, where they are left as a crust when the water gets evaporated.

2. Alkali Soil or Sodic Soils

A. Non-saline-alkali Soils : The colloidal complex of these soils is saturated with exchangeable sodium, and there is absence of appreciable quantities of soluble salts. These soils are often called *'black alkali'* soils, because they are black, owing to the effect of the high sodium content, which causes the dispersion of the organic matter. These soils are also called typical usar soils. These soils contain sodium carbonate (Na2CO3) in abundance.

(i) Exchangeable sodium percentage is greater than 15%.

(ii)Consequently pH ranges form 8.5 to 10 (strongly alkaline).

(iii) Total soluble salt (sodium) content is less than 0.1%.

(iv)Electrical conductivity (EC) is usually less than 4 dSm^{-1}.

(v) Colloidal complex is deflocculated and dispersed. The clay swells and chokes the soil pores. Hence, permeability to water and air is poor (or infiltration and aeration).

(vi) The presence of free sodium carbonate has a toxic effect on plant roots. Also, the high pH and poor physical condition of soil adversely affect plant growth.

(vii) Sodium carbonate absorbs organic matter, so there is great depletion of organic matter. Therefore, these soils are almost barren (*Usar*).

3. Saline-Alkali Soils

These soils are both saline and alkali. There can be all stages in transition with varying degree of dominance of salt content and pH. According to the movement of soluble salts, formation of saline-alkali and non-saline alkali soils depend. Soils contain Na-clay as well as excess soluble salts. If the soluble sodium salts are not leached out due to the insufficiency of rainwater, they remain in the soil. The soil thus contains Na-clay and excess soluble salts in solution. Such soils are known as *saline-alkali soil*. They are thus developed as a result of the combined process of *salinization* and *alkalization*. In spite of the presence of sodium clay (Na-clay) the soil remains friable and possesses aggregate, (flocculated). This is because the presence of sodium salts does not allow the sodium clay to get dispersed and keeps it flocculated. Thus, this soil behaves more or less like saline soils. If much water soluble salts are leached down, and soils contains Na-clay only then this soil behaves more or less as nonsaline alkali soil. Therefore the soil structure becomes unfavourable for the entry and movement of air and water. Usually these soils have the following characteristics :

(i) Exchangeable sodium is more than 15%.

(ii) A variable pH, usually above 8.5, depending upon the relative amounts of exchangeable sodium and soluble salts. When soluble salts are leached downward, the pH will rise above 8.5, but when the soluble salts again accumulate, the pH again falls to 8.5.

(iii) Generally soluble salts content is more than 0.1%.

(iv) Electrical conductivity is greater than 4 dsm^{-1}.

4. Degraded Alkali Soils

The soil does not contain free calcium carbonate ($CaCO_3$). As aresult of prolonged leaching under this condition, Na clay hydrolyses to NaOH which combines with CO_2 soil air and forms sodium carbonate (Alkaline condition).

$$\text{Na-Clay} + H_2O \rightleftharpoons \underset{\text{(Acid soil)}}{\text{H - Clay}} + NaOH$$

$$2NaOH + CO_2 \rightleftharpoons \underset{\text{(Alkali soils)}}{Na_2CO_3} + H_2O$$

Sodium carbonate (Na_2CO_3) dissolves humus. Humus (organic matter) is deposited in the lower layer. The lower layer thus acquires a black colour.

At the same time, a part of the exchangeable sodium of the surface layer is replaced by hydrogen. H^- Clay (acid soils) formed in this way does not remain stable. The process of breakdown of H^- clay under alkaline condition is known as *solodization* and the soil so formed is called *solod, soloth* or *degraded alkali soil.*

(i) The soil reaction of the surface layer is acidic (pH 6.0). This layer is usually very thin, hardly a few inches in depth.

(ii) The lower layer which constitutes the main soil body has high pH (more than 8.5).

(iii) ESP is greater than 15%.

(iv) EC less than 4 dsm-1.

(v) The lower layer has black colour.

(vi) It develops column as (prism-like) structure.

(vii)Soils become compact and have low infiltration and permeability.

FORMATION OF SALINE AND ALKALINE SOIL

Origin or development of saline and alkaline soil depends upon following factors:

1. Arid and Semi-arid Climate : Alkaline soils are those that have alkaline reaction or whose pH is greater than 7.0. Alkalinity is due to sodium salts in soil solution or the presence of sodium clay or both. They are formed in arid and semiarid regions , which have very low rainfall and high evaporation. The low rainfall in these regions is not sufficient to leach out the soluble products of weathering and hence, the salts accumulate in the soil. During rain, the salts dissolve in rainwater and move down in the lower layers. However, due to limited rainfall, the downward movement is restricted to a short distance only. In dry weather, the salts move up with the water and are brought up to the surface where they are deposited as the water evaporates.

2. Poor Drainage of Soil : During the periods of high rainfall, the salts are leached from the upper layer and, if the drainage is impeded, they accumulate in the lower layer. When water evaporates, the salts are left in the soil. Such soils are generally developed in low-lying areas or in basin shaped areas.

3. High Water Table : The ground waters of arid regions usually contain considerable quantities of soluble salts. If the water table is high, large amount of water moves to the surface by capillary action and evaporated, leaving, soluble salts on the surface.

4. Overflow of seawater over lands : Low-lying area near the sea, which gets seawater during tides. Salt water accumulates and enrich the soils with salts

5. Introduction of irrigation water : The ground water of arid regions is generally saline in nature. With judicious irrigation the percolating water may get linked with the saline ground water. During dry weather the soluble salts of the ground water may, thus, get carried to the surface and increase the salinity of the land. The irrigation water may be itself rich in soluble salts and add to the salinity of the soils.

6. Salts blown by wind : In arid regions near the sea, lot of salt are blown by wind year after year and get deposited on the lands. Due to low rainfall they are not washed back to sea and thus add salinity to the land. The salinity in Rajasthan has developed to a great extent, due to this reason.

7. Saline nature of parent rock materials : If soils develop from saline nature of parent rock material, soil would be saline.

8. Excessive use of basic fertilizers : Use of basic fertilizers like sodium nitrate, basic slag etc. may develop alkalinity in soil.

9. Humid and semi-humid regions : Alkaline soils develop in other area also, e.g., in semi-humid and temperate regions, especially in depressions where drainage is defective and where the underground water table is high or close to the surface.

Stages in Development :

There are three distinct stages in the evolution of saline and alkali soils. They are as follows :

1. Salinization (Saline Soils) : Soils contains excess of sodium salts while the clay-complex (soil-colloid) still contains exchangeable calcium and magnesium. In these soils the colloids are not damaged by sodium.

2. Saline-alkali Soils : The soluble sodium salts accumulated in a soil over a prolonged period from sodium clay (sodium becomes the predominant cation in soil solution). If the soluble salts (sodium) are not leached out due to the insufficiency of rain, they remain in the soil. They are thus developed as a result of the combined process of salinization and alkalization. Sodium salts keep soils in flocculated conditions.

$$\text{Ca-Clay} + \text{Na-Sats} \rightleftharpoons \text{Na-Clay} + \text{Ca-Salts}$$

3. Alkalinization (Non-saline alkali Soils) : When soluble salts (from saline-alkali soils) are removed by leaching as a result of the increase in rainfall or continued irrigation, it gives rise to non-aline alkali soils (only Na-clay in the soil colloids). In case of calcareous soils the calcium carbonate ($CaCO_3$) reacts with Na-Clay and gives rise to Ca-clay and sodium carbonate (Na_2CO_3). Due to low

$CaCO_3$, the Na_2CO_3 converts Ca-clay into Na-clay. The clay is thus sodium saturated.

$$\text{Na-clay} + CaCO_3 \rightleftharpoons \text{Ca-clay} + Na_2CO_3$$

If $CaCO_3$ is absent, i.e. in non-calcareous soils it forms degraded alkali soils. Na-clay hydrolyses (during leaching) and liberates NaOH, which combines with the CO_2 and forms sodium carbonate.

$$\text{Na-clay} + H_2O \rightleftharpoons \text{H-clay (acid)} + NaOH$$
$$2NaOH + CO_2 \rightleftharpoons Na_2CO_3 + H_2O$$

Detrimental Effects of Soil Salinity and Alkalinity

Saline Soils

1. Absorption of water and nutrients. Excessive salts in the soil solution increase the osmotic pressure of soil solution in comparison to cell sap. This prevents absorption of moisture and nutrients in adequate amounts by the roots.

2. Salt toxicity. When the concentration of soluble salts increase to high level then it produces toxic effect directly to plants. Saline soils are usually barren but potentially productive soils.

Alkali Soils (Saline – alkali and nonsaline-alkali)

1. Dispersion of soil particles. Under alkali soil conditions, the damage is not due to salt concentration. The Sodium adsorbed by clay and colloids causes dispersion of clay, which results in a loss of desirable structure and development of compact soil.

2. Physical properties are affected due to compactness of soil. Aeration, permeability, drainage and microbiological activity get reduced.

3. Availability of plant nutrients reduced. The high pH in alkali soil causes a reduction in the availability of plant nutrients such as phosphorus, calcium, nitrogen, iron, copper, manganese and zinc. (see soil reaction chapter for the details ; influence of soil reaction on availability of nutrients).

Under saline-alkali conditions there may be actually transitional stages, from high salinity-low alkalinity to low salinity-low alkalinity to low salinity-high alkalinity. Under such conditions, the crop may suffer due to high salinity as well as to unfavourable effects of alkalinity.

RECLAMATION OF SALINE AND ALKALI SOILS

Schoonover : (1959) in his study of soil problems in India, has listed the following technical requirements for reclamation of saline and alkali soils.

1. Adequate drainage.
2. Availability of sufficient water to meet crop needs and also leaching the salt below the root zone in the soil.
3. Better soil management to include perfect land leveling, good handling for irrigation, and advanced agronomic practices.
4. Protection and reclamation to be taken in large blocks.

5. Irrigation water should be of good quality.

Saline Soil Reclamation and Management

Saline soils in which the soluble salts contain appreciable amounts of calcium and magnesium do not develop into alkali soils by the action of leaching water. The reclamation is comparatively easy in such soils. The main problem is to leach the salts downward below the root zone and out of contact with subsequent irrigation water. Following to methods may be used for removal of salts **A. Mechanical Methods B. Cultural Methods.**

A. Mechanical Methods

1. Flooding and leaching down of the soluble salts. The leaching can be done by first ponding the water on the land and allow it to stand there for a week. Most of the soluble salts would leach down below the root zone. After a week, standing water (dissolved with soluble salts) is allowed to escape. Such 2 to 3 treatments are given to reclaim highly saline soils.

2. Scraping of the surface soil. When the soluble salts accumulate on the soil surface, scraping helps to remove salts. This is a temporary cure and salinity again develops on such lands.

B. Cultural Methods (Crop, Soils and Water Management)

1. Providing proper drainage. If the soil is not free draining, artificial drains are opened or tile drains laid underground to help wash out the salts.

2. Use of salt free irrigation water. Salt free good quality of irrigation water should be used.

3. Proper use of irrigation water. It is known that as the amount of water in the soil decreases the concentration of salts in the soil solution increases, thus moisture should be kept at optimum level or field capacity.

4. Planting or sowing of seeds in the furrow. The salt concentration even in smaller amounts, is most harmful to the germinating seeds and seedings. Water generally evaporates from the highest surface by capillary and hence, these points have maximum salt concentrations. If the seeds or seedlings are planted inside the furrows, they escape the zone of maximum salt concentrations and thus can germinate and develop properly during their early growth stage.

5. Use of acidic fertilizer. In saline soil, fertilizers of acidic nature (e.g., Ammonium sulphate) should be used.

6. Use of organic manures. The organic manures have very high water holding capacity. When sufficient amounts of these manures are added, the water holding capacity of soil increases and as a result the conductivity of the soil solution decreases similarly there is increase in percolation rate.

7. Ploughing and leveling of the land. Ploughing and leveling of the land increase the infiltration and percolation rate. Therefore, salts leach down to the lower levels.

8. Retardation of water evaporation from soil surface. Water may be conserved in the soil by retarding the water evaporation. Thus salts may remain in the lower level with the water.

9. Growing of salt tolerant crops.

(a) High salt tolerant crops : Barley, sugarbeet, cotton, etc.

(b) Moderately salt tolerant crops : Wheat, rice, sorghum maize, flax etc.

(c) Low salt tolerant crops : Beans, radish, white clover etc.

Reclamation and Management of Alkali (Saline alkali and non-saline alkali) Soils

Alkali soils can not be reclaimed by mere flooding the land, In case of saline-alkali soils, flooding is likely to do more harm. Leaching (flooding) down of soluble salts make the soil alkaline (only Na-clay remains in the soil). Soils get dispersed and become compact (impervious). In alkali (non-saline-alkali) soils, exchangeable sodium (Na-clay) is so great as to make the soil almost impervious to water. But even if water could move downward freely in alkali soils, the water alone would not leach out the excess exchangeable sodium. The sodium cation must be replaced by calcium cation and then leached downward. Following methods are used for reclaiming the alkali soils.

A. Chemical Methods

1. Application of Gypsum : By cationic exchange, calcium is often used to replace sodium in alkali soil. If the soils have no reserve of calcium carbonate, the addition of gypsum (calcium sulphate) is necessary. When gypsum is used as a reclaiming agent, calcium replaces the exchangeable sodium and converts the clay back into calcium-clay (Ca-clay).

$$\underset{\text{Alkali soil}}{\overset{Na^+}{\underset{Na^+}{\text{Clay complex}}}} + \underset{\text{gypsum}}{CaSO_4} \rightleftharpoons \underset{\text{Normal soil}}{Ca^{++}\ \text{Clay Complex}} + \underset{\text{Leachable}}{Na_2SO_4 \downarrow}$$

$$Na_2CO_3 + CaSO_4 \rightleftarrows CaCO_3 + Na_2SO_4 \downarrow$$

Sodium sulphate goes into solution and is then removed by washing it out with water or leaching down with water with the help of artificial drains. An addition of gypsum improves physical conditions of soil. Soils become flocculated and drainage improves, pH is lowered down to a desirable level.

Gypsum requirement of alkaline soil: For reasonable crop production on a sodic soil, the lowering of the ESP to the level of 10 is considered sufficient. The amount of gypsum required to be added to a sodic soil to lower the ESP to a desired value is known as **gypsum requirement.** It is expressed in milliequivalents of $Ca^{++}/100$ g of soil.

Gypsum requirement (GR)can be calculated from the data on CEC and ESP of the soil with the equation given below :

$$GR = \frac{ESP_1 - ESP_2}{100} \times CEC$$

Where,
ESP_1 = actual ESP of soil
ESP_2 = desired ESP of soil
CEC = cation exchange capacity of soil

For a sodic soil, suppose, CEC=20 and ESP=60, gypsum requirement to lower the ESP to 10, will be

$$G.R. \frac{60 - 10}{100} \times 20 = 10 \text{ m.e. of } Ca^{++} / 100 \text{ g soil.}$$

Besides gypsum that is best soils amendment for sodic soil, several other materials may be used for reclaiming alkaline soils. Gypsum equivalents of some such materials are given below :

Table 16.2 : Estimated efficiencies of various materials used to reclaim soils compared to gypsum.

Amendment	Gypsum equivalent
Gypsum ($CaSO_4 . 2H_2O$)	1.00
Sulphur (S)	0.18
Sulphuric acid (H_2SO_4)	0.57
Iron sulphate ($FeSO_4.7H_2O$)	1.62
Iron pyrite (FeS_2)	0.63

2. Use of Sulphur : In case of alkali soil that contain free calcium carbonate, addition of sulphur, Sulphuric acid, iron and aluminium sulphate, green manure (produce acidity) etc. reclaim the soil very effectively. The acidity developed during the course of their decomposition in soil, neutralises alkalinity. At the same time brings calcium carbonate into solution, which then reacts with the sodium clay and converts it into calcium clay.

When sulphur is spread on the soil, it is oxidised to sulphuric acid, which converts sodium carbonate into sodium sulphate. If calcium carbonate is not present in the soil, it should be added artificially when sulphur is used for reclamation. Reactions are as follows :

$$\underset{\text{sulphur}}{2S} + 2H_2O + 3O_2 \xrightarrow[\text{oxidation}]{\text{biological}} \underset{\text{sulphuric acid}}{2H_2SO_4}$$

$$\underset{\substack{\text{sodium}\\\text{carbonate}}}{Na_2CO_3} + H_2SO_4 \rightleftarrows CO_2 + H_2O + \underset{\text{leachable}}{Na_2SO_4\downarrow}$$

$$\underset{\substack{\text{calcium}\\\text{carbonate}}}{2CaCO_3} + H_2SO_4 \longrightarrow \underset{\substack{\text{calcium}\\\text{sulphate}}}{CaSO_4} + Ca\,(HCO_3)_2$$

In above mentioned both the cases, it is necessary to leach out the sodium salts, formed as a result of bases exchange with the help of artificial drains.

3. Addition of Organic Matter : The addition of organic matter increases acidity, thus helps in lowering the pH. Organic matter is especially helpful where sulphur is added to correct the alkalinity. The organic matter supplies food for the bacteria that stimulates the oxidation of sulphur to the sulphate form. The combination of sulphur, organic matter and gypsum has also been used successfully.

4. Use of Sulphuric Acid : Sulphuric acid changes the sodium carbonate to the less harmful sulphate and also tends to reduce the intense alkalinity. It should be used in the presence of calcium carbonate.

$$Na_2CO_3 + H_2SO_4 \rightleftarrows CO_2 + H_2O + \underset{\text{leachable}}{Na_2SO_4}\downarrow$$

5. Addition of Molasses : Addition of molasses in soil provides the source of energy for micro-organism, which on fermentation produce organic acids. The organic acids reduce the alkalinity of soil.

B. Cultural Method

Same cultural practices are followed as described in the reclamation of saline soils.

CALCAREOUS SOIL

Zonal soils of arid regions usually contain accumulations of lime at some point in the profile. Calcareous soil contains an accumulation of calcium and magnesium carbonates in varying proportions throughout the soil profile.

Classification of Calcareous Soils

Calcareous soils are classified into four groups as per the rating given by National Bureau of Soil Survey and Land Use Planning.

Table 16.3 : Classes of calcareous soils.

Class	Per cent $CaCO_3$
Non calcareous	Nil
Slightly calcareous	<5
Moderately calcareous	5 – 15
Strong calcareous	>15

Formation of Calcareous Soils

Calcareous soils are formed because of the following reasons :

1. Insufficient precipitation to leach out all the basic products of weathering, especially the less readily soluble calcium and magnesium salts, hence they accumulate in the soil.

2. As the concentration of salts in soil solution increases with weathering, calcium is precipitated as calcium carbonate or calcium sulphate and magnesium as magnesium carbonate as a result of the evaporation of water or its absorption by plants. While the sodium and potassium salts remain in solution.

3. As precipitation gradually increases, calcium and magnesium carbonates

and sometimes calcium sulphate, accumulate in the soil at varying depths, depending upon the penetration of rainwater.

Characteristics of Calcareous Soils

1. The clay complex is base saturated and calcium forms the predominant exchangeable base.

2The soils are highly buffered in presence of water.

3. The soil reaction is slightly to moderately alkaline (pH 7.5 to 8.5), depending upon the concentration of carbon dioxide in soil air.

Effects on Plant Growth

1. Very often the accumulation of calcium carbonate occurs in the root zone then it becomes an important factor in plant nutrition. When, it accumulates in the subsoil or in lower profile, it tends to form a hardpan by cementing the soil particles. The hardpan is usually impermeable and is very often the cause of water logging if it is formed within the root zone.

2. The high pH and the presence of free calcium and magnesium carbonates in these soils reduce the availability of some of the plant nutrients. It is often responsible for physiological diseases like lime-induced chlorosis of a number of crops.

3. A high level of calcium exerts a depressing effect on the absorption or uptake of certain nutrients like potassium and magnesium by the plant and thus upsets its balanced nutrition. On the whole, however, calcareous soils are very productive if properly managed and are suitable for a wide variety of crops.

Management of Calcareous Soils

Improvement of calcareous soils, if $CaCO_3$ is present in problematic amount, may be done by improving the drainage, sub-soiling for breaking the hardpan formed due to $CaCO_3$ accumulation at lower depth, and leaching. Acid forming substances like S, $FeSO_4$, $Al_2 (SO_4)_3$ may also be used followed by leaching.

EXERCISE

Q.1. Select the appropriate word :

1. In India nearly __________ million hectares of land is badly affected due to excess salts.
(a) 8.1 (b) 10.1
(c) 6.1 (d) 7.1

2. Electric conductivity is a fast simple method of estimating the amount of total soluble salts in soil because _________ in water conduct electric current.
(a) Cations (b) Anions
(c) Molecules (d) Ions

3. On the basis of presence of excess sodium salts and the predominance of sodium in the exchangeable complex, the soils are divided into ____________.
(a) Saline soils and non-saline soils (b) Saline soils and alkaline soils
(c) Saline soil and acidic soils (d) Non-saline soils and alkaline soils

4. The electrical conductivity of soil is measured in ____________.
(a) me/100 g (b) g/cc
(c) dSm^{-1} (d) ohms/m

5. The alkali soils if contain excess soluble salts, they are termed as ________ soils.
(a) Degraded alkali (b) Non-saline alkali
(c) Saline alkali (d) Saline

6. The pH of alkali or sodic soils is always ________.
(a) > 4.0 (b) > 8.5
(c) > 13 (d) > 15

7. The presence of ________ salts of sodium gives white colour to the soil.
(a) Chloride and carbonate (b) Chloride and sulphate
(c) Chloride and bicarbonate (d) Carbonate and bicarbonate

8. When nitrate salts of sodium are present in excess in saline soils, they give ______ colour to the soil.
(a) White (b) Grey
(c) Brown (d) Black

9. The sodium carbonate is an abundance in ________ soil.
(a) Saline (b) Saline-alkali
(c) Non-saline alkali (d) Degraded alkali

10. The total soluble salt content in saline and nonsaline alkali soils is _____respectively.
(a) > 1.0 and < 1.0 % (b) > 0.1 and < 0.1%
(c) < 1.0 and > 1.0 % (d) < 0.1 and > 0.1%

11. In spite of presence of sodium clay, the saline alkali soils are friable because the presence of _____ does not allow the sodium clay to get dispersed.
(a) Ca salts (b) Mg salts
(c) Na salts (d) K salts

12. Ground water of arid regions is generally ________ in nature.
(a) Alkaline (b) Acidic
(c) Neutral (d) Saline

13. The salinity in Rajasthan soils has developed to a great extent due to salts _____.
(a) Blown by wind (b) Accumulation by high water table
(c) Of poor drainage of soil (d) Formed from saline parent material

14. Sodium salts in saline alkali soils keep the soil in ________ condition.
(a) Ionised (b) Deionised
(c) Flocculated (d) Deflocculated

15. In case of calcareous nonsaline alkali soils, the $CaCO_3$ reacts with Na-clay and give viz._____
(a) Ca-clay and $CaCO_3$ (b) Ca-clay and Na_2CO_3
(c) Na-clay and Na_2CO_3 (d) Na-clay and $CaCO_3$

16. Excessive salts in soil solution in saline soils increase the _______ of soil solution in comparison to cell sup.
(a) Turgor pressure (b) Osmotic pressure
(c) Diffusion pressure (d) Vapour pressure

17. In alkaline soils, the sodium adsorbed by the clay causes __________ of clay which results in loss of desirable structure.
(a) Flocculation (b) Aggregation
(c) Dispersion (d) Precipitation

18. If gypsum is used as reclaiming agent, then Ca replaces the exchangeable ________ in alkali soils.
(a) Ca (b) Mg (c) Na (d) K

19. The amendment ________ is having highest gypsum equivalent .
(a) Sulphuric acid (b) Iron sulphate
(c) Iron pyrite (d) Elemental sulphur

20. The soils are strongly calcareous, if they contain ________ % $CaCO_3$

(a) < 5 % (b) > 10 %

(c) > 15 % (d) > 20 %

Q.2. Define the following terms :

1. Salinization 2. Black alkali soils 3. Alkalization

4. Saline alkali soils 5. Solodization 6. Reclamation

7. Gyspum requirement

Q.3. Write to the point :

1. State different types of alkali soils.

2. Why saline soils have ESP less than 15 ?

3. Name the four salts of sodium present in saline soils.

4. Why saline soils are called white alkali soils ?

5. Why the non-saline alkali soils are poor in permeability and aevation ?

6. Name the salt present in black alkali soils, which has toxic effect on plant growth.

7. What is pH, EC, ESP and TSS of saline soils ?

8. Why the lower layer in degraded alkali soils acquires black colour ?

9. Enlist the factors responsible for development of saline and alkaline soils.

10. Why the alkaline soils are formed in arid and semi-arid regions ?

11. Give the reactions in soil giving rise to degraded alkali soils.

12. State the deterimental effects of soil salinity on plant, growth.

13. Why absorption of water and nutrients is inadequate in productive saline soils ?

14. Why the saline soils are barren even though they are potentially productive ?

15. List out the technical requirements for reclamation of saline and alkali soils ?

16. Enlist the cultural methods for reclamation of saline soils.

17. How alkali soils are reclaimed with addition of gypsum ?

18. How sulphur reclaims the alkali soils ? Explain with reactions.

19. Enlist the chemical methods for reclaimation of alkali soils.

Q.4. Match the pairs :

1. Degraded alkali soils	1. To escape the zone of high salt concentration.
2. Schoonover	2. Wheat, rice, sorghum and maize.
3. High salt tolerant crops	3. Conductivity of soil solution decreased.
4. calcareous soils	4. May develop alkali soil.
5. Addition of gypsum	5. Formation of hardpan by cementing action
6. Use of organic manures	6. Barley, sugarbeet and cotton.
7. Use of sulphuric acid	7. Lime induced chlorosis in many crops.
8. Flooding saline-alkali soil	8. Reclamation of saline and alkali soils.
9. Planting of seedlings in furrows	9. Converts sodium sulphate to sodium carbonate.
10. Low salt tolevant crops	10. Clay complex is base saturated.
11. Accumulation of $CaCO_3$ in sub-soil	11. Surface layer is acidic.
12. High $CaCO_3$ and $MgCO_3$	12. Organic matter, NaOH and KOH
13. Acid forming substances	13. Beans, radish and white clover
	14. Changes sodium carbonate to sodium sulphate
	15. In flood water to check development of alkalinity.
	16. $FeSO_4Al_2(SO_4)_3$

17

Acid Soils

Nature of soil acidity, active and reserve acidity, formation, properties, classification, effect on plant growth and soil properties, management and lime requirement of acid soils, submerged soils.

Soils in humid regions become acidic as water containing weak acids flow through them, replacing basic cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) from the cation exchange sites with hydrogen and aluminium ions. Both humus and clay particles have large surface area with proportionally higher numbers of cation exchange sites than do silt and sand, so clayey and/or organic soils have the potential of being strongly acidic.

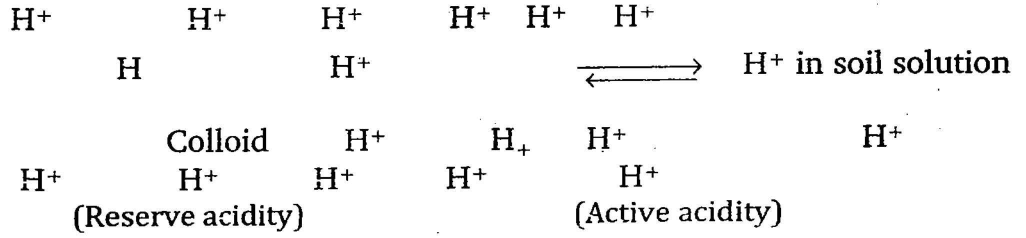
Acid soil is a base unsaturated soil which has got enough of adsorbed exchangeable hydrogen ions (H^+) so that to give soil a pH of lower than 7.0 and respond to lime application.

Nature of Soil Acidity

There are two types of soil acidity according to the presence of ions :

Active Acidity. In active acidity H+ ions remain freely present in soil solution and produce limited acidity.

Reserve or Potential Acidity. In soil colloidal complex, exchangeable hydrogen ions (H^+) are adsorbed and give soil a pH lower than 7.0. The magnitude of this type of acidity is very high. The equilibrium between active and potential acidity of soil may be shown by the following reaction :



In case of normal mineral soils, the acidity is mostly limited to the clay fractions. Here, Ca^{++}, Mg^{++} etc. are replaced by H^+.

Organic matter produces organic acids like citric acid, oxalic acid, acetic acid etc. and imparts acidity to the soil. In mineral soils, acidity may be produced by the presence of free H_2SO_4.

FORMATION OF ACID SOILS

Soils become acidic in high rainfall areas by leaching. Considerable portions of the exchangeable cations in acidic soils are various forms of hydrated aluminium and some lesser amounts of H^+ ion. Although some acidic soils develop from acidic parent materials, most soils develop acidity by leaching. As water containing hydrogen cations from various weak acids (such as carbonic and organic acids) moves through the soil, some of the aluminium cations (mostly $Al(OH)^{2+}$) replace the adsorbed basic exchangeable cations Ca^{2+}, Mg^{2+}, Na^+, K^+; then leaching water carries the removed cations deep into the soil profile or into the groundwater.

The hydrogen ions in soil solution which work to produce acidic soils, are from the following sources and result in development of soil acidity.

1. **Carbon dioxide** from decomposing organic matters and root respiration dissolves in water to form weak carbonic acid.

$$CO_2 + HOH \longrightarrow H_2CO_3 \longrightarrow HCO_3^- + H^+$$

These acidified water percolate through the soil and gradually cause soil acidity. Percolating water continuously move small amount of H^+, which replace solubilized basic cations of calcium, magnesium, potassium, sodium, and other elements. The replaced basic elements are leached from the root zone.

2. **Ammonium-containing fertilizers** are oxidized by bacteria to form nitrate and hydrogen ions. For each NH4+ cation oxidized, two H+ ions are liberated.

$$NH_4^+ + 2O_2 \xrightarrow{\text{(nitrifying bacteria)}} NO_3 + H_2O + 2H^+$$

This reaction applies to any source of NH^{4+}, including urea after hydrolysis and mineralization of NH^{4+} from organic materials. Some organic fertilizers can form acid because ammonium is the first nitrogen product of organic matter decomposition and carbonic acid (CO^2 in water) is produced as the organic materials decompose.

At the same time, a part of the NH^{4+} ions are adsorbed by the soil colloidal material. The ammonium ions so adsorbed replace calcium and other cations, which are leached down. The ammonium ions of the colloidal material get nitrified and form nitric acid. The residual anions give rise to acids like sulphuric and hydrochloric acids, which further deplete the soil solution and the colloidal complex of their bases. On these accounts, the clay gets desaturated. The H ion concentration increases and the soil pH is lowered. The reactions involved may be expressed as :

$$\underset{\text{Neutral soil}}{Ca^{++}\ \text{colloid}} + (NH_4)_2SO_4 \longrightarrow \begin{array}{c} NH_4^+ \\ \text{colloid} \\ NH_4^+ \end{array} + CaSO_4 \downarrow$$

$$\underset{\text{Ammonium ions}}{\begin{array}{c} NH_4^+ \\ \text{colloid} \\ NH_4^+ \end{array}} + 4O_2 \xrightarrow{\text{Nitrification}} \underset{\text{Acid soil}}{\begin{array}{c} H^+ \\ \text{colloid} \\ H^+ \end{array}} + \underset{\text{nitric acid}}{2HNO_3} + 2H_2O$$

3. Sulphur : Sulphur is an ingradient in some fungicides and fertilizers, oxidizes to sulfate and react with hydrogen to ions form acidity. Note that the sulfate ion itself is not acidic.

$$2S + 3O_2 + 2HOH \xrightarrow[\text{bacteria}]{\text{Thiobacillus}} 2SO_4^{2-} + 4H^+$$

4. Plant Roots : Some hydrogen ions are also released by plant roots as these are exchanged for other nutrient cations. In soils, studies have shown the values as much as 1.2 pH units lower in soil near roots than in the general mass of soil.

5. Leaching : Acidity increases as soils are more leached and the soils are lower in the basic cations, Ca^{2+}, Mg^{2+}, Na^+, K^+. Hydrated aluminium ions in solution at a pH below 5.5 become part of the exchangeable cations and increase acidity. However, soils high in carbonates (lime) are slow to become acidic because the supply of calcium is continuous as the lime reserves and calcium minerals in the soil dissolve.

The rainfall carries lime and other bases (Ca^{++}, Mg^{++} etc.) downward beyond the reach of plant roots. When all the soluble bases are lost, the H ion of the carbonic and other acids developed in the soil replace the basic cations of the colloidal complex. As the soil gradually deplete of its exchangeable bases through constant leaching, it gets desaturated and becomes increasingly acid. Thus, the regions having annual rainfall of 100 cm or more (humid region) have a high percentage of acid soils.

$$CO_2 + H_2O \longrightarrow \underset{\text{Carbonic acid}}{H_2CO_3}$$

$$H_2SO_3 + CaCO_3 \longrightarrow \underset{\text{Leachable}}{Ca(HCO_3)_2}$$

6. Acid Rain falls, when airborne sulfur oxides (mostly sulfur dioxide, SO_2) and nitrogen oxides (mostly nitric oxide, NO) are converted to sulfuric acid (H_2SO_4) and nitric acid (HNO_3) through oxidation and dissolved in rain drops. Rainwater made acidic by these strong acids may have a pH as low as 2.

7. Removal of Bases by Crops : Crop removal helps to make soils more acidic by depleting the reserves of calcium, magnesium, and potassium.

Characteristics

1. Acid soils have low pH and high proportion of exchangeable hydrogen and aluminium.
2. Kaolinitic and illitic types of clay minerals are dominant in these soils.
3. These soils have low cation exchange capacity and very low base saturation.
4. These soils have high, toxic concentration of Al, Fe and Mn and deficiency of Ca and Mg.
5. These soils have nutrient and microbial imbalances.
6. These soils are generally low in available phosphorus and have high phosphate fixation capacity.
7. Soil acidity inhibits biological nitrogen fixation.

Classification

The acidic soils are classified on the basis of pH as below :

pH range	Class
4.0 – 4.5	Very strongly acidic
5.0 – 5.5	Strongly acidic
5.5 – 6.0	Moderately acidic
6.0 – 6.5	Slightly acidic

Effects of Soil Acidity on Plants

The plant growth is affected by soil acidity. The effect of soil acidity may be direct or indirect.

Direct Effects

1. Toxic effect of H ions on root tissues.
2. Reduction in the permeability of the plant membranes for cations.
3. Disturbance in the balance between basic and acidic constituents through the roots.

Indirect Effects

1. Adverse effects on the availability of various nutrients i.e. phosphorus, copper, zinc etc.
2. High solubility and availability of elements like aluminium, manganese and iron in toxic amount due to high soil acidity.
3. Beneficial activities of soil micro-organisms such as decomposition of organic matter, nitrification and nitrogen fixation are adversely affected.
4. Prevalence of plant diseases.
5. Due to soil acidity, nutrients such as calcium and potassium may becom deficient.

MANAGEMENT OF ACID SOIL

The acid soil can be managed in two ways :

1. By growing acid tolerant crops.
2. By ameliorating the soils through the application of amendments.

1. Growing Acid Tolerant Crops : In acid soils acid tolerant crops shoul be grown. Choice of crops may be done according to soil pH. Crops can be divided into following groups :

(i) Highly acid tolerant crops : Rice, potato, sweet potato, oat, castor, echniochloa, paspalum etc.

(ii) Moderately acid tolerant crops : Barley, wheat, maize, turni brinjal etc.

(iii) Slightly acid tolerant crops : Tomato, carrot, red clover etc.

2. Ameliorating the Soils through the Application of Amendments: When liming materials are added to a soil, two general chang occur (a) the calcium and magnesium compounds applied dissolve in the presence of carbon.

Dioxide and (b) an acid colloidal complex will adsorb considerable amounts of calcium and magnesium ions.

Liming Materials. The common liming materials are :

1. Lime stone ($CaCO_3$)
2. Quick lime (CaO)
3. Hydrated (Slaked)Lime [$Ca(OH)_2$]
4. Dolomitic lime stone [$CaMg\ (CO_3)_2$]
5. Blast furnace slag ($CaSiO_3$)
6. Miscellaneous sources, such as wood ash, ground oyster shell etc.

1. Addition of Lime

(i) Reaction with Carbon Dioxide : When lime whether the oxide, hydroxide, or the carbonate is applied to an acid soil, the change in solution occurs is towards the bicarbonate form. This is because of the carbon dioxide pressure in the soil. It is usually several hundred times greater than that in the atmospheric air. It is high enough to cause a reaction. For the purely calcium limes, the reactions are

$$CaO + H_2O + 2CO_2 \longrightarrow Ca(HCO_3)_2$$
$$Ca(H_2O) + 2CO_2 \longrightarrow Ca(HCO_3)_2$$
$$CaCO_3 + H_2O + CO_2 \longrightarrow Ca(HCO_3)_2$$

(ii) Reaction with Soil Colloids : All liming material will react with acid soils, the calcium and magnesium replacing hydrogen on the colloidal complex. The adsorption in respect to calcium may be indicated as follows :

$$\begin{array}{l} H^+ \\ \qquad \text{Micelle} + Ca(OH)_2 \rightleftarrows Ca^{++}\ \text{Micelle} + 2H_2O \\ H^+ \end{array}$$

$$\begin{array}{l} H^+ \\ \qquad \text{Micelle} + Ca(HCO_3)_2 \rightleftarrows Ca^{++}\ \text{Micelle} + 2H_2O + 2CO_2 \uparrow \\ H^+ \qquad\qquad \text{(in solution)} \end{array}$$

$$\begin{array}{l} H^+ \\ \qquad \text{Micelle} + Ca(OHO)_2 \rightleftarrows Ca^{++}\ \text{Micelle} + H_2O + 2CO_2 \uparrow \\ H^+ \qquad\qquad \text{(solid phase)} \end{array}$$

As the above reaction of limestone proceed, carbon dioxide is freely evolved. In addition, the adsorption of the calcium and magnesium ions raise the percentage base saturation of the colloidal complex and the pH of the soil solution is pushed up correspondingly.

2. Use of Basic Fertilizer. Use of basic fertilizer like sodium nitrate, basic slag etc. reduces the acidity in soils.

3. Soil and Water Management. Proper soil and water management checks leaching of bases and enhances decomposition of organic matter.

Lime Requirement of Acid Soils

For reasonable crop production on a acidic soil, pH range from 6.0–7.0 is considered good. The amount of lime required to be added to acidic soil to raise the pH to a desired value is known as lime requirement. (Table 17.1)

The lime requirement of the soil is not only related to the soil pH but also to its buffer or cation exchange capacity. Some soils are highly buffered than others and, therefore, the lime requirement of soils having the same pH may differ considerably. The buffering capacity or cation exchange capacity depends upon the amount and type of clay and organic matter present in the soil. The larger these amounts, the greater will be the buffering capacity. Therefore, soils containing clay, peat, muck will be highly buffered and need less lime requirement than that required by coarse textured soils which have low clay and organic matter content.

Table 17.1: Lime Requirement to bring the soil to an indicated pH of the soil buffer suspension (Shoemaker, et al., 1961)

pH of Soil Suspension	**Lime required to bring the soil to indicated pH (tones per acre)**		
		Pure $CaCO_3$	
	pH 6.0	**pH 6.4**	**PH 6.8**
6.6	1.4	1.7	2.9
6.4	2.3	2.7	3.1
6.2	3.1	3.7	4.2
6.0	3.9	4.7	5.4
5.8	4.8	5.7	6.5
5.6	5.6	6.7	7.1
5.4	6.5	7.7	8.9
5.2	7.4	8.6	10.0
5.0	8.2	9.6	11.2
4.8	9.1	10.6	12.4

The most efficient way to use lime is to apply small amounts every year o alternate, but this liming programme increases the cost of application. Lime can be applied at any stage in the cropping system, but normally it is applied one or tw months before the sowing of crop. The efficiency of liming material depends upon its chemical composition and fineness. Oxides and hydroxides are the best a dissolved immediately upon coming in contact with water. The fine materials are quicker in correcting the soil pH.

Beneficial Effects of Liming Material on Soil

1. Lime makes phosphorus more available.

2. Lime increases the availability of nitrogen, as increase in nitrification a nitrogen fixation.

3. Organic matter decomposition is increased.

4. Lime makes potassium more efficient in plant nutrition.

5. Beneficial soil bacteria are encouraged.

6. Harmful aluminium, manganese and iron are rendered insoluble and harmless when a soil is well supplied with lime.

7. Calcium and magnesium become available.

8. Flocculating power of soil increases.

9. Improves the physical condition of the soil.

10. Checks soil erosion.

11. Fertilizer effectiveness increases.

12. Plant diseases favoured by acid soil are decreased due to liming.

CHEMISTRY OF SUBMERGED SOILS

Submerged soils are those soils which are saturated with water for a sufficiently long time annually to give the soil distinctive gley horizons resulting from oxidation-reduction process. While, the soils, which are in oxidized condition for the greater part of the growing season, are called as upland soils.

As a result of submergence, the physical, biological and chemical properties of lowland rice soils differ markedly from those of uplands. The major change that occurs in the soil environment due to flooding is depletion of oxygen.

Changes Occurring in a Submerged Soil

1. Depletion of Oxygen : Water fills all the pore-space of soil and replaces the air. The oxygen diffusion in the water layer above the soil is very slow and the rate of oxygen consumption in reduced soil is high. Because of this high demand of oxygen in flooded soil and slow oxygen supply through water, the soil is practically devoid of oxygen. This rapid depletion of oxygen takes place within a day or so. On flooding the warm soils of tropics during the rice-growing season, some oxygen trapped in blocked pore-spaces is rapidly utilized by facultative anaerobic organisms.

2. Accumulation of Carbon Dioxide : Land submergence not only restricts the oxygen supply but also stops the escape of soil gases. Soil gases like CO_2 and methane, accumulate and may escape as bubbles as pressure builds up. Measurements have shown that during the first three weeks of flooding some soils may generate up to 2.5 tones of CO_2 per hectare.

3. Electro-chemical Changes

(i) pH : The depletion of oxygen and accumulation of CO_2 and onset of reduction process markedly influence the pH value of the flooded soil. The changes in soil reaction not only affect the availability of plant nutrients but also affect the solubility of constituents toxic to rice. On flooding an increase in pH of 1.60 units within 30 days has been observed in an acid lateritic sandy loam soil. In calcareous soils flooding produces the reverse effect, i.e. decrease in pH.The pH of a submerged soil tends to be buffered around neutrality.

(ii) Redox Potential : The electro-chemical property that differentiates a submerged soil from an upland soil is its redox potential. After flooding there is a sharp drop in the potential and within a few weeks negative potentials are observed in most soils.

(iii) Specific Conductance : The specific conductance of a solution is a measure of its ionic content. The specific conductance of soil increases on flooding as Ca^{++} and $Mg++$ are mobilized by CO_2, organic acid and cation exchange. The Fe^{++} and Mn^{++} also go into soil solution following the reduction of their insoluble oxidized counterparts, and accumulation as NH^{4+}. The Calcareous soils low in organic matter shows no marked change in specific conductance. While calcareous soils rich in organic matter (2.3%) attains a level of 2 to 3 dSm^{-1}, electric conductance which decreases thereafter.

4. Mineralization of Nitrogen

Under anaerobic soil conditions mineralization of nitrogen is limited to ammonification stage due to depletion of oxygen, which is essential for the activity of nitrifiers. Ammonification of organic matter also proceeds at a low rate under submergence than in a well-drained soil. This is due to inefficient anaerobes responsible for mineralization of organic matter. The mineralization of nitrogen in water logged rice soils may be considerably higher than under well-drained conditions which accounts for good response of rice to organic matter fertilization.

ACCUMULATION OF AMMONIA

Mineralization of organic nitrogen in flooded soils stops at the ammonium stage due to prevailing anaerobic conditions. Accumulation of ammonium in flooded soil is, therefore, a good index of the capacity of a soil to meet the nitrogen demands of a rice crop.

Loss of Nitrogen

In water-logged soil, nitrogen is lost through several processes, viz. denitrification, ammonia volatilization, ammonium fixation, leaching and run off losses of nitrate and ammonia.

5. Phosphorus Transformation

Water-logging markedly increases the availability of native and applied P as compared to upland soils. The P transformation is also associated with Eh and pH changes in flooded soils.

6. Iron and Manganese Transformation

(i) Reduction of Fe : Reduction of Fe^{+++} to Fe^{++} takes place under anaerobic condition due to land submergence. High rate of reduction of iron is also associated with a high content of organic matter and a low content of active Fe, which retard the rate of reduction of Fe. Neutral and calcareous soils low in organic matter had less than 20 ppm soluble Fe.

(ii) Reduction of Mn : The reduction of oxides of Mn almost concurrently takes place with nitrate reduction. The kinetics of total reduced Mn in different soil types shows that almost all the active manganese was reduced within a week of flooding in all soil except some soils. These soils were high in active Mn and low in organic matter.

EXERCISE

Q.1. Select the correct word :

1. Soils in humid regions become acidic as water containing weak acid flow through them replacing basic cations on exchange sites with ________ ions.
   (a) Fe and H (b) Fe and Al
   (b) H and Al (d) Al and Fe
2. In normal mineral soils, acidity is mostly produced due to replacement of __________ ion by H ions.
   (a) Fe and H (b) Ca and Mg
   (c) Ca and H (d) Mg and Al
3. Carbon dioxide from decomposing organic matter dissolves in water to form ________.
   (a) Acetic acid (b) Citric acid
   (c) Carbonic acid (d) Oxalix acid
4. During oxidation of ammonium ions by bacteria, oxidation of each NH_4 ion liberates __________ H ions.
   (a) One (b) Two
   (c) Three (d) Four
5. When ammonium fertilizers added in soil, replace Ca and other cations and NH_4 of the colloidal complex get nitrified to form __________.
   (a) Nitric acid (b) Nitrous acid
   (c) Nitrite ions (d) Nitrate ions
6. The soil pH near the plant roots is as much as ________ units lower than the general soil mass.
   (a) 1.0 (b) 1.2
   (c) 1.6 (d) 1.8
7. Acid rains formed by diossolution of ________ acids in rain drops.
   (a) Sulphuric and hydrochloric (b) Hydrochloric and nitric
   (c) Sulphuric and nitric (d) Hydrochloric and carbonic
8. ______________ type of clay minerals are dominant in acid soils.
   (a) Kaolinite and montmorillonite (b) Kaolinite and vermiculite
   (c) Vermiculite and illite (d) Kaolinite and illite
9. __________ soils are generally low in available phosphorus and have high phosphate fixation capacity.
   (a) Saline (b) Alkali
   (c) Acid (d) Saline-alkali
10. The partial pressure of CO_2 in the soil air is ______ times greater than atmospheric air.
    (a) Fifty (b) Hundred
    (c) Two hundred (d) Several hundred
11. Addition of lime in acid soils, the adsorption of Ca and Mg on colloidal complex __________ its percentage base saturation.
    (a) Increase (b) Decrease
    (c) Lower (d) Increase and then lowers
12. During submergence gases like ________ accumulate and escape as bubbles as pressure builds up.
    (a) Ethane and methane (b) CO_2 and methane
    (c) CO_2 and ethane (d) CO_2 and O

13. The calcareous soils low in organic matter content shows __________ in specific conductance.
(a) Marked change (b) No marked change
(c) Much variation (d) Increase

14. Under submerged condition, mineralization of nitrogen is limited to ammonification stage due to ____________.
(a) Nitrates (b) Nitrites
(c) Deplection (d) Accumulation of CO_2

15. Accumulation of __________ in flooded soils is a good index of the capacity of soil to meet the N demand of rice crop.
(a) Nitrates (b) Nitrites
(c) Ammonium (d) Ammonia

Q.2. Answer in one sentence :

1. Why organic soils have potential of being strongly acidic ?
2. Name three organic acids produced during decomposition of organic matter.
3. Name four dominant basic cations in soil.
4. Why the soils high in carbonates are slow to become acidic ?
5. State the direct effects of soil acidity on plant growth ?
6. Name the nutrients which are possible deficient in acid soils.
7. State the two changes occurring in acid soils after liming.
8. Enlist the liming materials used for ameliovating acid soils.
9. Enlist the sources of H ions for development of soil acidity.
10. Why the acidic soils having same pH differ considerably in lime requirement ?
11. Why fine texture acidic soils have less lime requirement than course textured soils ?
12. Name two liming material which are best.
13. State the beneficial effects of liming.
14. Why the submerged soils are practically devoid of oxygen ?
15. What is the effect of submergence on acidic and alkaline soil pH ?

Q.3. Define the following terms :

1. Active acidity
2. Reserve acidity
3. Lime requirement
4. Submerged soil
5. Upland soil
6. Redox potential
7. Specific conductance
8. Mineralization

Q.4. Match the pairs :

1. Rain water	1. Low availability of Al, Fe and Mn
2. Crop removal	2. Tomato, carrot, red, clover
3. Soil acidity	3. PH 5.0 to 5.5
4. Highly acid tolerant crops	4. Replace H ions on colloidal complex
5. Soil subergence	5. 2.5 tonnes of CO_2 per hectare
6. Loss of N in submerged soil	6. Takes place with nitrate reduction
7. Liming material	7. Inhibits biological nitrogen fixation
8. Reduction of oxides of Mn	8. May have a pH as low as 2
9. Strongly acidic soil	9. pH tends to be buffered around neutrality
10. First three weeks of flooded soil generates	10. Rice, potato, sweet potato, custor.
	11. Depletes the reserves of Ca, Mg and K in soil hectace
	12. Denitrification, ammonia volutilization.

□□□

18

Quality of Irrigation Water

Concentration of soluble salts, boron, bicarbonates, relative proportion of sodium, classification, plant tolerance.

It has been already emphasised that the quality of irrigation water is important in the appraisal of salinity and alkali conditions in an irrigated area. The quality of irrigation water is determined by the concentration and composition of dissolved constituents in water.

The salts normally determined are calcium, magnesium, sodium, potassium and boron. Calcium and magnesium are determined by versenate titration, sodium and potassium are determined by flame photometer, and boron is determined by the colorimeter method. After determining the principal cations and anions, if they are summed up separately, the amount of cations must be equivalent to the amount of anions.

The following characteristics usually determine the quality of an irrigation water.

- Total concentration of soluble salts.
- Relative proportion of sodium compared to other cations.
- Concentration of boron or other elements that may be toxic.
- The bicarbonate concentration as related to the concentration of calcium + magnesium.

1. Total Concentration of Soluble Salts : It is determined by measuring the electrical conductivity of irrigation water. The best method to express total soluble salts is in terms of electrical conductivity for the purpose of classification of irrigation water. Irrigation water in use over a considerable time should have conductivity values less than 2.25 dSm^{-1}.Water with higher conductivity may be used occasionally, but it may lead to unsatisfactory conditions.

Saline soils have been defined as those whose conductivity of the saturation extract is greater than 4 dSm^{-1} at 25°C. It has been observed that the conductivity of the saturation extract of a soil, in absence of salt accumulation from ground water, ranges from 2-10 times as high as the conductivity of the applied irrigation water. This is due to the extraction of water by plant roots as well as evaporation. Therefore, moderate to high salt content can also result in saline conditions, even when drainage conditions are satisfactory. Salt sensitive crops may be adversely affected by irrigation water having conductivity values between 0.25 to 0.75 dSm^{-1}.

However, in general, irrigation water with conductivity values below 0.75 dSm^{-1} is satisfactory for irrigation so far as salt concentration is concerned. Water with electrical conductivity values between 0.75–2.25 dSm^{-1} is widely used and gives satisfactory crop growth under good management and favourable drainage conditions. But, if leaching and drainage are not satisfactory, it may lead to the development of saline soils. Water with electrical conductivity higher than 2.25 dSm^{-1}, which is usually unsatisfactory and not good. It may be worthwhile to mention here that leaching requirement of soils, therefore, depends upon the salt content of irrigation water besides other factor. The salient features of the salinity classes are given below :

Table 18.1: Salinity classes of irrigation water based on salinity hazard.

Water class	Electrical conductivity (dSm^{-1})	Soluble salt concentration g/l	Suitability
C_1 (Low salinity)	0.1–0.250	Less than 0.16	Safe with likelihood of any salinity problem
C_2 (Medium salinity)	0.25–0.75	0.16–0.5	Will need moderate leaching
C_3 (High salinity)	0.75–2.25	0.5–1.5	Cannot be used on soils with restricted drainage
C_4 (Very high salinity)	2.25–5.00	1.5–3.00	Unsuitable under ordinary conditions.

2. Relative Proportion of Sodium : This is determined by finding out the sodium adsorption ratio. The principal cations are calcium, magnesium and sodium with small amounts of potassium and the principal anions are carbonate, bicarbonate, sulphate, and chloride with fluoride and nitrate occurring in low concentrations. The alkali hazard due to irrigation water is determined by the absolute and relative concentrations of the cations. If the proportion of sodium to the calcium + magnesium is high the alkali hazard is high and if the proportion of calcium + magnesium to sodium is high , the alkali hazard is low.

Table 18.2 Irrigation water classes based on SAR (Sodium *Adsorption Ratio*)

Water class	SAR	Suitability
S_1 (Low sodium)	0 – 10	Can be used on all soils with little danger of exchangeable sodium
S_2 (Medium sodium)	10 - 18	Produce appreciable hazard in fine textured soils, can be used in coarse textured soils.
S_3 (High sodium)	18 – 26	Produce harmful levels of exchangeable sodium
S_4 (Very high sodium)	More than 26	Unsuitable for irrigation

Since the sodium adsorption ratio (SAR) of a soil solution is related to the adsorption of sodium by the soil it is advantageous to use SAR of irrigation water as an index of sodium or alkali hazard of the water. Irrigation water classes based on sodium hazard (SAR) are given in table 18.2.

3. Concentration of Boron : Boron is usually present in irrigation water ranging from traces to several parts per million. It is an essential element for growth of plants. The plant growth has been reported normal if the concentration of boron in water is in the range of 0.03 – 0.04 ppm. The maximum concentration of boron is 1 ppm beyond which it becomes toxic. The tolerance of various crops to different irrigation water classes based on boron concentration are given in the table below.

Table 18.3 : Tolerance limit of boron concentration in irrigation water for different crops.

Boron class	Sensitive crop	Semi-tolerant crops	Tolerant crops
1.	Less than 0.33	Less than 0.67	Less than 1.00
2.	0.33 – 0.67	0.67 – 1.33	1.00 – 2.00
3.	0.67 – 1.00	1.33 – 2.00	2.00 – 3.00
4.	1.00 – 1.25	2.00 – 2.50	3.00 – 3.75
5.	More than 1.25	More than 2.50	More than 3.75

4. Concentration of Bicarbonate : When the bicarbonate concentration of water increases, there is a tendency for calcium and magnesium to precipitate as carbonate. Residual sodium carbonate more than 2.5m.e./litre is not suitable for irrigation. While water containing 1.25 to 2.5 m.e./litre is considered marginally safe and the value below 1.25 m.e./litre is fully safe. The irrigation water classes based on RSC are given below :

Table 18.4 : Irrigation water classes based on residual sodium carbonate (RSC).

Water class	RSC (m.e./l)	Suitability
Low RSC	Less than 1.25	Safe for irrigation
Medium RSC	1.25 – 2.50	Marginally safe
High RSC	More than 2.50	Unsuitable for irrigation

CLASSIFICATION OF IRRIGATION WATER

The irrigation water can be classified from the viewpoint of salinity and sodium hazards as shown in table 18.5.

Table 18.5 : Classification of irrigation water.

Water class	Salinity Hazard Electrical Conductivity dsm^{-1}	Sodium Hazard SAR	Combination of Salinity and Sodium Hazard
1. Low	0.1-0.25 (C1)	0-10 (S1)	C1-S1, C1-S2 C1-S3, C1-S4
2. Medium	0.25-0.75 (C2)	10-18 (S2)	C2-S1, C2-S2 C2-S3, C2-S4
3. High	0.75-2.25 (C3)	18-26 (S3)	C3-S1, C3-S2 C3-S3, C3-S4
4. Very high	More than 2.25 (C4)	More than 26 (S4)	C4-S1, C4-S2 C4-S3, C4-S4

Low Salinity Water (C_1). This water can be used for irrigation for most crops. There are little chances of development of soil salinity. Some leaching is needed, but this usually occurs in normal irrigation practices except in soils of extremely poor permeability.

Medium Salinity Water (C_2). This water can be used with moderate leaching. Plants with moderate salt tolerance can be grown mostly without special practices for the control of salinity.

High Salinity Water (C_3). This water can not be used on soils with restricted drainage. Special management practice is required along with adequate drainage for salinity control and plants with good salt tolerance should be grown.

Very High Salinity Water (C_4). This water is not at all suitable for irrigation, but may be used occasionally under very special conditions only. If this water is to be used the soils must be permeable, drainage must be adequate, and water must be added in excess to provide considerable leaching and very tolerant crops should be grown.

Low Sodium Water (S_1). This water can be used for irrigation on almost all soils with little danger of development of harmful levels of exchangeable sodium. Sodium sensitive crops may accumulate injurious concentration of sodium.

Medium Sodium Water (S_2). This water can produce appreciable hazard in fine textured soils, which have high cation exchange capacity, specially with low leaching conditions, unless gypsum is present in soil. However, this water can be used in coarse textured soils or in organic soils with good permeability.

High Sodium Water (S_3). This water may produce harmful levels of exchangeable sodium in most soils. It requires special soil management practices like good drainage, high leaching and organic matter additions. Soils with large amounts of gypsum may not develop harmful levels of exchangeable sodium from the use of this kind of water. Exchangeable sodium should be replaced in soils by the use of chemical amendments. The amendments should not be used with very high salinity water.

Very High Sodium Water (S_4). This water is not suitable for irrigation except at low and perhaps medium salinity. When this water is to be used, it can be used with the addition of gypsum or other amendments or with the solution of calcium present in the soil.

Plant Tolerance to Salinity, Exchangeable Sodium and Boron

The tolerance of plants to salinity, exchangeable sodium and boron varies from plant to plant. The salinity tolerance of different plant species has been mentioned in Table 18.6. The tolerance to exchangeable sodium in Table 18.7 and the tolerance to boron are given in Table 18.8. According to the situation prevailing in the field, different crops species may be grown.

Table 18.6 : Relative salinity tolerance of selected crop plants.

High salt tolerant	Medium salt tolerant	Low salt tolerant
Date-palm	Pomegranate	Pear, Grapefruit,
Spinach	Grape, Cucumber,	Apple, Plum,
Barley hay	Olive, Lettuce,	Orange, Almond
Barley grain	Tomato, Onion,	Lemon, Carrot,
Sugarbeet	Cabbage, Peas	Peach
Cotton	Cauliflower, Potato	Pineapple, Guava,
	Sweet clover–white and yellow	Radish, Beans
	Wheat, Oat, Soybean,	Red clover,
	Sunflower, Maize	Field beans,
	Castor, Sorghum, Sugarcane	Paddy

Table 18.7 : Relative tolerance of selected crop plants to exchangeable sodium.

Tolerant	Semi-tolerant	Sensitive
Rice	Wheat, Bajra	Chick-pea,
Dhaincha (*Sesbania species*),	(Pearl millets)	Groundnut,
Sugarbeet	Barley, Cotton,	Urad (black gram)
	Oat, Sugarcane,	Maize, Cotton,
	Berseem, Mustard	Mung, (green gram)

Table 18.8: Relative tolerance of plants to boron.

Tolerant	Semi-tolerant	Sensitive
Data-palm, Turnip,	Potato, Peas,	Plum, Pear,
Sugarbeet, Cabbage,	Cotton, Barley,	Apple, Apricot,
Alfalfa, Lettuce,	Tomato, Wheat,	Grapes, Peach
Onion, Carrot	Radish, Oat,	Orange, Lemon
	Sweet Potato, Beans	Grapefruit

EXERCISE

Q.1 Select the correct word :

1. Irrigation water in use over a considerable time should have a conductivity value ____.

(a) < 1.25 dSm^{-1} (b) 2.25 dSm^{-1}

(c) 3.25 dSm^{-1} (d) 4.25 dSm^{-1}

2. Salt sensitive crops may be adversely affected by irrigation water having conductivity values between ________ dSm^{-1}.

(a) 0.15 to 0.25 (b) 0.25 to 0.50

(c). 0.25 to 0.75 (d) 0.50 – 0.75

3. In general, irrigation water with conductivity value below ________ dSm^{-1} is satisfactory for irrigation as far as salt concentration is concerned.

(a) 0.25 (b) 0.50

(b) 0.75 (d) 1.0

4. Water with electrical conductivity higher than ________ dSm^{-1} is not considered suitable for irrigation.
   (a) 1.25 (b) 2.25
   (c) 3.25 (d) 4.25
5. The irrigation water of the salinity class ________ can be used with moderate leaching.
   (a) C1 (b) C2
   (c) C3 (d) C4
6. The irrigation water having the soluble salt concentration of ________ g/l is unsuitable for irrigation under ordinary conditions.
   (a) 0.15 (b) 0.30
   (b) 0.03 (d) 3.00
7. The alkali hazard due to irrigation water is determined by the ________ concentration of cations.
   (a) Absolute (b) Absolute and relative
   (c) Relative (d) Comparative
8. The irrigation water class S2 can be used safely for ________ soil.
   (a) Fine textured (b) Course textured
   (c) Clayey (d) Loamy
9. ________ are high salt tolerant crops.
   (a) Sugarbeet and cotton (b) Tomato and cabbage
   (c) Apple and orange (d) Peach and puddy
10. ________ are tolerant crops to exchangeable sodium.
   (a) Chickpea and groundnut (b) Barley and cotton
   (c) Oat and Berseem (d) Dhaincha and sugarbeet

Q.2. Write in short :

1. Name the principal cations determining the quality of irrigation water.
2. Write the characteristics determining the quality of irrigation water.
3. Why the conductivity of saturation extract of soil is higher than the conductivity of applied irrigation water ?
4. Name three low salt tolerant crops ?
5. Name two sensitive crops to exchangeable sodium.
6. Name three vegetable crops tolerant to boron concentration ?
7. State three fruit crops sensitive to bron concentration.

Q.3. Match the pairs :

1. Toxic concentration of boron
2. RSC of water more than 2.5 me/l
3. S3 irrigation water class
4. Rice crop
5. C4 irrigation water class
6. RSC of water less than 1.5 me/l
7. Onion and carrot

1. Very salt tolerant crops should be grown
2. Fully safe for irrigation
3. Tolerant to boron concentration
4. High salt tolerant
5. Sensitive to boron concentration
6. Beyond 1.0 ppm
7. Tolerant to exchangeable sodium
8. Not suitable for irrigation
9. Can be used with high amount of gypsum in soil
10. Sensitive to exchangeable sodium.

19

Soil Survey

Purpose of soil survey-methods, mapping units, types, importance, land capability classification, suitability and unsuitability of land.

Soils need to be managed in better way to produce the basic needs. In order, to increase agricultural productivity the only way is to manage the soil resource on sustainable basis. Soil survey is one of the best tools for the management of soil resource.

Soil survey is a study and mapping of soils in their natural environment. It is the systematic examination, description, classification and mapping of soils of an area. Soil survey comprises a group of interlinked operations involving :

- Field work to study the important characteristics of soils and the associated external land features, such as landform, natural vegetation, slope, etc.
- Laboratory analysis to support and supplement the field observations.
- Correlation and classification of soils into defined taxonomic units.
- Mapping of soils, that is establishing and drawing soil boundaries of different kinds of soils, on standard topographical base map.
- Interpretations of soil survey reports, that is making predictions about the potential of soils for alternative uses, like agricultural crops, grasses, fruit, forestry, or plantation crops and ascertaining their management requirements for sustained production.
- Transfer of agrotechnology from the research stations to farmers' fields through soil taxa, which act as wheels for such a transfer.

Purposes of Soil Survey

The purposes of soil survey are both fundamental and applied :

Fundamental : Soil surveys help in expanding our knowledge and understanding of different soils, as regards to their properties, genesis, and classification for sustainable development are concerned.

Applied : Soil surveys and soil maps help in making predictions about the behaviour of different soils for agriculture, forestry, engineering, urban development, recreation, etc. They further help in :

- Transferring technology by correlating the characteristics of soils of known behaviour and predicting their adaptability to various uses and productivity under defined set of management practices. These predictions can also be used to make practical recommendations for the management of degraded soils.

- Providing information needed for developing optimum land use plans and for bringing new areas under irrigation and drainage networks. They also help in evaluating suitability of soils for irrigation and/or agricultural crops and a variety of other uses.
- Delineating the degraded soils, such as saline-alkali, waterlogged or flood prone, water and wind eroded and so-called wastelands
- Suggesting soil and water conservation measures to ameliorate these soils.
- Land settlement, rehabilitation, tax appraisal, locating and designing highways, airports and other engineering structures and in public sanitation works.
- Delineating disease infested areas and may provide indirect help in controlling the diseases, for instance. Recently, the zinc deficiency in human beings, especially children, has been related to its deficiency in sandy soils of Punjab (India).

Methods of Soil Survey

Soil survey methods primarily concern the studying of soil profiles in the field as well as in the laboratory. It is also concerned with mapping soils according to well-defined legends; collecting all relevant information about the climate, physiography, hydrology, geology, vegetation, present land use, scientific data about recommended practices and their responses ; socio-economic conditions of the area ; and preparing soil survey reports and soil maps. To carry out these operations grid survey and free survey methods are normally adopted.

Grid Survey : The procedure is adopted for mapping small areas, such as a micro watershed or an agricultural research station. The traverse lines are located on

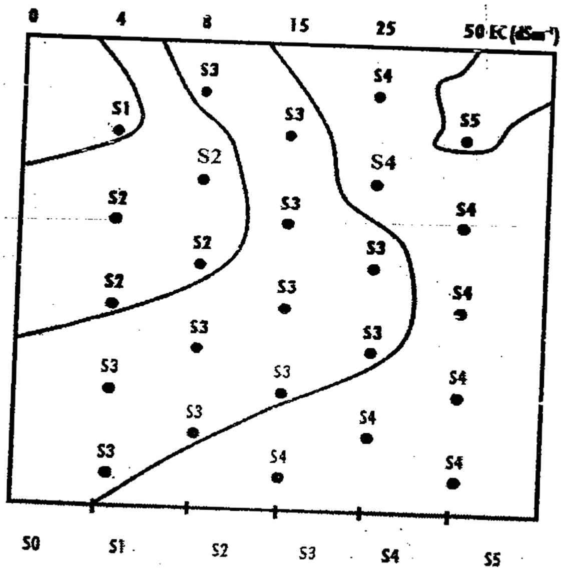


Fig. 19.1 : Grid Survey procedure for traversing. The boundaries separate soils with varying sodicity levels.

a grid pattern and the density of mapping is adjusted according to the area surveyed so that the number of observations per cm² of the final map is independent of the scale. Generally four to five observations per ha are recommended. Points of comparable observations are drawn (Fig.19.1). In this computer age, grid survey at georeferenced points (with Latitude and Longitude) have been found to be of great value in digitization of the database and generating several thematic maps of practical value. Such surveys, however, are expensive.

Free Survey : In free survey, the surveyor chooses observation points on the assumption that changes in physiography, as observed by aerial photo or satellite imagery interpretation (Fig. 19.2) and other surface features, such as soil colour,

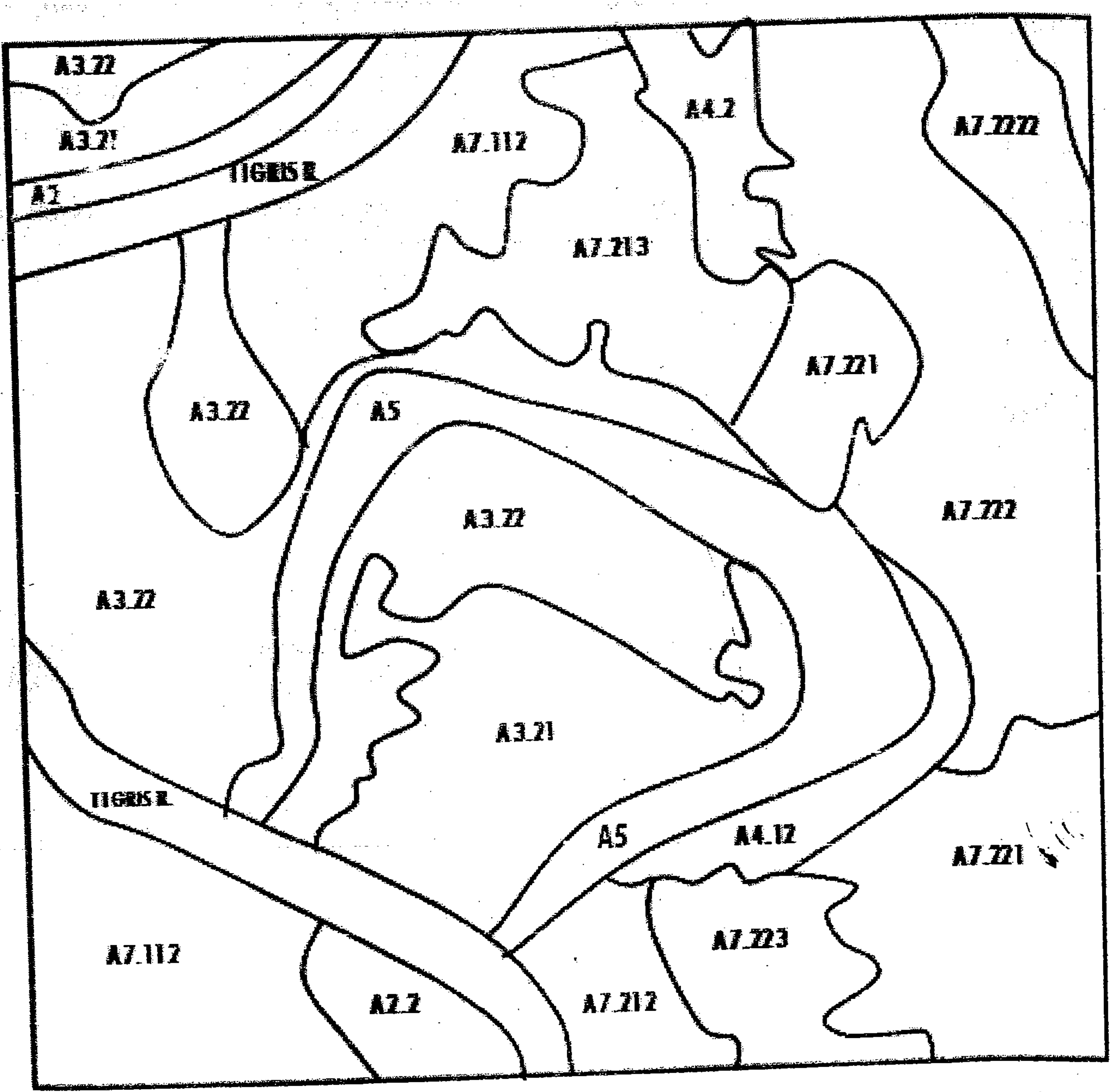


Fig. 19.2 : Major Physiographic and photo interpretation units of the recent alluvial plain showing A2.2–Foreland (high), A3.12 Recent point bars, uncultivated; A3.21 Old Point-bars, cultivated; A4.12 River-levee old; A4.2 Irrigation levee; A5 Oxbow-lake; A7.1 Silted basin; A7.2 Medium basin, cultivated (7.21). Uncultivated (A7.22).

vegetation and land use, which are indicative of differences in soil characteristics. The density of observations can be varied as the mapper concentrates on confirming the inferred boundaries and checking the uniformity of the soil within each boundaries. On small scales, the inferred boundaries are often accepted as soil boundaries and very limited efforts are made to find soils within the physiographic boundaries. On large scale, however, several new boundaries within the physiographic boundaries are recognised depending upon the scale of mapping.

Soil Mapping Units

1. **Soil series.** A soil series represents a group of soils having similar horizons but they may differ in the surface texture. It is given a geographic name either of the locality where it is well developed or where it was first recognised, for example, Tiwsa representing a deep black soil in India.

2. **Soil type.** It is a sub-division of series based on the texture of the surface soil. It is named by adding the textural class name of the surface horizons to the series name, for example, Tiwsa silty clay.

3. **Soils phase.** Phases in soil survey are mostly sub-divisions of soil types in respect of soil slope, degree of erosion, stoniness, rockiness and salinity, for example, Tiwsa stony clay ; meaning Tiwsa clay, stony phase.

Types of Soils Survey

Depending upon the objective, method, type of base map available and the intensity of observations, four major types of soil surveys are recognised. They are :

1. Detailed
2. Reconnaissance
3. Detailed-reconnaissance [a combination of (1) and (2) above]
4. Semi-detailed

1. Detailed Soil Survey : This type of survey is undertaken in priority areas, such as pilot projects, agricultural research stations, and micro-watersheds and in areas for urban development. For this kind of survey, cadestral maps on 1 : 5,000 to 1 : 8,000 or aerial photos of 1 : 10,000 scales are used depending upon the intensity of survey and agricultural developmental needs of an area. The traverse lines are on a grid pattern. The survey enables identification of soil unit's upto phases of series for planning development of individual parcels of land. The soil boundaries are demarcated based on actual traverses throughout the course. The resulting soil map provides sufficient information for interpretation of various kinds of soils and for understanding their pedogenic evolution. Such a survey is very time-consuming and expensive and recommended only for priority areas or micro-watershed planning and development. The detailed soil survey is of two types, i.e. of low and high intensity.

2. Reconnaissance Soil Survey : The reconnaissance survey is undertaken to prepare resource inventory of large areas. It identifies broadly, the kinds of soils and their extent of distribution. It enables to assess broad potentialities of soils and recognition of areas of promise that are suitable for intensive agriculture and those requiring priority treatment for amelioration. For this survey, base maps of 1: 100,000 or smaller (1 : 250,000) are used. The survey relies on aerial photo or remotely-sensed data interpretation to develop soil-physiographic relationship. The land types, land-use, texture, mottling, tone, etc. are used as the basis for boundaries delineations. These are checked in the field by few at-random checks to develop and confirm correlation between soils and land types. The soils are identified by traversing representative areas to determine soil patterns and composition of map units. The boundaries, plotted by interpretation of remotely-sensed data, are confirmed by at-random field checks.

The soil map emerged out from this type of survey provides information needed for broad or regional level land use planning. It also provides information about potential and problems of soils for agricultural development. This kind of mapping precedes detailed soil survey of potential areas. The map units show phases of association of soil families.

3. Detailed-reconnaissance Survey : This kind of survey combines both the detailed and reconnaissance surveys described above and is undertaken for understanding distribution of basic soil classes of series/families and their phases. The selected areas that have development potentials are surveyed in detail and the other at reconnaissance level.

4. Semi-detailed Survey : This survey comprises very detailed study of some selected strips cutting across many physiographic units for developing correlation between physiographic units and soils. Once the correlation is developed and is found to be valid by random checking, the rest of the area is checked at-random and soil boundaries, based on physiographic units, delineated. This kind of survey provides sufficient information about various kinds of soils, including problematic or degraded soils.

Importance of Soil Survey

1. To make optimum use of our limited soil resources, we must have in-depth knowledge about different soils, their morphology, characterization, behaviour, kind and degree of problem-their extent and distribution on the landscape. This can be achieved through soil survey and mapping.

2. Soil survey is necessary for preparing an accurate inventory of different soils, their kind, and extent of distribution so that we can make prediction about their behaviour.

3. Soil surveys are useful in defining, classifying and mapping of soils.

4. Profile studies are preceded by soil survey or classification.

5. The agricultural and silvicultural values of land can be assessed with the help of soil surveys.

6. The natural soil resources can also be determined with the help of soil surveys.

7. The extension specialists may also use the maps for making recommendations and suggestions.

8. Soil surveys are useful to engineers and hydrologists. Prospective road beds estimates of water run-off and infiltration etc. can be studied and known by knowing the various soil characteristics.

9. They are helpful in finding out nutritionally deficient areas, badly eroded soils, poorly drained soils, saline, alkaline or acidic soils and for suggesting metho for their reclamation and improvement.

10. Soil surveys are also helpful in land classification for agricultural purposes. It forms a basis for regional level planning and for micro-level plannin (micro-water shed, micro-catchments etc.).

11. Soil surveys are useful in rehabilitation, public sanitation, land settleme and tax appraisal and in designing engineering structures like highways, airports etc.

12. Soil surveys are also useful in land evaluation and appraisal, and i sociological studies.

Land Capability Classification

On the basis of the soil survey maps and reports, a land capability classificati has been developed in which every acre of land is classified according to its *capabilities* and *limitations*. The suitability of various kinds of soil is taken i consideration mainly for agricultural purposes. The basic characteristics of soils along with climate, erodibility, landscape features and other natural haza determine the suitability of a soil for a particular purpose.

The factors, which determine the capability of soil, are :

- Depth of soil, stoniness, rockiness.
- Texture and structure of soil.
- Permeability (movement of air and water through soil).
- Relief, as expressed by slope.
- Extent of erosion.
- Susceptibility to overflow and flooding and degrees of wetness.
- Presence of toxic salts, alkali and other unfavorable chemical properti such as pH, gypsum, salts, etc.
- Severity of climate (temperature and moisture). The capabi classification, however, does not suggest the most profitable use of soils Further, these groupings are subject to change as new information about soils and their response becomes available.

The capability classification consists of three categories, namely :

1. Capability classes
2. Capability subclasses and

soils having not enough available moisture for cultivation. Need carefu management for grazing and forestry; shown as red on maps.

Class-VIII : Non-arable, extremely rough, rocky, arid, wet or extremely salin land, suited only for wild life or recreation. Have very severe limitation, for instance highly eroded land, barren mountain tops (as in the Himalayas) or rocky undulating surfaces shown as purple on maps.

Capability Sub-classes

The capability sub-classes are based on kinds of dominant limitation, such as wetness or excess water (w), climate (c), soil (s) and erosion (e). The sub-classes are mapped by adding limitation symbols to the capability class number subscripts.

Capability Units

These are further sub-division of capability sub-classes. A capability unit includes soils, which are sufficiently uniform in their characteristics, potential, and limitations and require fairly uniform conservation treatments and managemen practices.

EXERCISE

Q.1. Select the correct word :

1. __________ is a study and mapping of soil in their natural environments.
(a) Soil classification (b) Soil survey
(b) Soil formation (d) Soil mapping

2. To carry out soil survey operations _____and _______ methods are adopted.
(a) Details and semi detailed survey (b) Grid and free survey
(c) Fundamental as applied (d) True as specific

3. Grid surveys are adopted for __________ areas.
(a) Large (b) Small
(c) National level (d) State level

4. In Grid surveys generally ____________ observations per ha are taken.
(a) 4 To 5 (b) 8 to 10
(c) 10 to 15 (d) 18 to 20

5. In _____ survey method changes in physiography is considered through ai photographs, satteilite imageries.
(a) Grid (b) Free
(c) Fundamental (d) Applied

6. _____________ represent group of soils with similar horizons.
(a) Soil series (b) Soil phase
(c) Soil type (d) Soil order

7. _______________ is a subdivision of soil series.
(a) Soil phase (b) Soil type
(c) Soil family (b) Soil taxa

8. Soil phases are subdivisions of _____________ .
(a) Soil order (b) Soil type
(c) Soil family (d) Soil class

9. In land capability classification, land are classified according to _____and _____.
(a) Capabilities and limitations (b) Secondary and primary
(c) Useful and unuseful (b) Required and not required

Q.2. Match the pairs :

1. Detailed soil survey	1. Study of selected strips
2. Detailed reconnaissance soils survey	2. 1 : 250,000 scale
3. Reconnaissance soil survey	3. 1 : 10,000 scale
4. Semi detailed soil survey	4. Combination of 1 & 3.
	5. Combination of 2 & 4.

Q.3. Short notes on :

1. Detailed soil survey.
2. Reconnaissance soil survey.
3. Importance of soil survey.
4. Purpose of soil survey.
5. Land classes of maximum capabilities.
6. Land capability class unsuitable for cultivation.

□□□

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Soil Classification

Soil classification, purpose, evolution, classification, early system of soil classification. recent system, soil taxonomy, epipedon, endopedon. Soil orders, soil temperature regimes, soil moisture regimes.

Classification is the grouping of objects in some orderly and logical manner into compartments. Attempts to classify soils have been made since the earlier days. Farmers have experienced different kinds of soils and classified them on the basis of texture. In modern times correlation has been made between soil and parent material.

Purposes of Classification

The purposes of soil classification are to :

1. Organise our knowledge in such a way that it contributes to economy of thought.

2. Remember properties of the objects classified.

3. Brings out and understand relationships among individuals and classes of the population being classified.

4. Learn new relationship and principles in the population being classified.

5. Establish groups or sub-divisions (classes) of the objects under study in a manner useful for practical and applied purposes in :

- Predicting their behaviour,
- Identifying their best uses,
- Estimating their productivity,
- Providing objects for research and
- Extrapolating research findings to other areas (agro-technology transfers).

EVOLUTION OF SOIL CLASSIFICATION SYSTEM

Man seems to have a natural urge to sort out and classify the natural objects of his environment. Soils are no exception , being the objects of common use by man for food, fibre fodder, fuel and shelter.

Early Systems of Soil Classification

Early systems of soil classifications, although having limited application, were quite simple and practical. The aim of these systems was primarily utilitarian, with little emphasis on the internal fabric and characteristics.

1. Economic classification : One of the earliest systems of soil classification, adopted by the Revenue Department, for grouping soils according to their productivity for the purposes of taxation. The criteria used were soil colour and texture in combination with the potentialities for irrigation. For instance, soils suitable for growing wheat, rice, groundnut or cotton. Such a system served limited purpose and became obsolete when the land use changed.

2. Physical classification : It is one of the earliest systems and was based on soil texture, a property associated with soil productivity. The soils were termed as Loamy soils, Sandy soils, Clayey soils etc. This system of classification was applicable to the zonal soils only.

3. Chemical classification : The grouping of soils by their chemical composition has not been used to a great extent as the data on soil analysis can not be classified according to any definite pattern. **Still soils were grouped as :** Calcareous soils, gypsiferrous soils, acid soils, alkaline soils, etc. These characteristics do not permit to classify all kinds of soils occurring in nature. Some of the designations of the chemical classification have, however, been incorporated in the Genetic System of soil classification.

4. Geological classification : In the 18th and 19th centuries, geologists and geographers recognised close relationship between soil and its parent rock and proposed classification system based on the presumed underlying parent material. According to this system, two broad groups of soils are recognized :

Residual or Sedentary Soils : Developed in-situ from the underlying rocks, like basalt, limestone or sandstone.

Transported Soils : Developed on unconsolidated sediments, like alluvium, colluvium or aeolian materials.

Such formations were reflected in the nomenclature used to describe them, e.g. Sandstone soils, alluvial soils and aeolian soils. These attempts, however, failed to recognise the dynamic processes of soils genesis, controlled by climate and vegetation- the two active factors of soil formation, which overcome the influence of parent material with the passage of time and hence upset the geological system of classification. For instance, a granite in Himachal Pradesh and in Tamil Nadu, as acted upon by different climate and produces two different soils, that is Podzolic and Lateritic soil, respectively. Similarly, a basalt in Madhya Pradesh and in Kerala gives rise to two types of soils (Black Cotton and Laterites) that are as far apart in their properties as their geography. However, a knowledge of the geology of the parent material is of great value in explaining many properties of a soil.

5. Physiographic classification : According to this system the characteristics of the landscape were considered and geomorphic terms, such as level soils, basin soils, terrace soils, mountain soils, hilly soils, upland soils, and lowland soils were introduced to classify soils. Though, a close relationship between soils and landscape exists and is increasingly used as a base in modern soil survey and mapping programmes, yet a classification based only on physoigraphy may have limited value as two or more soil groups with different properties may be classified in one group.

Recent Systems of Soil Classification

V.V. Dokuchaiev, a Russian scientist, while working in Central Russian Upland realised a rather uniform loess-like parent material that extends for hundreds of kilometers where an increasing temperature gradient is imposed from north to south and an increasing annual rainfall and moisture gradient from east to west. These differences in climatic elements were associated with important vegetation patterns varying from forest to steppe (Prairie), and left their imprint on the parent material producing distinct soil differences. These observations led Dokuchaiev- the founder of the modern pedology – to establish the concept of soil as an independent natural body and resulted in a series of publications on soil genesis and classification (Dokuchaiev 1886). Therefore, the Russian approach to soil classification in naturally tended to emphasise on soil genesis and hence the term is Genetic system of soil classification.

1. Dokuchaiev's Genetic System : The first classification of soil, as proposed by Dokuchaiev (1900) divides soils into three categories; Normal, Transitional and Abnormal Soils. These categories were later termed as Zonal, Intrazonal, Azonal soils, respectively.

Table 20.1: Genetic system of soil classification (Dokuchaiev, 1900)

A. Zonal Soils (Normal Soils)

Zones	Soil Type
Boreal	Tundra (dark brown) soils
Taiga	Light-grey podzolised soils
Forest steppe	Grey and dark-grey soils
Steppe	Chernozem
Desert steppe	Chestnut and brown soils
Aerial or desert zone	Aerial soils (brought down by wind), yellow Soils, white soils, etc.
Sub-tropical and zone of Tropical forests	Laterite or Red soils
B. Intrazonal soils (Transitional Soils)	
	Dry land Moor soils, or Moor meadow soils, Carbonate- containing soils
C. Azonal Soils (Abnormal Soils)	Secondary alkaline soils
	Moor soils
	Alluvial soils
	Aeolian soils (brought down by wind)

2. Coffey's System : Coffey (1912) emphasized that soils, as independen natural bodies, should be classified on the basis of their own properties. He proposed five major classes of soils as under :

Arid soils
Dark Coloured Prairie Soils
Light coloured Timbered Soils
Black Swamp Soils
Organic Soils

Each class was sub-divided into series on the basis of parent material and the series into types (an obsolete term) on the basis of surface soils texture.

3. Marbut's Morphogenetic System : His scheme of soil classification was based on the iron-alumina and lime content. At the highest categoric level, he divided Zonal soils into 2 classes as Pedalfers and pedocals. The former showing accumulation of iron and aluminium and the later shows accumulation of calcium as calcium carbonate. The pedalfers were presumed to occur in areas of high rainfall having real surplus of water for leaching. The pedocals occur in areas of high evaporation having real deficit of water (Table 20.2).

Table 20.2: Morphogenetic system of soil classification

Category VI :	**Pedalfers (VI-1)**	**Pedocals (VI-2)**
Category V :	Soils from mechanically comminuted materials. Soils from siallitic decomposition products.	Soils from mechanically comminuted materials.
Category IV:	*Soils from alitic decomposition products*	
	Tundra	Chernozems
	Podzols	Dark-brown soils
	Grey-brown podzolic soils	Brown soils
	Red soils	Grey soils
	Yellow soils	Pedocalcic soils of arctic and tropical regions
	Prairie soils	
	Lateritic soils	
	Laterite soils	
Category III :	*Groups of mature but related soil series*	
	Swamp soils	Swamp soils
	Rendzinas	Rendzinas
	Glei soils	Glei soils
	Alluvial soils	Alluvial soils
	Immature soils on slopes	Immature soils on slopes
	Salty soils	Salty soils
	Alkali soils	Alkali soils
	Peat soils	Peat soils
Category II:	*Soil series*	*Soil series*
Category I :	*Soil units or types*	*Soil units or types*

4. Zonality concept and soil classification : The morphogentic system of Marbnt was revised by Baldwin, Kellog and Thorp (1938). According to the evised system, the soils were grouped in 3 orders, viz., *Zonal*, *Intrazonal*, and *zonal*, following the Russians zonality concept (Table 20.3).

Zonal Soils : The characteristics of the zonal soils are determined primarily y the environment, especially climate and vegetation. The differences due to the arent material are rendered subordinate by domination of climatic influences. The oils are termed as *Zonal* because the development of their profiles closely orresponds to the climatic and vegetation zones in which they occur.

Intrazonal Soils : The soils occur within a zone, but reflect the influence of some local conditions such as topography and/or parent material. Under these conditions, the characteristics imparted by the local conditions predominate.

Azonal Soils : The soils have poorly developed profiles because of time as a limiting factor. They include young soils without horizon differentiation.The soils developed on recently laid alluvium or colluvium belong to this group.

Table 20.3 : Revised system of soil classification according to zonality concept Baldwin et al. 1938 as modified by Thorp and Smith, 1949

Order	Suborder	Great soil groups
Zonal Soils		
	1. Soils of the cold zone	Tundra soils, Sierozem soils Brown soils, Reddish Brown soils
	2. Light-coloured soils of arid regions	Desert Soils, Red Desert soils Chestnut soils, Reddish chestnut soils
	3. Dark coloured soils of the semi-arid sub-humid, and humid grassland	Chernozem soils, Prairie or Brunizem soils, Reddish Prairie soils Degraded Cshernozem soils
	4. Soils of the forest grassland transition	Noncalcic Brown soils Podozol soils
	5. Light-coloured podzolised soils of the timbered region	Gray wooded, or gray Podzolic soils Brown Podzolic soils, Soil-brun acide Gray-brown podzolic soils Red-yellow Podzolic soils
	6.Lateritic soils of forested warm temperate and tropical regions	Reddish-brown lateritic soils Yellowish-brown lateritic soils Laterite soils.
Intrazonal Soils		
	1.Halomorphic (Saline and alkali) soils of imperfectly drained arid regions and littoral deposits	Solonchak or Saline soils Solonetz soils (partly leached solonchak) Soloth soils
	2.Hydromorphic soils of marshes swamps seep areas, and flats	Humic-gley soils Alpine Meadow soils Bog and Half-bog soils Low humid-Gley soils, Planosols Ground Water Podzol soils Ground Water Laterite soils
	3. Calcimorphic soils	Brown forest soils, Rendzina soils
Azonal Soils	No subroder	Lithosols, Alluvial soils, Regosols

SOIL TAXONOMY

(A COMPREHENSIVE US SYSTEM OF SOIL CLASSIFICATION)

In order to overcome the shortcomings of old classification systems, US soils Survey Staff under the leadership of Guy D. Smith, in cooperation with many other institutions, have been working since 1951 to arrive at a classification that narrows the differences in different view points. Each year, starting from 1953, an approximation was produced and tested. In 1960, a comprehensive system of soil classification, popularly known as the "7th approximation"(Soils Survey Staff, 1960) was published. The system was put into official use in the U.S.A. and adopted in many other countries, including India, Iraq, Belgium and Holland. A supplement of 7th approximation appeared in 1964 taxonomy (Soil Survey Staff, 1975). From its inception, soil taxonomy was designed to serve the soil survey needs. Soil classification system was published in the form of book as Soil Taxonomy in 1975.

Salient Features : This system of soil classification is based on the properties of soils as they exist today. While one of the objectives of the system is to group soils similar in genesis. The specific criteria used to place soils in different groups are those of soil properties.

The system has an edge over the earlier systems in respect of the following :

1. Unlike the Genetic System, the comprehensive system is based on measurable soil properties. Efforts have been made to define all classes in terms of soil properties that exist today.

2. It considers all such properties which affect soils genesis or are the outcome of soil genesis. Hence soil genesis forms the backbone of the comprehensive system. But it does not appear in the definition of soil taxa.

3. The common definition of a class of taxonomic system is type or orthotype.

4. The nomenclature, using coined words, is derived mainly from Greek and Latin languages. Although it appears difficult, yet, once understood, it is the most logical system and helps in relating the place of taxon in the system and in making interpretations.

5. A new category, i.e. subgroup, has been introduced to define the central concepts of great groups and their intergrades in order to express and recognise more clearly that soils are in continuum and show gradual change in many properties.

6. Unlike the Genetic System, it is an orderly scheme without prejudices and facilitates easy remembering of the objects without undue taxing the human memory.

Structure of Soil Taxonomy

The system has six categories of classification (fig 20.1). From the highest to the lowest level of generalizations, these are grouped under two broad categories, viz., *higher* and *lower*.

Higher Categories

1. Order : The highest category in the system.

2. Suborder : Comparable to great soil groups of the Genetic system.

3. Great Group : A basic category, based on diagnostic subsurface horizons.

Lower Categories

4. Subgroup : A new category designed to define the central concepts of great groups.

5. Family : A practical category for making predictions and landuse plans.

6. Series : The lowest and the most specific category.

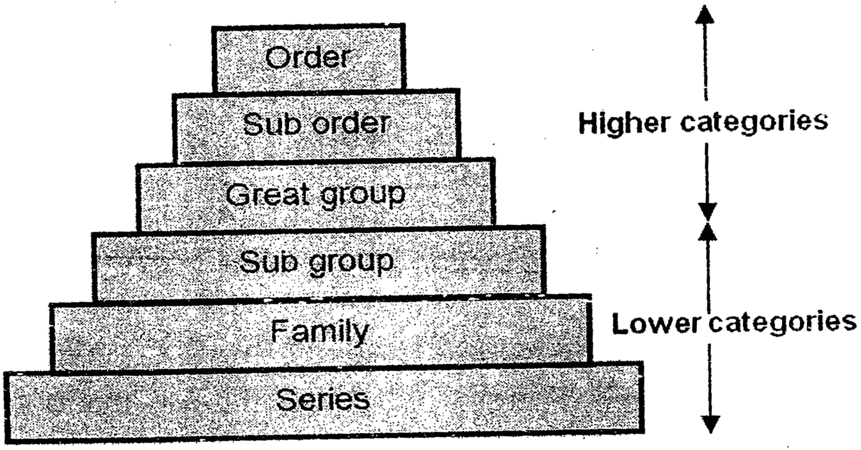

Fig. 20.1. The hierarchy of Soil Taxonomy.

The categories are a bit difficult to explain although to a person having long experience in soil classification even though the descriptions may seem logical and clear. These six categories are briefly explained and defined in the following paragraphs. Names are considered as proper nouns and should be capitalized.

Order : This is the most generalized category. All soils fit into one of the 11 orders. Six of the orders are differentiated by the presence or absence of diagnostic horizons or of other features. These features are characteristics of major processes of soil formation which are greatly affected by the contrasting climates. Entisols have "undeveloped" profiles and Inceptisols & Andisols have weak development as illustrated by slightly formed horizons. Vertisols are dominated by the effects of having a large percentage of shrink-swell clays. The Histosols are organic soils, formed because of slow organic matter decomposition in stagnant water.

Suborder : Suborder within a soil order are differentiated largely on the basis of additional soil properties and horizons resulting from differences in soil moisture, soils temperature, and dominating effects of chemical or textural features. Today 60 sub-orders are recognized. Suborder is distinctive to each order and is not interchangeable to other orders.

Great group : Soil great groups are subdivisions of suborders. An approximately 230 great groups are identified world wide have been established largely on the basis of differentiating soil horizons and soils features. The differentiating soil horizons include those that have accumulated clay, iron and/or humus and those that have pans (hardened or cemented soils layers) that interfere with water movement or root penetration. The differentiating soil features are the self-mixing (expansion and contraction) properties of clays, soil temperature, and major differences in content of calcium, magnesium, sodium, potassium, gypsum, and other salts.

Subgroup : Each soil great group is divided into three kinds of subgroups; one representing the central (typic) segment of the soil group; a second which as properties that tend towards (intergrade to) other orders, suborders, or other great groups and a third (extragrade), which has properties that prevent its classification as typic or an intergrade to another soil category. Nearly, 1000 subgroups are known in the United States.

Family : Soil families are separated within a subgroup primarily on the basis of soil properties important to the growth of plants or behaviour of soils when used for engineering purposes. The soil properties used include texture, mineralogy, reaction (pH), soil temperature, the area's precipitation pattern, permeability, thickness of horizon, structure, and consistency. About 4500 families have been identified in the United States.

Series : Each family contains several similar soil series. There are 12620 or more soil series in the United States. Soil series have narrower ranges or characteristics than the soil family. The name of the soil series has no pedogenic (soil formation) significance but represents a prominent geographic name of a river, town, or area near where the series was first recognized. Soil series are differentiated on the basis of observable and mapable soil characteristics. Soils in the same series have similar properties such as colour, texture, structure, consistence, thickness, reaction (pH), and number and arrangement of horizons in the soil pedon and their chemical and mineralogical properties. Soils of a given series must have about the same kinds, thickness, appearance, and properties of horizons.

Soil Phase : It is used in association with soil series but is not considered as a classification category of the system. Phases of soil series are mapping units. Their major use is to delineate soil areas for practical uses, such as farming and municipal or country zoning. Phases have differences in surface soil texture, the solum thickness, the percentage slope, the stoniness, the saltiness, the extent of erosion damage, and other conditions. Mapping units are polypedons which may have small portions of other polypedons included in them.

DIAGNOSTIC HORIZONS OF MINERAL SOILS

Diagnostic horizons are used to differentiate among soil order, suborders, great groups, and sub groups. Diagnostic horizons that form at the soil surface are called *epipedons*; those forming below the surface, are *endopedons*. The brief description of each horizon given below is not official; it is given for quickly orienting the reader.

Epipedons (Surface Horizons)

Following are the surface horizons (Epipedon). A compound word : *OH UMAA Pl.* is suggested by taking first letter to facilitate the naming of epipedons.

Albic horizon : A strongly leached E (A2) horizon. Common as a white layer, near the surface of spodosols, or in upper Alfisol profiles. A surface or subsurface horizon that is light colored (>4 in color value, when moist; and >5 in value, when dry) caused by eluviation (leaching out) of coatings of clay and free iron oxides. The light shade is the color of the remaining sand and silt. The clay deposited below it may cause a perched water table.

Anthropic epipedon : A people made mollic horizon. A surface horizon formed during use of soil by people for long periods of time as homesites or as sites for growing irrigated crops. Basic cation saturation is high; when not irrigated, the epipedon is dry for 7 years out of 10.

Histic epipedon : An organic surface horizon underlain by mineral soil . A surface horizon that is saturated with water at some season unless artificially drained, generally between 20 and 30 cm thick and containing at least 20-30 per cent organic matter if not plowed. In each case, the limiting organic matter content depends on the amount of mineral portion that is clay. The lower percentage is used if the horizon has no clay and the higher percentage if the horizon has 60 per cent or more clay.

Mollic epipedon : A dark, friable surface horizon, not strongly acidic, (Found in Mollisols, and some Vertisols.). A surface horizon that is dark colored, contains more than 1 per cent organic matter, and is generally more than 25 cm thick unless and/or shallow to an impermeable layer. It has more than 50 percent basic cations saturation and massive when dry. The mollic must have Munsell value darker than 3.5 when moist and 5.5 when dry, Munsell chromas of less than 3.5 when moist. For sandy soils, the mollic epipedon may be as shallow as 18 cm or one-third of the depth to a hardpan or bottom of an argillic or natric horizon or to a lime zone, whichever is deeper.

Ochric epipedon : A thin or light-colored surface horizon (common in Aridisols, Entisols, Inceptisols). A surface horizon that is too light in color (higher value or chroma than mollic epipedon), too low in organic matter, or too thin to be either a mollic or an umbric epipedon.

Plaggen epipedon : A people-caused high-humus horizon. Anthropic surface layers of soil 50 cm. or more in thickness that has been produced by long continued manuring.

Umbric epipedon : An acidic dark horizon. (common as the Ultisol surface.) A surface horizon similar to a mollic epipedon but having less than 50 per cent basic cations saturations.

Endopedon (Sub–surface Horizons)

The important endopedons are given below :

Agric horizon : A tillage-caused clay and humus accumulation horizon. A subsurface horizon that has formed under a plowed layer by the movement of silt, clay, and humus into voids created by worms, shrink-swell cracks, and capillary pores.

Argillic horizon : A clay accumulation horizon. (Common in Alfisols and Ultisols). A subsurface horizon into which clay has moved. The presence of clay films on ped surfaces and in soil pores in evidence of clay movement. The argillic horizon is at least one-tenth as thick as the sum of all overlying developed horizons unless it is over 15 cm thick.

Cambic horizon : A 'colour' or weakly developed B horizon. (common in Inceptisols.) A subsurface horizon that has texture finer than loamy fine sand and in which materials have been altered or removed but not accumulated. Evidences of alteration include the elimination of fine stratifications; changes caused by wetness, such as gray colours and mottling; redistribution of carbonates; yellower or redder colors than in the underlying horizons. It is a common horizon but weakly developed.

Kandic horizon : An argillic horizon of kaolinite-like clays. This is horizon proposed to indicate the accumulation of clays having more cation exchange capacity (CEC) than Oxisols and less CEC than montmorillonitic clay layers. The presence of clay films is not required. The layer has a CEC of less than 16 Cmo1e/kg of clay and is at least 30 cm thick.

Natric horizon : Like an argillic but with a high exchangeable sodium content. A subsurface horizon that is a special kind of argillic horizon containing 15 per cent or more of exchangeable sodium, or SAR of the saturation extract is 13 or higher within a 40-cm depth.

Oxic horizon : A highly weathered B horizon. (common in Oxisoi.) A subsurface horizon that is a mixture principally of kaolinite, hydrated iron and aluminum oxides, quartz, and other highly insoluble primary minerals, and containing very little water- dispersible clay. It is at least 30 cm thick and has over 15 per cent clay of less than 16 Cmole/kg of clay for its CEC.

Sombric horizon : An acidic humus accumulation, tropical B horizon. A subsurface horizon formed in well-drained mineral soils, consisting of illuvial humus. Basic cation saturation is low (less than 50 per cent). Restricted to tropical and subtropical regions.

Spodic horizon : An acidic, cool area, humus and/or sesquioxide accumulation in B horizon. (common in Spodosols.) A subsurface horizon in which amorphous materials consisting of organic matter plus compounds of aluminium and usually iron have accumulated. The spodic is either sandy textured and has a >2.5 cm thick cemented (sesquioxide or humus) layer or has an iron plus-aluminum content divided by the clay content of over 0.2

Endopedons from Accumulations of Solubilized Substances

Calcic horizon : A calcium carbonate accumulation horizon. (Common in

Aridisols.) A surface (if exposed by erosion) or subsurface horizon is more than 15 cm thick that has more than 15 per cent calcium carbonate equivalent, at least 5 per cent more carbonates than the C horizon.

Gypsic horizon : A gypsum accumulation horizon. A weakly cemented or noncemented subsurface horizon (or on the surface when eroded severely) that contains a high concentration of gypsum $CaSO_4.2H_2O$ mostly. Thickness in cm x gypsum percentage is equal to or greater than (≥) 150 cm-per cent.

Salic horizon : A soluble salt accumulation horizon. A saline horizon, usually below the surface at least 15 cm thick that contains at least 2 per cent salt. Thickness in cm x percentage > 60 cm-per cent.

Sulphuric horizon : An horizon high in sulphides. A surface or subsurface horizon rich in sulphide minerals or high-sulphur organic matter, when drained, oxidizes to sulfuric acid. Oxidized soil pH is less than 3.5 and is therefore toxic to most plants.

Hardpan Horizons

Duripan : It is a silica-cemented hardpan, usually with some carbonates. A subsurface horizon that is cemented mostly by silica. Although carbonates may be present, duripans will not slake in water nor in 8 per cent hydrochloric (HCl) acid but will disintegrate in hot concentrated KOH solution or alternating acidic and basic solutions. Basic solutions dissolve silica.

Fragipan : A dense, brittle minimal-cemented hardpan. A natural subsurface horizon with high bulk density relative to A and B horizons (the solum) above, seemingly cemented (small amounts of silica at contact points) when dry but showing a moderate to weak brittleness when moist. The layer is low in organic matter, mottled, slowly or very slowly permeable to water, and usually shows occasional or frequent bleached cracks, forming polygons. It may be found in profiles of either cultivated or virgin soils but not in calcareous material.

Petrocalcic horizon : A hard carbonate-cemented hardpan. An indurated (hardened) subsurface horizon cemented by carbonates and not penetrable by spade or auger. At least 2.5 cm thick and thickness times percentage $CaCO_3$ is ≥200 cm-per cent.

Petrogypsic horizon : A hard gypsum-cemented hardpan. A surface or subsurface horizon that is cemented so strongly by gypsum that dry fragments will not slake in water. Cementation restricts plant root penetration. Fits other requirements for gypsic horizon.

Placic horizon : A very hard iron-cemented hardpan. A sub-surface horizon cemented by iron, iron and manganese, or by iron, and organic matter, forms most readily in both humid tropics and cold regions.

SOIL MOISTURE REGIMES

The moisture regimes attempt to indicate the extent of naturally available water in the soil depth of maximum root proliferation.

Aquic : Usually wet with anaerobic saturation for a period long enough to produce visual evidence of poor aeration (mottling and gleying [gray coloring]).

Udic : Usually adequate water throughout the year.

Ustic : Deficient water but most of the water available comes during the cropping season.

Xeric : Deficient water and with a dry cropping season; most of the precipitation comes in the non-cropping time of year.

Aridic : Very water deficient; long dry periods; short wet periods.

Torric : Same criteria as aridic but used at specified location in the classification system.

Because moisture regimes indicate when and how long the soils major root zone is wetted, the precipitation patterns are only part of the cause for the moisture regime.

TERMINOLOGY FOR "FAMILY" GROUPINGS

Family groupings are based on :

(1) Mineral particle classes,

(2) The soil mineralogy classes,

(3) Soil temperature classes,

(4) Rooting depth,

(5) pH, lime, sand, particle coatings and/or permanent cracks.

Only the first three properties which are most common are discussed below :

1. Particle Size Classes

The intent is to separate soils of quite different textures into separate families. The seven groups are :

Fragmental : Mostly made up of stones, cobbles, gravel, and very coarse sands without enough fine particles to fill voids larger than 1 mm.

Sandy-skeletal : Over 35 per cent of material is coarser than 2 mm diameter with enough "sand" to fill voids larger than 1 mm.

Loamy-skeletal : As "sandy-skeletal" except "loam" fills the voids.

Clayey-skeletal : As "sandy-skeletal" except "clay" fill the voids.

Sandy : All material is sand or loamy sand except "very fine sand" size fraction.

Loamy : All material is between "sandy" and "clayey."

Clayey : Material is more than 35 per cent clay. (fine clayey is 35-60 per cent clay; very fine clayey is more than 60 per cent).

2. Soil Mineralogy Classes

For most of the root zone soils, terms are used to indicate dominant minerals, such as *carbonatic* (carbonates), *serpentinic* (serpentinite minerals) and *siliceous* (over 90 per cent silica). Clayey soils with over 50 per cent of the clay of one type may be called *montmorillonitic, kaolinitic, illitic, oxic,* and so on, to indicate the dominant clay. The most common term is mixed, meaning that no mineral makes up more than 40 per cent of the soil. *Mixed* is used with clayey soils, also. Other terms may be used for special materials (*e.g.*, cindery for over 60 per cent of volcanic ash or cinders.)

3. Soil Temperature Classes

Temperature classes are based on mean annual soil temperature and the difference between mean summer and mean winter temperature. Mean annual soil temperature is determined by measurement mostly in the deep root zone and can be estimated in most of the United States by adding 1°C to the mean annual air temperature. The soil temperature classes for temperate region soils are defined in terms of mean annual soil temperature as :

Pergelic : 0°C (32°F); Permafrost present (unless dry)
Cryic : 0-8°C (32-47°F); summer soil temperature below about 15°C
Frigid : 0-8°C (32-47°F); summer soil temperature above about 15°C
Mesic : 8-15°C (47-59°F)
Thermic : 15-22°C (59-72°F)
Hyperthermic : 22°C (72°F)

Tropical region soils, characterized by having a difference in temperature between mean summer and mean winter of less than 5°C (9°F), are grouped into the following mean annual soil temperature classes by adding iso-prior to the correct temperature name : ***isofrigid, isomesic, isothermic,*** and ***isohyperthermic.*** These four soil temperatures are common in many tropical climates at different elevations.

Examples of Family Names

A "Correct" sequence for writing family and sub-group names are not clearly given. Because the U.S. taxonomy system develops from the most specific to the most general. Some persons prefer to write the names with the sequence from the left to right giving series, family and then sub-group. The reverse order of this can also be used.

Hirapur series of Fine, montmorillonitic, hyperthermic. Chromic Haplusterts.

Chikli series of Fine, montmorillonitic, hyperthermic, Typic Ustochrepts.

THE SOIL ORDERS

The 11 soil orders, which include all the world's soils, are a diverse group. The orders discussed in the following section in the development sequence beginning with organic parent materials (Histosols). These are followed by Entisols, the leas developed mineral soils, and then the Inceptsisols and Andisols having intermediat development. The remaining orders discussed roughly in order of extent of profi leaching and weathering, beginning with the Aridisols. A compound word (AVAAMIHOUSE) is suggested by taking first letter to facilitate the naming of all the orders.

1. **Histosols :** These are organic soils that have developed under water saturated environment. They are highly rich in organic matter. If clay content is low they may have 12 per cent organic carbon but if clay content is more than 50 per cent, the organic carbon content may go as high as 18 per cent. These soils may be productive for vegetables.

2. **Entisols :** Those soils that have little, if any, profile development are known as Entisols. These are mineral soils devoid of natural genetic horizons or only have the beginnings of such horizons. Such soils are found under a variety of climatic conditions. Soils found in desert belong to this classification. The productivity of these soils varies with their location and properties. With controlled water supply and proper fertilisation, these soils have good productivity. They are good for a variety of vegetables, groundnut, citrus, wheat, paddy etc.

3. **Inceptisols :** These soils have better profile development than Entisols, but are less developed than other soil orders. The horizons in Inceptisols are formed mostly from alteration of the parent materials. The horizons are formed with accumulation of clay. Iron and aluminium oxides are normally absent. The productivity of such soils is limited due to poor drainage.

4. **Andisols :** Andisols were first recognised in Japan and were named as Volcanic ash material. They are dark coloured, low bulk density soil that has developed on volcanic ash parent material. They do not have an albic horizon, but that must have andic properties loose or friable colored mollic or umbric surface horizon overlying a brown cambic B- horizon. These have one or both of the following, low bulk density (< 0.9 g/cc) or 60 per cent or more vitric volcanic ash within 60 cm of the mineral soil surface.

5. **Aridisols :** In accordance with the nomenclature, these mineral soils are found in arid, i.e. dry areas. Since they are found in dry areas they are light in colour, poor in organic matter and are not subjected to leaching. They may be used for cultivation with irrigation. They may possess a horizon of calcium carbonate (calcic), calcium sulphate (gypsum-gypsic) or more soluble salts (salic). They are in fact desert soils.

6. **Vertisols :** These mineral soils have a high content of clay particles, usually more than 30 per cent of the swelling type of clay sometimes even to a depth of one meter. During the dry season, these soils contract and give rise to deep cracks, which disappear in the wet. season or after irrigation. They are found mostly in sub-humid or semi arid climates where the temperatures are moderate to high. Such soils are good for crop production and are fine textured. They are plastic and sticky when wet and hard when dry. Thus the management of such a soil is difficult as there is a very little time for their proper preparation by tilling. These soils are good for the production of cotton, millet, sorghum, wheat, paddy etc.

7. Mollisols : These soils have a thick surface horizon, which is dark in colour, and dominated by divalent cations. These soils are agriculturally important. They possess normal granular or crumb structure, do not harden on drying and with moderate to heavy fertilization, these soils are productive.

8. Spodosols : These soils belong to forests with low content of bases. The subsurface horizon has accumulation of organic matter and sesquioxide. They have a coarse texture and acid parent material subject to leaching which leads to the formation of Spodosols. They are found in humid climates where temperature is low. The natural vegetation of forests is favourable for the development of Spodosols. These soils are not very fertile, but with proper fertilization they are quite productive.

9. Alfisols : These are moist mineral soils having grey to brown surface horizons. They have medium to high base content. In illuvial zone silicate clays get accumulated. These are found in cool and hot humid regions. These soils are quite productive due to their medium to high base content and good texture.

10. Ultisols : These soils are normally forest soils with low content of bases. They are normally moist and develop under warm tropical conditions. They are weathered and are formed normally under forest vegetation. These soils respond to good management practices, have clay of 1:1 type with oxides of iron and aluminium and give good crop production with adequate fertilization.

11. Oxisols : These are the most highly weathered soils. The sub-surface horizons are high in clay with hydrous oxides or iron and aluminuim. Silica is removed from silicate minerals due to intense weathering and leaching in the horizon, thus leaching high amounts of iron and aluminium oxides. These soils are productive with supplements of phosphorus and micronutrients.

EXERCISE

Q. 1. Select the correct word :

1. The early system of economic classification of soil survey a limited purpose and became obsolete when the __________ changed.

(a) Knowledge (b) Land use
(c) Properties (d) Fertility

2. Geological classification of soil is based on underlying__________.

(a) Rocks (b) Parent material
(c) Properties (d) Colour

3. A granite rock in Himachal Pradesh and Tamilnadu, as acted upon by different climate and vegetation, produces two different soils as ________ irrespectively.

(a) Black cotton and laterites (b) Podzolic and lateritic
(c) Laterites and black cotton (d) Lateritic and podzolic

4. According to ___________ classification, the characteristics of landscape were considered and geometric terms introduced to classify soils.

(a) Physical (b) Geological
(c) Chemical (d) Physiographic

5. ___________ had a series of publications on soil genesis and classification.

(a) Dokuchaiev (b) Marbut
(c) Coffey (d) U.S.D.A. staff

6. According to zonality concept, the soils where the time has been a limiting factor to produce horizonation are termed as _______ soils.
(a) Zonal (b) Intrazonal
(c) Azonal (d) Transitional

7. Morphogenetic system of soil classification was based on __________ content.
(a) Fe, Al and lime (b) Fe, Al and Ca
(c) Fe, Al and Mg (d) Fe, Al and salts

8. Pedalfers is the soil class which shows accumulation of ___________.
(a) Lime and Al (b) Lime and Fe
(c) Fe and Al (d) Fe, Al and Lime

9. The characteristics of zonal soils are determined primarily by the environment, especially _____________.
(a) Topography and vegetation (b) Climate and vegetation
(c) Temperature (d) Climate

10. In comprehensive system of soil classification, there are _______ categories.
(a) Six (b) Eight
(c) Nine (d) Eleven

11. ____________ is the highest category in comprehensive system of classification.
(a) Series (b) Order
(c) Suborder (d) Great group

12. Sub-group is a new category in comprehensive system designed to define the ___________ of great groups.
(a) Central concept (b) Basic principle
(c) General concept (d) Principle

13. Great groups are identified on the basis of differentiating soil ___________.
(a) Properties (b) Soil horizons
(c) Soil features (d) Soil horizons and soil features

14. Soil series represent the prominent ________ name of river, town or are where firstly recognised.
(a) Physiologic (b) Logic
(c) Geologic (d) Geographic

15. _________ are the mapping units used to delineate soil areas for practical uses.
(a) Soil series (b) Phases of soil series
(c) Families (d) Soil series of family

16. ____ are used to differentiate the orders, suborders great groups and subgroups.
(a) Diagnostic character (b) Diagnostic horizons
(c) Varying properties (d) Varying characters

17. ______________ horizon is a strongly leached A_2 horizon.
(a) Albic (b) Histic
(c) Mollic (d) Ochric

18. ____________ epipedon has more than 50% base saturation and massive when dry.
(a) Umbric (b) Mollic
(c) Anthropic (d) Histic

19. ____ is a horizon proposed to indicate the accumulation of clays having high CEC.
(a) Kandic (b) Cambic
(c) Agrillic (d) Agric

20. Spodic is a horizon with accumulation of ____________ in B horizon.
(a) Cu and Mg (b) Na and K
(c) Fe and Al (d) Ca and Fe

Q.2. Answer to the point :

1. Enlist the early systems of soil classification.
2. Name the soil group classified as per chemical classification.
3. State the two soil groups recognized as per geological classification.
4. State the major classes of soils proposed by Coffey (1912).
5. Which are the two soil classes given by Marbut at the highest categoric level ?
6. Why the USDA classification is called as 7th approximation ?
7. Enlist the higher and lower categories in comprehensive system of classification.
8. What is the basis of differentiation of soil series ?
9. Name the endopedons from accumulation of solubilized substances.
10. List the different hardpan horizons.

Q.3. Answer in short :

1. State the purposes of soil classfication.
2. Give the salient features of comprehensive system of soil classification.
3. Explain various moisture regimes in soil.
4. State the basis for famiily grouping.
5. Enlist the different family groups based on particle size classes.
6. State the soil temperature classes for temperature and tropical regions.
7. Enlist the different orders in comprehensive system of soil classification.
8. Write in short about the order Vertisol.
9. Enlist the different epipedons.
10. Which are various types of endopedons ?

Q.4. Define :

1. Soil classification
2. Epipedons
3. Endopedons
4. Duripan
5. Petrocalcic horizon
6. Calcic horizon
7. Entisol
8. Inceptisol
9. Andisols
10. Histosols

Q.5. Make the suitable pairs :

1. A zonal soils	1. Morphogenetic system of classification
2. Taxonomic Suborders	2. Backbone of comprehensive system
3. Basalt in Madhya Pradesh	3. Undeveloped soil profile
4. 7th Approximation	4. Two hundred thirty
5. Marbut	5. Gives rise to laterite soil
6. Soil genesis	6. Zonality concept of soil classification
7. Histosols	7. Young soils without horizon differentation
8. Basalt in Kerala	8. Dominated by swell-shrink clays
10. Baldwin et al. (1938)	10. Very high moisture content
11. Vertisols	11. Sixty
12. Family	12. Gives rise to black cotton soil.
	13. Purpose of soil classification
	14. Organic soils
	15. Evolution
	16. Practical category for making land use plans.

□□□

21

Soils Erosion and Conservation

Definition, Types of erosion, natural erosion, water erosion, wind erosion, erosion by ice, loss of nutrients, soil conservation techniques

Soil erosion is the removal of part of the soil, or the whole soil, by the action of wind or water. It is detachment transportation of soil from one place to another by the action of wind, water or so. Soil erosion is a natural process that occurs without human intervention, but it can be greatly increased by cultivation of the land. The erosion is caused by the felling of trees, cultivation of the cleared land and overgrazing. Erosion in northern Europe is belived to have begun with the clearing of woodlands about 5000 years ago. Water erosion, and wind erosion had devastating effects. The clear-felling of forests on steps slopes and in the humid tropics followed by cultivation is continuing to cause erosion. The results of erosion may not be entirely negative. For example, sediment derived from erosion in Ethiopia helped to sustain Egyptian agriculture for thousands of years. The same effects ensured the fertility of the Ganges-Jamuna plain in India, although this is now threatened because excessive felling of trees in the Himalayas has led to excessive run-off of water and deposition of sediment which, in turn, have led to serious flooding in Bangladesh.

Natural Erosion

Natural or geological erosion has several effects. It has occurred throughout the history of the Earth from the time that rocks were first exposed to the influence of the atmosphere, shaping the land surface and forming sedimentary rocks from weathered rock and soil. Water erosion of hill slopes has widened valleys and produced colluvium on the foot slopes and alluvium in valley bottoms. Eroded material is carried by rivers to sea where the coarser particles form deltas. As an example of natural erosion, wind-blown fine sand, known as loess, has been deposited in thick sheets in Kashmir forming some of the Earth's most fertile soils. So, erosion is not always negative.

The rate at which natural erosion occurs depends on the vegetation cover of the land surface, its slope, the size of rock fragments and soil particles at the surface, and the climate conditions.

Effects of Soil Erosion

1. Loss of soil to support the growth of crops, grassland and forests.

3. Deposition of sediment loads causing rivers to change course.

4. Variable seasonal flow of rivers and flooding.

5. Water pollution : Erosion of 1 t of soil containing 0.2% N and 0.05% P will transfer 2 kg N and 0.5 kg P to rivers and lakes.

6. Air pollution : fine soil ; particles in the air reduce solar radiation at the surface of the Earth and might affect chemical processes in the atmosphere.

Erosion of soil can be described under three subheads

1. Erosion by water and
2. Erosion by wind
3. Erosion by ice

1. Erosion by Water : Water is a most potent agent of erosion. The rate of erodibility is directly proportional to the current of water and volume of water.

Classification of Water Erosion

Erosion by water is classified into following three categories.

A. Raindrop splash erosion

B. Surface flow or sheet erosion, and

C. Channalized flow erosion.

A. Raindrop Splash Erosion : Raindrops fall with an approximate speed of 914 cm/s (30 ft/s). When raindrops strike bare soil, they beat it into flowing mud, which splashes as much as 61 cm (2 ft) high and 152 cm (5 ft) away.

These soils most readily detached by raindrop splash erosion are fine sands and silt. Coarser particles are not shifted about as much because of their greater volume and weight. Most soils of finer texture, such as clays and clay loans, are not readily detached, because of the strong forces of cohesion that keep them aggregated, although clays can be in a dispersed state after freezing and thawing actions or when they are very wet or tilled excessively with only meager additions of organic matter.

During heavy rain, bare soil aggregates are disrupted, splashed, shifted about, and packed together more closely. As muddy water flows down through natural openings of the soil into the profile below, the soil sediment plugs the pore openings. The result is a sealed soil surface, which, upon drying, forms a crust that is only slowly permeable to air and water. Water that should move downward into the soil profile during subsequent storms or irrigation now moves over the wet slogged surface, carrying soil particles with it to pollute surface waters.

The erosive effect of raindrops will be understood, if we consider the energy of a rainstorm. The range of impact velocities is from less than 1 m s^{-1} for small drops to about 9 m s^{-1} for big drops. A storm with big raindrops has therefore much greater kinetic energy than one with small drops.

B. Surface Flow Erosion : The detachment of sand and silt grains and soil; splash lower the rate of infiltration of water. Water runs off the surface if the rate of infiltration falls below the rate of rainfall and tends to collect in channels. Initially these may be natural depressions, tracks made by man or animals, or wheel marks or furrows made by farm machinery. The deeper the water in these channels the faster the flow, turbulence increases and more soil particles are detached by the flowing water and carried down slope. When the channels are sufficiently shallow to be covered over by cultivation they are called rills. They are called gullies when they are too deep to cover by normal cultivations.

Runoff water is responsible for much soil erosion, moving the soil particles by surface creep saltation (valutation or leaping), and suspension. Surface creep means movement of wet and supersaturated soil downhill by a rolling or dragging action. Vaultation results when turbulent water causes soil particles to hop or skip as they moved downward. Smaller soil particles that never touch the soil surface as they are moved along in the water flow are carried by suspension. Uniform cutting off of the soil surface is sheet or laminar erosion.

C. Channelized Flow Erosion : As water moves over the surface of the soil, some of it concentrates in low places to cut deeper depressions or channels. Continued flow develops minor channels called rills; later, major rills and large gullies may be formed by the scouring action of increasing volumes of channels muddy water carrying enormous amount of sediment that will be deposited somewhere downstream.

Loss of Nutrients

Soil which has been eroded becomes shallower, several experiments have shown that this results in lower crop yields. One cause of the decrease in crop yield is loss of nutrients in topsoil and run-off. In an experiment, 55 t ha^{-1} of soil was croded over a period of 5 years. The soil that was lost contained 1200 kg organic matter, 75 kg nitrogen, 16 kg phosphorus and 34 kg exchangeable cations.

Effect of Soil and Land Characteristics

The amount of erosion at any site depends on the erosivity of the rainfall, the erodibility of the soil, the characteristics of the land, and its use and management. These factors were combined by workers in the United States in an empirical equation known as the Universal Soil Loss Equation (USLE).

$$A = RKLSCP$$

Where,

A = Annual soil loss,

R = Erosivity of rain,

K = Soil erodibility factor,

L and S = Length and angle of slope factors, respectively.

C = Crop management factor,

P = Soil conservation factor.

1. The erodibility of soil, K, is high if it contains particles which are easily detached by raindrop impact and are transported by surface run-off. The strength and size of soil aggregates are therefore important (Section 2.2). These properties can be measured in the laboratory, for example, by shaking the soil on sieves of different mesh size under water. For use in the USLE the value of K is obtained from the loss of soil per unit of rainfall erosivity, R, using a standard field plot 22.1 m long on a 9% slope which is kept bare of vegetation and ploughed up and down slope.

2. The angle (or percent) of slope affects both raindrop splash and the velocity of water moving over the surface, the effect of both becoming greater as the slope increases. The volume of run-off increases with the length of slope and the soil loss becomes greater.

3. Crops and natural vegetation provide a cover, which protects the soil from the direct impact of raindrops. Permanent grass and trees provide cover throughout the year, but for annual crops the cover is present only during the growing period and when the stubble and other residues remain.

4. There are various conservation measures to reduce erosion. They include terraces, construction of protective banks along the contour, cropping in strips along the contour, or maintaining grass strips at intervals down slope.

B. Erosion by Wind

Wind causes erosion of dry, bare soil. The two factors that determine its extent are wind speed and the size of the soil particles and aggregates. The amount of wind erosion to be expected from an area of land can be calculated from an empirical equation.

$$A = f(I, K, C, L, V)$$

Where,

A = soil loss;
f = function of
I = index of soil erodibility based on wind-tunnel tests or soil texture;
K = soil surface roughness, including the height and spacing of ridges;
C = climatic factor, including mean wind speed, rainfall and evapotranspiration
L = length of unsheltered land downwind;
V = index of vegetative cover.

C. Erosion by Ice

Ice is an important erosion force in some parts of the world today, but in the Pleistocene Ice Age significant changes took place in the landscape of large amounts of material were removed from many areas.

Glaciers are effective agents of erosion, because they can carry more varied and large particles than rivers or wind. Debris that is carried makes the ice body ver abrasive and freeze-thaw cycles produce more weathered material. The ice can pluck at loosened material increasing erosion. This results in removal of large volumes of debris. Many land scapes are the product of past glaciation, including many of the U-shaped glacial troughs in Himalayan mountains.

Main causes of Soil Erosion induced by Man can be listed as under

1. Destruction of Woodlands : Removal of the vegetative cover exposes the soil to the erosion effect of rainfall and may cause water erosion especially on steep slopes.

2. Cultivation of Grasslands : Water erosion occurs, as in (1) above, and in a climate which is seasonally arid, or if these is drought, the soil may blow especially if it is itself of wind-blown origin.

3. Cultivations : They leave the soil bare of a vegetative cover before there is a crop canopy and after harvest; when the soil is bare it may be subject to water or wind erosion.

4. Cultivation of Steep Slopes : Exacerbated by cultivating up and down the slope which creates channels for run-off and may lead to the formation of gullies.

5. Intensive Grazing by Domestic Animals : May destroy the vegetative cover and lead to wind or water erosion; goats on hill sides and herds of cattle near water-holes are particularly destructive.

6. Paths and Animals Tracks : Collect run-off because of reduced infiltration and may lead to rill and gully formation.

7. New Roads : Increases run-off from roads and embankments may cause rills and gullies to form.

8. Disturbance by mining and other activities which leave the soil unprotected.

SOIL CONSERVATION

The safe way to protect soil is not to expose it directly to wind or rain, but if arable crops are to be grown this is not practicable. Several methods have, therefore been devised to protect soil against erosion.

The various methods of conserving soil against erosion

Biological : Various ways of maintaining a cover of vegetation during the periods of high erosion risk.

- good crop management
- use of rotations
- cover crops to stabilize slopes
- strip planting
- mulching with stubble and weeds
- correct stocking rate on pastures
- use of trees and hedges as windbreaks

Cultivations : Use of ordinary farm implements to prepare land for an arable crop.

- contour ploughing
- use of graded furrows
- minimum tillage

Mecchanical Protection : Various forms of terrace, which are semi-permanent.

- graded channel
- absorption terrace
- bench terrace
- irrigation terrace

EXERCISE

Q.1. Select the appropriate word and fill in the blanks :

1. ____ is the removal of part of the soil or wholes soil by the action of wind or water.

(a) Soil inversion (b) Soil erosion

(c) Runoff (d) Profile inversion

2. Erosion of 1 tonne of ordinary soil transfers ___ kg N and P, respectively to rivers and lakes.

(a) 4 and 1 (b) 20 and 5

(c) 0.5 and 2 (d) 2 and 0.5

3. Soil erosion caused due to rain drops is ____.

(a) Gully erosion (b) Splash erosion

(c) Rill erosion (d) Channel erosion

4. When shallow channels are formed due to water erosion are called _____.

(a) Gullies (b) Rills

(c) Ravines (d) None of these

5. Lower crop yields in eroded soils are mainly because of_____.

(a) Loss of nutrients from top soil (b) Runoff

(c) A and B (d) Low germination

Q.2. Answer to the point

1. List out any four factor that determine the rate of natural erosion.

2. Enlist any four effects of soil erosion.

3. State different types of water erosion.

4. State the universal soil loss equation.

5. State the empirical equation to calculate soil erosion by wind.

6. Enlist the causes of soil erosion induced by human.

7. List out the biological control methods for sol conservation.

8. Enlist various forms of terraces for soil conservation.

❑❑❑

22

Soil Biology

Soil organisms, bacteria, fungi, actinomycetes, algae, viruses their distribution and factors affecting their growth, development and population.

A great variety of organisms live in the soil. Soil animals, generally referred to as the soil fauna, range n size from earthworms and termites to those that can only be seen with a good hand lens. Microorganisms can only be observed under an optical or electron microscopes; although small in size their numbers are large. The groups of organisms and their population in soil are given below.

Table 22.1 : Groups of Organisms and their Population in Soil.

Microorganisms in fertile soil (millions g^{-1})		Animals in mull soil under beech Millions ha^{-1}	
Bacteria	1-100	Earthworms	1.8
Actnomycetes	0.1-1	Millipedes	1.8
Fungi	0.1-1	Centipedes	0.8
Algae	0.01-0.1	Mites and springtails	44.1
Protozoa	0.01-0.1	Others	13.5

The carbon in soil microorganisms accounts for about 3% of the soil organic carbon, that is, they contain about 1 tonne of carbon per hectare in soil with 1.5% carbon to 15 cm depth.

Soil Fauna

The soil fauna can be classified in terms of body length as micro (less than 0.1 mm), meso- (0.1 to 10 mm) and macro- (greater than 10 mm). Protozoa are the only important members of the micro fauna. Animals which burrow into soil, but spend much of their time outside it are not included in the soil fauna. Earthworms, members of the Lumbricidae, are macro fauna and are often present in large numbers in soils.

Soil Microorganisms

Five groups of microorganisms are listed in table 22.1 Within each group there is a diversity of physiological requirements. The heterotrophs require an organic substrate whereas autotrophs do not. Populations of zymogenous organisms grow rapidly when an organic substrate is added, but autochthonous organisms respond very little. Microorganisms also differ in their requirements for oxygen gas : the obligate aerobes require it for respiration, the obligate anaerobes require its absence, and the facultative organisms can adapt to its presence or absence. All the microorganisms require mineral nutrients.

Terminology used to describe the physiological requirements of soil microorganisms.

Heterotrophs use organic compounds as their source of carbon.

Autotrophs use carbon dioxide or carbonates as their source of carbon. Two groups are :

Photoautotrophs, which obtain their energy from photosynthesis;

Chemoautotrophs, which obtain their energy from the oxidation of compounds.

Zymogenous organisms proliferate rapidly in the presence of an organic substrate.

Autochthonous organisms consume comparatively resistant organic materials at a steady rate.

Aerobic organisms require oxygen gas for respiration; usually called obligate aerobes.

Anaerobic organisms will grow only in the absence of oxygen; usually called obligate anaerobes.

Facultative organisms can adapt to the presence or absence of oxygen.

The various soil micro-organisms are discussed below.

BACTERIA

Bacteria are involved in the nitrogen and carbon cycles, and also in other cyclical transformations in soil. Bacteria have wide environmental tolerance and have a well established biotic relationships with other microorganisms or with higher plants. They account for a little less than half of the total microbiological tissue of the soil. Generally, in well aerated soil, bacteria and fungi dominate the microbiological spectrum of the soil. However, in soil with little or no O_2, the major biological and chemical activities in soil are primarily the responsibility of bacteria. They decompose a wide variety of natural substances rapidly.

Winogradsky 1925 classified the bacteria in two broad divisions.

1. The Autochthonous or Indigenous Species : The autochthonous population comprises numerous indigenous bacteria whose abundance is relatively fixed or stable in the soil. They derive their nutrients from the organic fraction of the soil, and they do not require an external nutrient supply or energy source for their survival and growth.

2. The Zymogenous or Fermentation Producing Microorganisms : Zymogenous organisms are relatively much less but they are the most active group in the chemical transformation.

Bacterial Population in Soil

Normally, in one gram of soil the number varies from 1 million or less to several billions. Usually, the population of bacteria ranges from 1 to 3 billion/g. This is, however, an average figure and holds good for ordinary soil. The number may rise drastically in highly fertile soil, and particularly when external supply of the organic substances is made to soil. This increases is generally of a short duration and subsequently the population tends to attain stability.

One trillion bacterial cells, weigh 1 g and a direct count estimate of 2 billion bacterial cells/g of soil, accounts for approximately 0.2% of the soil weight. Based on these assumptions it is calculated that nearly 4600 kg live weight of bacteria/hectare are normally available.

Distribution Pattern in Soil

There is no uniform pattern of the distribution of bacteria in soil. Even in the same horizon of the soil the pattern is haphazard. Soils of horizon A are rich in organic matter and hence harbour maximum bacterial population. In horizons B and C where the level of organic matter is low, the population of bacteria is also low. Organic exudates and the sloughed off material of root surfaces provide an abundant source of energy material and this results in the luxuriant growth of microorganisms in the soil surrounding the roots. The root surface environment known as rhizosphere is a very suitable site for microbial growth. The bacteria in soil are generally present in the film of colloidal material coating the mineral particles. They occur in small colonies in soil and 77% of the soil-bacteria occur in groups and the remaining 23% appear as single cells.

Factors affecting Bacteria

Soil in general is quite rich in bacterial population, but it is also observed that many of the bacteria are either inactive or show a very low level of activity. The following factors affect the bacterial population in soils.

1. Moisture : Moisture is one of the most important factors governing bacterial activity. Excessive water leading to the water logging situations does not favour the growth of microbes directly and also the effect in indrect through depletion inn O_2 level and simultaneous increase in CO_2 concentration. The optimum level for aerobic bacteria in normally between 50 to 75% of the soil moisture holding capacity. Ammonification can proceed under stringent drought than can nitrification. There is a marked reduction in the population of bacteria in soil as it undergoes drying. Soil bacteria on an average are resistant to such extreme environments.

2. Aeration : Bacteria are more predominant in properly aerated soil. Most bacterial species need a sufficient supply of oxygen. Generally, soil contains more that 10% oxygen and in most-well-drained soils, the value may be above 20%. In wet periods or following heavy irrigation the oxygen content in soil is around 3% or even less. It may be safely said that, within a range of 50-80% of moisture holding capacity, soil is endowed with good soil aeration. In such wet condition, a good combination of moisture and aeration occurs, that favours the growth and activities of the heterotrophic bacteria in soil.

3. Temperature : Optimum temperature range for soil bacteria is 25 to 35°C. However, a large number of bacteria may be isolated over a range of 10 to 40°C. The bacterial population is affected by high temperatures especially at the upper surface. At lower levels of soil where the roots are plenty, even in drier situations, the soil temperature is usually either optimal or sub-optimal for bacteria.

On the basis of temperature tolerance for their growth and proliferation, bacteria may be grouped into 3 categories.

(a) Mesophiles : Those with an optima in the vicinity of 25 to 35°C and with a capacity to grow between 15 to 45°C. Most of the soil bacteria fall under this category.

(b) Psychrophiles : Certain species prefer low temperature say below 20°C. True psychrophiles are generally not present in soil. In severely cold months when the temperature falls below 20°C the bacteria isolated from soil at such a time, are not really psychrophiles but cold tolerant mesophiles.

(c) Thermophiles : Bacteria growing between 45-65°C are obligate thermophiles. Such species usually do not grow below 40°C.

4. Soil Reaction : Bacteria normally prefer the alkaline side of neutrality. The common range for different bacteria is between pH 4 to pH 10. *Azotobacter chroococcum* flourishes both in acidic and alkaline soils, but rarely below pH 6. A. *indicus* on the other hand, had been isolated from very acidic soils having pH 3. Similarly, *Thiobacillus thiooxidans* tolerates an acidity of pH 6. By and large, highly acid or alkaline conditions tend to restrict many common bacteria. The greater the hydrogen ion concentration the smaller is the size of the bacterial population.

Chemoautotrophic Bacteria

Bacteria, depending upon their mode of nutrition, are largely heterotrophs. A few species, however, exhibit different nutrition behaviour and they may be loosely grouped as autotrophs. Unlike green plants which derive their energy from sunlight certain bacteria species obtain the energy needed for growth and biosynthetic reactions from the oxidation of inorganic materials and they are known as chemoautotrophs. Obligate chemoautotrophs are limited exclusively to inorganic oxidations, others like the facultative autotrophs, obtain energy from the oxidation of either inorganic materials or organic carbon. Coupled with all these characteristics, the synthetic powers of chemoautotrophs is truly great. This group though numerically small, has great economic and agricultural mportance. Certain very important genera like *Nitrosomonas nitrobacter,* Ferrobacillus and certain species of Thiobacillus, are representative of true chemoautotrophs. Most chemoautotrophs are strict aerobes. Others are capable of proliferating in the absence of O_2 and require an O_2 rich substance like nitrate for *Thiobacillus denitricans* sulphate for *Desulpho vibrio* and CO_2 for *Methanobacillus.*

Some of the important energy yielding reactions related to such bacterial species are :

$NH_4 + 1\frac{1}{2}O_2 \longrightarrow NO_2^- + 2H^- + H_2O$ *Nitrosomonas*

$NO_2 + \frac{1}{2}O_2 \longrightarrow NO_3^-$ Nitrobacter

$S + 1\frac{1}{2}O_2 + H_2O \longrightarrow H_2SO_4$ Thiobacillus

$2H_2 + O_2 \longrightarrow 2H_2O$ Hydrogenomonas

$4H_2 + SO_4^- \longrightarrow S^- + 4H_2O$ Desulfovibrio

$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$ Methanobacilus

Chemoautptrophs may be subdivided as follows. This division is on the the basis of the element whose oxidation provides the energy for growth and cell synthesis.

(i) Nitrogen compounds oxidized	
(a) Ammonimum oxidized to nitrite	*Nitrosomonas*
(b) Nitrite oxidized to nitrate	*Nitrobacter*
(ii) Inorganic sulphur compounds converted to sulphate	*Thiobacillus*
(iii) Ferrous ion converted to the ferric state	*Ferrobacillus, Gallionella*
(iv) H_2 oxidized	*Hydrogenomonas, Methanobacilus, Desulfovibrio*
(v) CO oxidized to CO_2	*Carboxydomonas*

Role of Bacteria in Soil

Bacteria are essential for soil fertility. The major contribution of bacteria is to decompose organic nitrogenous compounds in plant and animal residues, with the ultimate liberation of ammonium. The latter can be oxidized to nitrate only by nitrifying bacteria. Such bacteria obtain their energy by the exothermic oxidation of ammonia to nitrite and of nitrite to nitrate. Chemoautotrophic bacteria are mainly responsible for such transformation.

Another important contribution of bacteria is in the nitrogen cycle. Certain bacterial species are unique in fixing atmospheric (molecular) nitrogen in the form of ammonium nitrogen. Molecular nitrogen is fixed only by prokaryotic cells. Nitrogen can be fixed bacteria either symbiotically, in which case they grow in the roots of the host plants and form nodules or by free living bacteria. Two genera, Azotobacter (aerobic) and Clostridium (anaerobic) are the best known nitrogen fixers. Azotobacter is very ccommon in the rhizosphere region of plants and they maintain themselves on the root exudates. The plants rich in Azotobacter population have been observed to grow better. Besides nitrogen fixation, Azotobacter is also useful to the host plants through the production of gibberellins and possibly other growth hormones, which results in an increased crop yield due to bacterization.

FUNGI

In well-aerated cultivated soils, fungi account for the largest part of the total microbial protoplasm. This dominance in mass is the result of the large diameter and the extensive network of fungus filament. Fungi play various roles in soil. They are known to be plant pathogens, active participants in the decomposition of plant and animal residues and also involved in mycorrhizal association.

The fertile land may harbour as much as 10 to 100 m of active fungus filaments per gram of soil. Assuming the mold filament has an average diameter of 5 and a specific gravity of 1.2. The live weight of fungi is approximately 575 kg per hectare.

Type of Fungal Structure in Soil

Fungi are present in different forms in soil, ranging from unicellular forms to a much branched filamentous structure. They vary in size and life cycles. Some fungi live in soil purely in the vegetative form, some of them don't have reproduction structures at all and they are simply grouped as sterile mycelia. The following list summarizes the common fungi isolated from soil (Table 22.2)

Table 22.2 : Common Fungi Isolated from Soil

I. Phycomycetes	
A. *Mucorales*	Absidia, Cunninghamella, Mortierella, Mucor, Rhizopus, zygorrhynchus.
B. *Pernosporales*	Pythium
II. Ascomycetes	Chaetomium
III. Fungi imperfecti	
A. *Moniliaceae*	Aspergillus, Penicillium, Acrostalagnus Botrytis, Cephalosporium Gliocladiu, Monilia, Scopularopsis, Spicaria, Trichoderma, Trichothecium, Verticillium.
B. *Dematiaceae*	Alternaria, Cladosporium, Pullularia
C. *Tuberculariaceae*	Fusarium, Cylindrocarpon, Rhizoctonia
IV. Mycelia Sterilia	As indiated above, members of fungi imperfecti are more common in soil than representatives of other groups. *Aspergilli* and *Penicillia* are the maximum in soil.

Role of Fungi in Soil

Fungi in soil are associated with various types of activities. Some important ones are listed below :

1. Utilization of Carbonaceous Materials : In this category five major groups have been identified : Saprophytic fungi, lignin decomposers, coprophilic fungi, predaceous types and root inhabiting fungi. Members of phycomycetes are generally associated with sugar decomposition and they rarely decompose lignin and cellulose. Basidiomycetes as a group are lignin decomposers.

2. Utilization of Proteinaceous Substances : Many fungi are active in the formation of ammonium and simple nitrogen compounds in soil. various fungi participate in this process.

3. Plant Pathogenicity : Certain soil fungi are common plant pathogens particularly root pathogens. Some saprophytic species act as pathogens and at an opportune time invade living tissues.

4. Mycorrhizal Formation : A number of fungi are associated with the root of the plants and they develop a specialized symbiotic associated with the host plant, known as mycorrhiza. Two well known mycorrhizal association i.e. *ectomycorrhiza* and *endomycorrhiza* are the result of two groups of fungi. In the former case members of basidiomycetes and a few ascomycetes are involved, whereas in the latter, the major contribution is by certain members of phycomycetes.

Factors affecting Soil Fungi

Survival, adaptation and establishment of fungi in a particular soil is determined by a number of environmental factors. These factors are discussed below.

1. Organic Matter : Distribution of fungi is largely determined by the availability of oxidizable carbonaceous substrates. The upper horizon is rich in organic matter and correspondingly this layer is also rich in filamentous fungi. In general, the organic matter status of the soil decreases with depth and this has a direct bearing on the fungal population, therefore, the soil at lower depths is poor in fungi. Green manures or other energy rich carbonaceous materials and these amendments increase the size of fungal populations.

2. Hydrogen Ion Concentration : The acidic side of pH is generally more favourable to soil fungi. Biochemical transformation in acid habitats are the therefore, largely as a result of fungi. In soil amended with inorganic fertilizers, particularly those rich in ammonium salts, the population of filamentous fungi increases. Such an increase is generally due to the acidification of soil on account of the microbial oxidation of nitrogen, which leads to the formation of nitric acid.

3. Temperature : Temperature plays an important role in regulating soil fungi. The fungi are mostly mesophilic and when the temperature reaches extreme conditions, it has an adverse effect on fungi. Except for a few thermophilic or psychrophyllic species, high and low temperatures respectively are not conducive for soil fungi. In tropical soils, the high temperature noted during summer month say April, May and a part of June are unsuitable for the survival of fungi in soil.

4. Moisture : Population density of soil fungi is positively related to the moisture level of soil. In case of fungi too, water is the major constituent of living cells, 15-30% water content is quite conducive for soil fungi. Any deviation from this range is not favourable for most fungi. Certain soil fungi may grow above and below the said moisture regimes. An excessive moisture level in soil is harmful to fungi. In places where water stagnates, the diffusion of O_2 necessary for aerobic metabolism is inadequate for microbiological demand and in such situation fungi are among the first suffer.

5. Aeration : Fungi being aerobes most abundant in the upper few inches ") of soil where gaseous exchange takes place freely. At the lower horizons the population of fungi decreases due to poor O_2 availability and due to the accumulation of CO_2.

6. Soil Profile : The upper few inches of the soil profile are rich in organic matter, have free gaseous exchange and are adequately moist to support the better growth of fungi. Fungi are hence plenty in the upper horizon. In addition, root widely spread in the region favour the fungal flora in many ways. At deeper depth of soil, say after 40-50 cm. The fungal flora is almost negligible and this environment is suitable for the growth of certain anaerobic bacteria.

7. Season : The seasons of a year have a pronounced effect on soil mycroflora. Hot summer months as stated earlier, are not suitable for fungi and this is the time when the lowest fungal counts are reported. Varying temperate and moisture regimes coupled with nutrient availability in soil, which are closely linked with seasonal changes, affect soil fungi. The seasonal cropping system has its own effect on fungi. When the temperature level drops down to a steep low, fungi find it difficult to survive.

8. Vegetation : The structure and property of the soil is a result of the cover vegetation on it. Plants growing in a locality change the nutrient status, moisture regime and aeration. There is a regular supply of plant debris to the soil surface, which enhances the nutrient status. With the addition of plant litter the activity of fungi in soil is enhanced. Depletion in litter accordingly decreases the fungal population.

ACTINOMYCETES

Actinomycete is a transitional group between bacteria and fungi and in soil they are numerically second to bacteria. Structurally they are unicellular organisms that produce slender branched mycelium and undergo fragmentation. They also produce asexual spores by the division of mycelium. Morphologically the branched, aerial, individual hyphae are similar to fungi but are less broad, with a diameter in the range of 0.5 to 1.2.

Distribution in Soil

Actinomycetes are widely distributed in different types of soils, but they are more abundant in surface soil. In soil with a high pH the population of actinomycetes is very high. Composts, river mud and river beds are other places rich in this group. Physical characteristics, organic matter content and pH of soil determine the population of actinomycetes in soil. In dry soil with a high pH the population is much higher than other microorganisms. Their numbers are also considerably larger in grasslands and pasture soils than in cultivated fields. Virgin soils are relatively poor in actinomycetes. Most Actinomycetes are mesophilic, but forms like Streptomyces, Thermoactinomycces and Thermomonospora are the thermophilic.

Depth, moisture content, soil reaction, soil type and soil vegetation as in the case of bacteria and fungi, are important factors which influence the occurrencce and distribution of actinomycetes in soil. The number of actinomycetes decreases with the depth of soil, but they increase in proportion to bacteria by 10-65%.

Classification

Alexander (1961) classified actinomycetes within the order actinomycetales. The actinomycetales comprise four families and none genera.

I. Mycobacteriaceae : Mycelium rudimentary or spores absent.

(a) Mycobacterium : Gram positive, aerobic rods commonly acid fast, non-motile and usually non-branching. Soil saprophytes are included in the genus.

(b) Mycococcus : Gram positive, aerobic, mesophilic cocci, not acid fast. Found singly, in clumps or in short chains.

II. Actinomycetaceae : True mycelium formed. Spores produced by hyphal fragmentation. Spores not in sporangia. In early growth, the mycelum is continuous, but subsequently it fragments into bacillary or coccoid segments.

(a) Actinomyces : Anaerobic or micro-aerophilic. Conidia not formed. Typically parasitic, causing human and animal diseases.

(b) Nocardia : Obligate aerobes. Cells occur as slender filaments. Aerial mycelium rarely formed and conidia not produced. Colonies similar to those of true bacteria, common soil organisms.

III. Streptomycetaceae.

(a) Streptomyces : Conidia formed in chain on aerial hyphae, aerobic. Abundant in soil.

(b) Micromonospora : Conidia formed singly at the terminal end of short conidiophores, never in chains of spores. No growth at 50-65°C.

(c) Thermoactinomyces : Similar to the Micromonospora except for growth at 50 to 65°C.

IV. Actinoplanaceae : True mycelium formed. Spores produced in sporangia.

(a) Actinoplanes : Sporangiospores motile. Aerial mycelium rare.

(b) Streptosporangium : Sporangiospores not motile. Aerial mycelum common.

Seventy to ninety per cent of the actinomycetes in virgin and cultivated fields are *streptomyces,* less than a third are *Nocardia* strains and *micromonospora* hardly contributes about 5 per cent.

Role of Actinomycetes in Soil

Actinomycetes perform following important functions in the soil.

1. Decomposition of Organic Matter : Actinomycetes are one of the most active decomposers of various types of organic matter. In order of preference, water soluble carbohydrates are most readily attacked followed by hemicellulose and cellulose. On account of an efficient enzymatic set up they decompose a wide variety of substances available in soil. Streptomyces and Nocardia organisms are active decomposer of cellulose in soil. Certain actinomycetes, like actinoplanes and

Streptomyces, can decompose keratin due to the presence of keratinase enzyme in them. Certain members of actinomycetes are capable of attacking even lignin rich materials. Streptomyces species play an active role in the formation of humic acid, which though quite resistant to chemical and microbial attack, has been reported to be degraded by Nocardia.

2. Plant Pathogen : Amongst the many actinomycetes present in soil only a few act as plant pathogens. The most common pathogen is *Streptomyces scabies* which is responsible for potato scab disease. Streptomyces alni is associated with *Alnus glutinosa* (alder) and the organism forms root nodules which are now considered to be associated with nitrogen fixation.

3. Antibiosis : Some species of Streptomyces are capable of synthesizing antibiotics. Almost three-fourth of the Streptomycete isolates may produce antibiotics. The amount of antibiotics being produced in soil is not of much significance, but in the laboratory when the conditions are optimal large amounts of antibiotics are produced. In soil, the situation is not that conducive due to limited nutrient availability and competition amongst the soil microorganisms. Though the amount detected in soil is very small it can exert a localized inhibitory effect. This behaviour in the root region has a special significance.

Actinomycetes are responsible for the synthesis of certain important antibiotics like streptomycin, chloromphenicol, chlorotetracyline, oxytetracyline and cycloheximide.

4. Microbial Equilibrium : Besides the production of antimicrobial metabolites, few species of Streptomyces liberate extra-cellular proteases which lyse bacteria. This has importance in the microbiological equilibrium in soil.

ALGAE

Algae group as a whole being mostly autotrophic, occurs predominantly on the surface of soil where light is freely available. The availability of moisture is also an important factor for the distribution of algae in soil. The population of algae, however, is much less than the other three groups of microorganisms discussed. Algae too are more dominant during rainy seasons when they grow and multiply luxuriantly on the soil surface.

Soil algae are normally unicellular forms. In general, they are smaller and less developed than their aquatic counterparts. Algae are the most abundant at or close to the soil surface but they are also isolated from the lower horizons. Movement of algae to lower horizons may be normally due to rain and soil animals particularly earthworms which have been identified as agents for the downward movement of algae.

From soil the autotrophs need nitrogen, potassium, phosphorus, magnesium, sulfur, iron and other micro-nutrients. From the atmosphere they derive CO_2 and energy in the form of light, once all these requiremnts are met with, the autotrophic algae thrive in soil. It is interesting to note that although many algae are obligate photo-autotrophic it is not uncommon to observe heterotrophy in several species of chlorophyceae, cyanophyceae and diatoms. For such heterotrophic strains, the energy source is not light but is not light but is rather the oxidation of organic carbon. Such algae known as *facultative photo-autotroph* arc capable of metabolizing a large variety of carbohydrates like starch, sucrose, inulin, glucose, galactose, glycerol and citric acid. It has been noted that green algae, diatoms and blue green algae are abundant in soil. Geographically in temperate climates members of chlorophyceae are more frequent and the members of the diatoms are smaller in size, where as in tropical soils blue green algae are dominant.

In addition to the above two groups, soil is very rich is cyanophycean algae. The unique character is exhibited certain members of blue green algae in fixing atmospheric nitrogen. Many species of blue greens have been suggested to be useful in reclamation of alkaline soil, so called 'Usar' or chopan soil in India. It has been indicated the simply by putting such alkaline soils under water coverage for a certain period and allowing the members of blue green algae to grow on wet soil for a few years, the soil may be made fertile.

Factors Affecting Soil Algae

Following factors affect the algal population in soil :

1. Light and CO_2 : Light and CO_2 are the two major factors regulating algal distribution, are generally not in short supply. Obtaining an adequate supply of CO_2 rarely poses a problem as CO_2 and bi-carbonates are usually produced in excess of the demand. Similarly, light in normal course is also adequately available for autotrophs. However, light is a determining factor with respect to the vertical distribution of soil algae. At deeper depths light is a major determinant. As such the population is most dense in the upper 5 to 10 cm soil which falls off drastically with depth.

2. Moisture : Algae as a whole prefer continuous saturated soil. Prolonged saturation permits new communities to appear. Under excessive dried situation cells normally may die. However, like other microorganisms they survive by producing thick walled resting bodies which are resistant to dry condition.

3. Temperature : Temperature too has its effect on the densities of algal cells. Drought may have an adverse effect and lead to the death of cells, similarly, low temperature is important in relation to loss of water.

4. Soil Reaction : Algae prefer neutral or alkaline soil and so the widest diversities of species are found within this range. It has also been noticed that in acidic soil, members of chlorophyceae are more common whereas in alkaline environments cyanophyceae are abundant. Diatoms are less frequently encountered in acid soils, whereas they are abundant in calarous areas.

5. Inorganic Nutrients : Amongst nutritional aspect carbon, nitrogen and phosphorus have been, intensively investigated. Besides, the above nutrients calcium (Ca) is another element which also plays an important role in algal distribution. The effect of Ca is more pronounced on the quality of the algal flora than in its richness. This is because calcareous soils are rich in nitrates and phosphates and hence, they favour rich algal flora. The addition of fertilizers to agricultural soil, encourages the growth of cyanophyceae. Mixture of phosphorus and potassium s quite effective, where as ammonium nitrate is relatively less effective. Similarly potassium has less effect than phosphorus. Effects of phosphorus and nitrogen are quite pronounced on algae and soils rich in phosphates and nitrates were also quite rich in algae.

6. Organic Matter : An interesting interrelationship has been observed between soil algae and other microorganisms of soil. It has been noticed that the growth of heterotrophic algae in dark is promoted by bacteria and actinomycetes found in the region. Interaction has also been reported between algae and fungi or bacteria. An increased growth of a coccid green algae in the vicinity of a bacterium. This probably was on account of the ability the bacterium to decompose organic nitrogen compounds, which in turn proved useful to the algae.

Role of Algae in Soil

1. **Germination of Seeds** may be unaffected, stimulated or inhibited by algae. That roots of angiosperms as such are not affected by soil algae, but algal extracts may stimulate their development. On the contrary, root of certain plants may stimulate algal growth. The algal extract may inhibit the growth of phytopathogenic fungi.

2. The algal population in soil plays an important role in **soil fertility.** In places like rice fields, where the population density of algal cells in very high, the dead or live algae may act as fertilizers.

3. In deserts and other barren soils, algal crusts may prove useful in **binding soil particles** together. This has great ecological importance, because it helps in prevention of soil erosion and facilitates recolonization of the soil be higher plants.

4. Most important function of soil algae, particularly of certain members of cyanophyceae, is to **fix atmospheric nitrogen.** A large number of cyanophycean members can fix atmospheric nitrogen symbiotically or non-symbiotically.

PROTOZOA

The phyllum Protozoa is represented by primitive, unicellular organisms, which vary in size from several microns to one or more centimeters. Protozoa being representatives of the animal kingdom are in no way less important in soil ecosystem. Along with soil micro-flora, this group plays an important part in the ecological and biochemical processes operating in soil. Normally, cells of protozoa are devoid of chlorophyll, but interestingly there are a few transitional genera which resemble algae and are provided with chlorophyll pigments. Furthermore, there are certain genera which are claimed both by plant and animal experts as being in their domain.

Two prominent stages are encountered in the life cycle of protozoa—an active phase in which the organism feeds, multiplies and leads an active life and a resting or cyst stage. The latter stage is usually observed when conditions are unfavourable. The normal mode of reproduction in protozoa is asexual. The mother cell divides longitudinally or transversally into two halves which are called daughter cells. In certain protozoa sexual reproduction is very simple; morphologically similar mating cells fuse and exchange of genetic materials takes place between the two. After the exchange, the two cells separates and new individuals emerge. Protozoa are of wide occurrence in different types of soil. Certain soils may contain a few types only whereas others may exhibit as wide variety of them.

Types of Protozoa

The following are the five major classes identified in the phylum protozoa.

(a) Mastigophora or flagellates–Locomotion by means of flagella (1-4 number)

(b) Sarcodina (= Rhizopods) –Locomotion by means of pseudopodia

(c) Ciliata or Ciliates–cilia present throughout the active phase of lfe cycle

(d) Sactoria–Cilia present only during young stage.

(e) Sporozoa–No specialized locomotory organelles.

In soil only the first three types of protozoa are found and hence the following discussion will be based on them only.

(i) Phytomastigophora and

(ii) Zoomastigophora

Phytomastigophora

These are usually endowed with chlorophyll and like normal plant cells they grow photosynthetically. Representative of *zoomastigophora* are typically animal like and are devoid of chlorophyll. The members of Sarcodina do not possess permanent locomotory organs. Movement in this case is by means of temporary protoplasmic extensions from the body of the cell. The unique feature of the cell in Sarcodina is the lack of a rigid external surface and this remits frequent change in the animal body. The organisms, as and when required, produces protoplasmic extrusions from the cell body, which are known as pseudopodia. Pseudopodia as indicated are not permanent structures, but simply as extension of the protoplasm and are sent forth or withdrawn as the need of the organisms may be.

In ciliate there are numerous hairs around the cell and movement of the organism is through the action of these hairs. Ciliates are normally very small in size, ranging from 10-80 in length. Some typical soil cilicates are Colpoda, Vorticella, Oxytrichia, Colpidium, Halteria and Balantiophorus.

Factors affecting Protozoa in Soil

Amongst the various factors affecting distribution and density of protozoa in soil, the most important are the presence of adequate food supply and moisture.

1. Food Supply : The population of protozoa is the highest near the surface of the soil, particularly in the upper 6 inches. At lower depths the population is generally low. This is directly related to bacterial floara in the region. In the upper layer of soil, more numerous bacterial species account for the higher protozoan cells. As a corollary, any soil amendment which favours the growth of bacteria in soil, also helps tin the rapid built up of the protozoan population. In agriculture fields, where manuring and fertilizing s done, both bacteria and protozoa are abundant.

2. Moisture : The moisture level of soil affects protozoa both in quality and quantity. For protozoan too, adequate water supply is essential for physiological activity. Water also helps in the lateral and vertical movement of protozoa. Generally, protozoan are aerobic and hence a steady supply of O_2 is necessary for their good growth. Most protozoa are indifferent to pH variations. Many species, however, are susceptible to extreme variations. Cool and damp conditions are favourable to protozoan. On the whole, the population, both of bacteria and of the associated protozoan fauna, is determined by other soil conditions—the nature of the organic cycle, the moisture status and the base status.

Role of Protozoa in Soil

The role played by soil protozoa is not properly understood. Normally it is expected that many protozoa, being bacteria feeders, regulate the size of the bacterial population. Protozoa being detrimental to the growth of useful bacteria may affect soil fertility. Protozoa mainly affect the organic cycle indirectly. Their constant predation on bacteria contributes to the general turnover of readily available nutrients. This appears to favour biochemical activity. An increase in the growth of higher plants, when treated with amoebae and ciliates, has been reported.

VIRUSES

Unlike the other microorganisms viruses do not form a major soil microbial population and is beyond the resolution of light microscopy, but can be easily studied with the help of recent techniques like SEM and TEM. Such sub-macroscopic organisms are called viruses and though numerically lesser in number in soil, play an important role and are economically very important. These infective agents are responsible for many disease of plants and animals. There are many strains of viruses which also infect microorganisms like bacteria and actinomycetes and in such condition they are designated as bacteriophages and actinophages.

The characteristic features of viruses is their intimate relation with a suitable host. Also, viruses are limited in their host range and as such they infect and parasitize only specific plants, animals microorganisms. Viruses normally grow and multiply only when they are inside the host body. They do survive outside the host for varying periods buy no activity is noticed during the period. Certain plant viruses like those responsible for mosaic disease of wheat, oats and tobacco and big vein disease of lettuce, persist in soil, when the respective host plants are harvested. In a true sense, such viruses are not a native resident of soil and they simply live in the soil and retain their infective capacity as long as the host crop is not available. The period thus, spent in soil may be for a year or little more. There are reports that certain animal and human viruses also survive in soil and retain their infective ability for some time. By and large the soil is more rich in bacterial and actinomycetes viruses i.e. bacteriophages and actinophages. Morphologically bacteriophages posses head and tail like structures. The diameter of the bacteriophage normally does not exceed 0.05 to 0.10 μ and the tail which is somewhat longer and quite narrow measures approximately 0.2 μ in length.

EXERCISE

Q.1. Select the appropriate word and fill in the gaps :

1. ____ organisms use organic compounds as their source of carbon.
(a) Autotrophs (b) Facultative
(c) Autochthonous (d) Heterotrophs

2. ___ organisms consume comparatively resistant organic materials at a steady rate.
(a) Photoautotroph (b) Autochthonous
(c) Zymogenous (d) Chemoautotrophs

3. In an ordinary soil, the population of bacteria ranges from _____.
(a) 0.1 ro 1 billion g^{-1} (b) 1 to 2 billon g^{-1}
(c) 1 to 3 billion g^{-1} (d) 3 to 4 billion g^{-1}

4. The root surface environment in soil is known as _____.
(a) Root exudates (b) Organic rich material
(c) Rhizosphere (d) Atmosphere

5. In general ____ % of soil bacteria occur in small colonies and groups.
(a) 23% (b) 55%
(c) 10% (d) 77%

6. The optimum soil moisture content or aerobic bacteria is normally between ___ of mosture holding capacty of soil.
(a) 10-20 % (b) 20-40 %
(c) 40-50 % (d) 50-75 %

7. The common soil pH range for different bacterial population is between pH ____.
(a) 4.0 to 7.0 (b) 7.0 to 10.0
(c) 4.0 to 10.0 (d) 3.0 to 7.0

8. Mesophilic bacteria require optimum temperature ranging from ___ or their growth.
(a) 10-15°C (b) 15-25°C
(c) 25-35°C (d) 15-45°C

9. Inorganic S compounds are oxidized to sulphate and provide energy for growth of ___ bacteria.
(a) Nitrosomonas (b) Hydrogenomonas
(c) Thiobacillus (d) Ferrobacillus

10. Which of the followng two genera are the best known nitrogen fixers ?
(a) Nitrosomouas and Thiobacillus (b) Nitrosomonas and Nitrobacter
(c) Azotobacter and Clostridiam (d) Azotobacter and Nitrobacter

11. Besides nitrogen fixation, ____ is also useful to the host plant through the production of gibberellins and other growth hormones.
(a) Azotobacter
(b) Rhizobium
(c) Nitrosomonas
(d) Nitrobacter

12. Which of the following micro-organisms are dominant in mass in soil ?
(a) Bacteria
(b) Fungi
(c) Algae
(d) Actinomycetes

13. The members of Fungi imperfecti ____ are more common in soil than representatives of other groups.
(a) Aspergillus and penicillum
(b) Absidia and pythium
(c) Alternaria and cladosphorium
(d) Fusarium and rhizoctomia

14. The soil fungi, members of ____ are generally associated with sugar decomposition.
(a) Ascomycetes
(b) Phycomycetes
(c) *Fungi imperfecti*
(d) Dematiacae

15. The fungi, members of basidiomycetes and a few ascomycetes are involved in ____ association.
(a) Ectomycorrhizal
(b) Endomycorrhizal
(c) Bacterial
(d) Fungal

16. ____ pH is generally more favourable to soil fung.
(a) Neutral
(b) Alkaline
(c) Acidic
(d) Acidic to alkaline

17. In general, the fungi are mostly ____.
(a) Psychrophylic
(b) Mesophilic
(c) Thermophilic
(d) Mesophilic and therophilic

18. Maximum (70 to 90%) of the actinomycetes in virgin and cultvated fields are ____.
(a) Streptomyces
(b) Nocardia
(c) Mcromonospora
(d) Streptosporangium

19. The actinomycetes belonging to the genera nocardia are reported to degrade ____ in soil.
(a) Lignin
(b) Humic acid
(c) Cellulose
(d) Keratin

20. The actinomycetes belonging to the genera ____ are capable of synthesizing antibiotics.
(a) Nocardia
(b) Thermoactinomyces
(c) Micromonospora
(d) Streptomyces

21. Which one of the following is not synthesized by actinomycetes.
(a) Chlorotetracycline
(b) Oxytetracycline
(c) Gibberellin
(d) Streptomycin

22. The unique character of blue green algae is ____.
(a) Fixation of atmospheric N
(b) Ammonium oxidation
(c) NO$_2$ oxidation
(d) Decomposition of lignin

23. Many species of ____ have been suggested to be useful for reclamation of alkaline soil.
(a) Bacteria
(b) Actinomycetes
(c) Diatom algae
(d) Blue green alage

24. Continuous saturated soil is favourable for the growth and development of ____ in soil.
(a) Algae
(b) Fungi
(c) Bacteria
(d) Protozoa

25. ____ may inhibit the growth of phytopathogenic fungi.
(a) Bacterial extract
(b) Algal extract
(c) Fungal extract
(d) Protozoa extract

26. In _____ protozoa, the locomotion is by means of pseudopodia
    (a) Mastigophora (b) Ciliata
    (c) Sactoria (d) Sarcodina
27. The movement of ciliate protozoa s through the action of _____.
    (a) Pseudopodia (b) Hairs around the cells
    (c) Special organelles (d) Flagella

Q.2. Answer to the point :

1. Name the two broad divisions of bacteria given by Winogradsky (1925).
2. Why A horizon of soil harbors maximum bacterial population ?
3. Name the four factors affecting soil bacteria ?
4. What do you mean by psychrophile bacteria ?
5. What are chemoautotrophic bacteria ?
6. Name the oxidation reaction which provides energy for growth of nitrosomonas bacteria in soil.
7. Name the bacteria that obtain the energy from the oxidation of hydrogen.
8. List out the different types of fungi in oil.
9. List out five major groups of oil fungi identified to utilize carbon.
10. What do you mean by mycorrhiza ?
11. Name the two mycorrhizal associations.
12. State the relationship between soil fungi and organic matter.
13. What is the conducive water content for soil fungi ?
14. Why the fungal flora is negligible at lower depths of soil below 40-50 cm ?
15. What are Actinomycetes ?
16. Name the three thermophilic actinomycetes.
17. List out the four families of actinomycetes within the order actinomycetales.
18. Name the pathogen responsible for potato scab disease.
19. Name the agents responsible for movement of algae to lower horizons in soil.
20. What do you mean by facultative photo-autotroph algae ?
21. State the favourable pH range for growth of algae in soil.
22. Why the effect of Ca is more pronounced on the quality of algal flora ?
23. What is the role of algal population in deserts and barren lands .
24. How algae act as fertilizer ?
25. Name the five major classes identified in phylum protozoa.
26. Give a differentiating point between phytomastigophora and zoomastgophora.
27. Name the bacteria feeder organism.
28. Define virus.
29. How viruses are infective to plants, animals and micro-organisms ?

❑❑❑

23

Soils in India

Red, Laterite, Black, Alluvial, Desert, Tarai, Saline and Alkali, peaty and marshy, Brown hill, Sub-mountainance and mountain medow soils of India. Konkan Coast, Western Ghat and Deccan plateau soils of Maharashtra.

Soils of India have been divided into the following eleven major groups (Fig-23.1) : These soil groups are discussed below.

1. Red Soils : Red colour in red soils are due to the presence of various oxides or iron. They are either formed in situ or from the products of decomposition of rocks washed to a lower level. They include soils locally known as red sandy soil and red alluvium. They are mostly formed under sub-humid climate from a number of rock. formations like granite, shales etc. Their main features are a light texture, porous structure, absence of time, and low soluble salts. They are generally poor in fertility constituents such as nitrogen, phosphoric acid, potash and lime and are highly deficient in organic matter. They have a low base exchange capacity and the colloidal complex is base saturated. They are neutral in reaction, the pH ranging from 7.0 to 7.5. The characteristics clay mineral is kaolinite. Area of red soils are whole of Madras and Mysore, part of Andhra Pradesh, M.P., Orissa and Bihar (Chota Nagpur), Birbhum (W.Bengal), Santhal Pargana (Bihar), Mirzapur, Jhansi and Hamirpur districts of U.P. and eastern half of Rajasthan.

1. Laterite : They are found mostly in areas of high rainfall. They are light in texture and have an open free draining structure. There is no retention of water. There is practically no horizon differentiation in the soil profile. They are deficient in lime and are slightly to moderately acid in reaction. The pH varies from 5.0 to 6.0. They are low in base exchange capacity.

Laterite soils formed at high levels have a pale red colour are highly gravell and are poor in all fertility constituents. If these formed a low levels have a darker colour probably due to a great accumulation of humus, a slightly finer texture an are quite well drained.

These soils are found all along the west coast of Maharashtra, Mysore, and Kerala, on tops of hills in the Deccan, Madhya Pradesh and in Orissa along th Eastern Ghat.

3. Black Soil : The black soil developed from Basaltic rock under semi-ari conditions. The soils are black or dark brown in colour. They include soils locally known as *regur or black cotton soil, deep black soil, medium black soil.* The colo varies considerably alluvium soil of Narmada and Tapi are blackish brown. Thei texture ranges from sandy loam to heavy clay. Some black soil may be porous and other may be compact and impervious. One of the characteristics features of black soil is that it swells on wetting during the rainy reason and shrinks and cracks in summer. The base exchange capacity of deep black soil is quite high (50 to 75 meq/100g). The pH varies from 7.5 to 8.5. The soils are on the whole low in fertility. The soils are deficient in nitrogen and phosphorus. They are rich in potash and lime. The black soils are found in parts of Maharashtra, Gujarat, M.P., Rajasthan, U.P., A.P., Madras (Chennai) and Mysore.

4. Alluvial Soils : They are characterized by extreme depth and gray or grayish brown colour. Their texture varies from sandy loam to clay loam. The structure is also variable, loose and free draining in the case of sandy soils, and compact and impervious in clayey soils. In immature alluvial soils there is no distinct horizon differentiation. These soils are most fertile, they are deficient in nitrogen phosphorus and humus but are well supplies with lime. Their base exchange capacity is comparatively low. The pH varies from 7.0 to 8.0

They are very extensive in area cover large parts of Rajasthan, Punjab, U.P., Bihar and W. Bengal and extend even into west Assam and north Gujarat. The soils developed in the eastern parts of the Indo-Gangetic plains are, however, markedly different from those in the eastern region.

5. Desert Soils : They have developed in arid regions mostly under the influence of physical weathering. They are mainly sandy. They contain large amounts of soluble salts and varying proportions of lime. They have a high pH and are very poor in fertility constituents. Desert soils are found in large parts of Rajasthan, south Punjab and in range of Kutch. The temperature regime is very high throughout the year. The rainfall ranges from 50 cm to less than 10 cm.

6. Saline and Alkaline Soils : These soils are developed in arid and semi-arid regions. Basin shaped topography (poor drainage) is also responsible for their development. They are mainly found in the black soil region in the south and west, in the Indo-Gangetic alluvium in the north, and in the deltaic and coastal regions all along the west and east coast.

7. Peaty and Marshy Soils : They are formed in depression under submerged conditions and have acquired a blue colour due to the presence of ferrous iron. Peaty soils are found scattered in Kerala, north Bihar and north U.P. and have developed in humid regions as a result of the accumulation of large quantities of organic matter.

8. Tarai Soils : Tarai soils have a wet regime and high water table conditions for most part of the year. Tarai soils are foot hill soils and extend in strips of varying widths at the foot of the Himalayas in Jammu and Kashmir, U.P., Bihar and W.Bengal. Soils under the natural conditions are thickly vegetated and swampy. Several types of grasses and trees form the native vegetation, on removal of which the soils become highly productive. The soils were derived from the materials washed down by the erosion of mountains. Their parents materials are of alluvial sediments and consist of hard clay.

9. Brown Hill Soils : These soils are formed on the hills under forests. They are mainly found in the Himalayas on sandstones and shales. The surface soils are dark brown, loam to silty clay in texture, acidic to neutral in reaction. These soils may be classified in order Alfisols.

10. Sub-montane Soils : These soils are formed in high rainfall regions of sub- Himalayan under coniferous forests. The soils are acidic in reaction. The organic matter accumulation is high and there is absence of free lime.

11. Mountain Meadow Soils : These soils are occur at high elevation in the Himalayas. The soils are shallow with grass vegetation.

SOILS OF MAHARASHTRA

Maharashtra is one of the four Littoral states in India that border the Arabian sea and located between 15°44 and 21°40 N latitude. And 73°15' and 80°33 E longitude. It is the third largest state, next to Madhya Pradesh and Rajasthan in the country. It cover an area of 30.76 mha which is 10% of the total geographical area of India. It has 31 administrative districts with Mumbai as capital and Nagpur as the second capital. It is bounded by Gujarat and Dadra Nagar Haveli in the North West; Madhya Pradesh in the North ; Andhra Pradesh and Karnataka in the South East. It has a population of 7.9 m which is 9.3 per cent of the total population of the country.

The state can be divided into three broad physiographic regions; Western Konkon Coast, Western Ghats (North Sahyadris) and Deccan plateau.

The State is endowed with wide variations in physiography, climate and geology and natural vegetation which are responsible for the development of large variety of soils. TGA is 307.6 lakh ha. It is divided in 3 regions Viz. Konkon Coast, Western Ghat and Deccan plateau.

A. Western Konkan Coast Region

This region comprises Sindhudurg, Ratnagiri, Thane and Raigad districts (Fig. 21.2). The rocks formed in this region are Deccan trap, granites, gneisses and laterites. The soils occurring in different land forms are as under :

1. Soils of Coastal Lands with Residual Hills : The gentle sloping coastal low lands are observed in patches and are covered with moderately shallow to deep soils with aquic and or swell shrink characteristics. These soils are slightly saline in the vicinity of creeks and no saline at other places; they are calcareous neutral to alkaline in reaction having pH 7.5 to 8.5 , clayey, with high amount of bases and have high water holding capacity. The soils located on moderately sloping residual hills are lateritic in nature and show intensively leached surfaces. They are loamy and slightly acidic with pH 5.0 to 6.5 with moderate base status.

2. Soils of Undulating Lands and Narrow Valleys : The moderately sloping undulating lands with moderately shallow to moderately deep, slightly acidic with pH 5.5. to 6.5 , loamy soils with moderate to well developed B- horizons. They are moderate to severely eroded and show moderate stoniness. The mesas and steeply and sloping side slopes of these undulating lands support very shallow, well drained, loamy moderate to slightly acidic with pH (4.5 to 6.5), soils with little profile development have a lithic contact with 50 cm of the surface; at places low base status, loamy well developed soils profiles (Haplustalfs) with moderate to severe erosion and strong stoniness are observed.

The narrow valley support moderately to gently sloping moderate shallow to deep well drained, loamy slightly acidic to neutral (pH 5.5 to 7.5) soils with moderate profile development.

3. Soils of Valley Lands : Gently sloping valley land develop moderately deep to deep, well drained , loamy to clayey, neutral (pH 6.5 to 7.5) soils with well to moderate developed soil profiles. The soils are slightly eroded.

4. Soils of Undulating Rolling Lands : Moderately steeply to very steeply sloping undulating and rolling lands develop well drained, loamy-skeletal, neutral (pH 6.5 to 7.5) soils with almost no profile development and having a lithic contact with 50 cm of the surface. They are severely eroded and are moderately stony.

5. Soils of Elongated Ridges and Hills : Moderately steeply to steeply sloping spurs consist of very shallow to shallow, excessively drained, loamy, soils with severe erosion and strong stoniness. These lands also have the rocky exposures at places. Gently sloping tops of the spurs also consist of moderately deep moderately well drained, neutral (pH 6.5 to 7.5), slightly calcareous at places, clayey, cracking soils with moderate erosion.

6. Soils of Uplands and Narrow Valleys : Moderately sloping uplands consist of deep well drained neutral (pH 6.5 to 7.5), clayey to loamy typic Ustropepts with severe erosion and slight stoniness. The valley slopes consist of extremely shallow, well drained, slightly acidic (pH 5.5 to 6.5) loamy, lithic Ustorthents and rocky exposures at places. These soils are moderately to severely eroded.

7. Soils of Dissected Hills and Intervening Valleys : Moderately steeply sloping dissected hills ad intervening valleys consist of very shallow to shallow, well drained to somewhat excessively drained, slight acidic (pH 5.5 to 6.5) loamy lithic Ustorthents and Lithic Ustropepts with moderate to severe erosion.

Very Gently sloping valley lands at places consist of moderately deep, moderately well drained, neutral, clayey, cracking soils with moderate erosion.

Land Use : In valley-annual crops, horticultural crops like banana, chickku, coconut, arecanut and spices, like clove, black pepper and pulses are grown on hill slopes and Terraced lands, Mango, cashew Jack fruit and pine apples are grown on hill. Minor millets like pearl millet and varai, pulses like gram, beans, pigeonpea are cultivated on the hill slopes as well as terraced lands. Oil seeds like sesamum and niger are common in this area. Besides the above crops, the area is under natural moist deciduous forest of Teak, Yen, and Terminalia species.

B. Western Ghats

Include hilly and high lying of terrain of basaltic origin in the district of Dhule, Nasik, Ahmadnagar, Pune, Satara, Kolhapur, Sangli and Sindhudurg. Deccan trap and laterite forms the major parent rocks, soils observed in the region are as under :

1. Soils of Undulating Western Foot Hill Slopes and Narrow Valleys : This region consist of very shallow well drained to somewhat excessively drained slightly acidic (pH 5.5 to 6.5), Lithic Ustorthents and Typic Ustropepts that have low water holding capacity they are prone to severe erosion and moderate to strong stoniness. Gently sloping valley floor are covered with shallow, moderately well drained, slightly acidic (pH 5.5 to 6.5) loamy Lithic Ustorthents and Typic Ustropepts. The soils have moderate water holding capacity and are prone to severe erosion.

2. Soils of Spurs : Moderately steep spurs are covered with very shallow, somewhat excessively drained, slightly acidic (pH 5.5 to 6.5) loamy Lithic Ustropepts, with rockout crops at places. They are severely eroded and have moderate to strong stoniness. Moderately sloping spurs consist of moderately deep to deep well drained neutral (pH 6.5 to 7.5) loamy Typic Ustropepts and Udic Rhodustalfs with severe erosion and moderate stoniness.

3. Soils of Eastern Hill Slopes and Narrow Valleys : This consist of shallow, well drained, to somewhat excessively drained, slightly acidic 9 (pH 5.5 6.5) loamy, Lithic Ustorthents and Typic Ustropepts. The gently sloping hills are endowed with deep to very deep well drained, slightly acidic, (pH 5.5 to 6.5) loamy to clayey Udic Rhodustalfs. Gently sloping foot hills at places are covered with moderately deep to very deep, well drained, neutral (pH 6.5 to 7.5) clayey cracking soils with moderate erosion high base saturation and high CEC and very high to high water holding capacity. Gently sloping narrow valley floors have very shallow, to shallow, moderately well drained, neutral (pH 6.5 to 7.5) clayey. Typic Ustorthents and Typic Ustropepts with moderate erosion.

Land Use : Rice, Nagli, Ragi, Jowar, and other cereals in Kharif , and groundnut gram, and niger, and sugarcane are grown in irrigated regions. A part of the area is under deciduous forest. Considering the high rainfall, high humidity and low temperatures, spices, fruit crops like mango, jackfruit, cashew, karonda and jamun can be successfully grown in this area. There is vast potential for growing tapioca and strawberry.

C. North Deccan : Maharashtra Plateau

Maharashtra Plateau : Maharashtra(deccan) plateau region is divided into 3 subregions viz. (a) Upper Maharashtra (Deccan) plateau, (b) Lower Maharashtra (Deccan) plateau (c) Lower Maharashtra (Deccan) plateau (Metamorphic).

(a) Upper Maharashtra (Deccan) Plateau : Consists areas in Nasik Aurangabad, Jalna, Ahmadnagar Beed, Latur, Pune, Satara , Sangli districts and some eastern tahsils of Kolhapur district. This region covers the rain shadow and rain scarcity zones of subdued hills at higher elevation, plateaus of Ajanta, Balaghat, Harischandra and Mahadeo ranges on the eastern side of the Western Ghats and the interhilly basins. The important parent materials are basalt and alluvium near Krishna and Godavari.

1. Soils of summits and spurs : Steeply to moderately sloping with gently to very gently sloping spur and summit tops; very shallow to shallow, excessively drained slightly acidic to neutral (pH 5.5 to 7.5) loamy-skeletal, Lithic Ustorthents usually associated with rockout crops. This soils are severely eroded and have strong stoniness.

Moderately sloping spurs are covered with extremely shallow to very shallow, excessively drained, slightly acidic to neutral (pH 5.5–7.5), loamy-skeletal to clayey-skeletal, Lithic Ustorthents and Typic Ustropepts associated with rockout crops.

Gently to very gently sloping spur and summit tops consist of very shallow to shallow, well drained, neutral (pH 6.5 to 7.5), clayey – skeletal Lithic Ustorthents and Typic Ustropepts with moderate erosion. At places, cracking, calcareous, clayey Typic Ustropepts and Vertic Ustropepts with high water holding capacity are also observed.

2. Soils of undulating lands with mesas and buttes : Moderate and moderately steeply sloping undulating lands consist of extremely shallow to very shallow, excessively drained, loamy to clayey skeletal, neutral (pH 6.5 to 7.5), at places calcareous Lithic Ustorthents with severe erosion and strong stoniness.

Gently sloping undulating lands consist of very shallow, somewhat excessively drained, loamy, calcareous, and non-calcareous, neutral (pH 6.5-7.5), Lithic Ustorthents and shallow, well drained, clayey, Typic Ustropepts with severe erosion and moderate stoniness. At places, deep Udic Rhodustalfs with moderate erosion, and deep calcareous, cracking, Vertic Ustropepts and Typic Chromusterts with high water holding capacity are also observed.

Moderately sloping undulating lands with occasional mesas and buttes consist of very shallow, excessively drained to somewhat excessively drained, neutral (pH 6.5-7.5) loamy –skeletal to clayey-skeletal Lithic Ustorthents with severe erosion and strong stoniness. These soils are associated with rockout crops at places.

3. Soils of plains : Moderately sloping plain lands consist of shallow, well drained, loamy, neutral (pH 6.5-7.5) Lithic Ustorthents with very severe erosion and slight stoniness associated with moderately deep, well drained, neutral, (pH 6.5-7.5) clayey, Typic Ustropepts with moderate erosion and slight stoniness.

Gently sloping plains consist of very shallow to shallow, well drained, neutral (pH 6.5-7.5) loamy and at places clayey calcareous Lithic Ustorthents and Typic Ustorthents, associated with moderately deep, well drained, calcareous, slightly alkaline (pH 7.5-8.5) cracking, clayey Vertic Ustropepts with moderate erosion.

Very gently sloping to nearly level plains and valleys consist of moderately deep to deep, well drained, slightly to moderately saline, slightly alkaline (pH

.5-8.5) calcareous, clayey and cracking, Vertic Ustropepts, Typic Chromusterts and Entic Chromusterts with moderate erosion, moderate to high water holding capacity and high amount of bases on the exchange complex.

Land Use : The important crops in the western portion of the region in kharif and rabi are sorghum, groundnut, pearlmillet, wheat, sugarcane, black gram, pigeonpea, gram and nagli. Vegetables like onion and fruit crops like grapes and banana are also grown in the area.

Shallow soils in the eastern sector are cultivated to kharif crops like pearlmillet, sorghum, pulses, groundnut, while the moderately deep to deep soils are cultivated to sorghum, safflower and gram in rabi after kharif fallow.

(b) Lower Maharashtra (Deccan) Plateau : The region consists of northern central and eastern tehsils of Dhule, Jalgaon, northern and southern tehsils of Aurangabad and Jalna districts, north eastern tehsils of Ahmadnagar, many tehsils of Solapur, Osmanabad, Nanded, majority tehsils of Buldana, Akola, Amravati, Wardha, Yavatmal districts and some tehsils of Nagpur districts. It is divided into western portion and eastern portions. The western sector covers Sangli, Solapur, Osmanabad, Jalna, Jalgaon, Dhule and Buldhana districts of rain scarcity zone. The eastern portion covers Nanded, Parbhani, Yevatmal, Akola, Amravati, Wardha and some tehsils of Nagpur district. Parent material consist of basalt and alluvium deposited along Tapi, Godavari, Purna rivers and their tributaries.

1. Soils of summits and spurs : Moderate sloping summits and spurs are endowed with extremely shallow to very shallow, excessively drained, loamy and clayey-skeletal, neutral (pH 6.5 to 7.5), Lithic Ustorthents and Typic Ustorthents with severe erosion and strong stoniness.

Gently sloping summits and spurs have extremely shallow, to moderately deep, excessively drained, neutral (pH 6.5 –7.5) loamy to clayey skeletal Lithic and Typic Ustorthents associated with rockout crops with severe erosion and strong stoniness. At places well drained, calcareous, cracking Typic Ustropepts, Vertic Ustropepts and Typic Chromusterts are also observed.

2. Soils of isolated hillocks and pediments : Moderately sloping isolated hillocks ad pediment surfaces consist of extremely to very shallow, somewhat excessively drained, neutral (pH 6.5-7.5) loamy-skeletal and loamy Lithic Ustorthents and Typic Ustorthents with severe erosion and moderate stoniness.

Gently to very gently sloping isolated hillocks and pediments consist of shallow to slightly deep, well drained, calcareous, neutral to alkaline (pH 6.5-8.5) cracking, clayey to clayey-skeletal Vertic Ustropepts and Typic Ustropepts with moderate erosion.

3. Soils of undulating lands : Moderately sloping undulating lands consist of very shallow, somewhat excessively to excessively drained, neutral (pH 6.5-7.5), loamy to clayey-skeletal Lithic and Typic Ustorthents with severe erosion.

Gently sloping undulating lands consist of slightly deep to moderately deep, well drained, moderately calcareous, neutral to moderately alkaline (pH 6.5-8.5), cracking, cracking Vertic Ustropepts and Typic Ustropepts with moderate erosion. These soils are inherently fertile with low permeability and infiltration ad narrow period of workability.

Gently sloping undulating lands also consist of very shallow, well drained, clayey, cracking, Lithic Ustorthents with moderate water holding capacity and moderate erosion.

4. Soils of rolling lands with mesas and buttes : Moderately steeply to steeply sloping mesas and buttes consist off extremely to very shallow, somewhat excessively drained, neutral (pH 6.5-7.5) loamy to clayey-skeletal, Lithic Ustorthents and Typic Ustorthents with severe erosion.

Gently sloping rolling lands consist of very shallow, well drained, neutral (pH 6.5-7.5) loamy-skeletal to loamy Lithic Ustorthents and Lithic Ustropepts, at places very shallow to shallow, clayey-skeletal and clayey, cracking, Lithic Ustorthents and Typic Ustropepts with moderate erosion and moderate water holding capacity. Very shallow Lithic Ustorthents at places are also associated with rockout crops.

Very gently sloping rolling lands consist of very deep, moderately well drained, neutral to alkaline (pH 6.5 to 8.5), calcareous, Vertic Ustropepts, Typic Chromusterts and Typic Ustropepts with moderate erosion.

5. Soils of dissected table lands : Moderately steeply sloping dissected ridges and moderately sloping table lands consist of very shallow to shallow, somewhat excessively drained, neutral (pH 6.5-7.5) loamy-skeletal and loamy Lithic Ustorthents and shallow, clayey Typic Ustropepts with severe erosion and strong stoniness.

Gently sloping table lands consist of extremely shallow to very shallow, somewhat excessively drained and well drained, neutral (pH 6.5-7.5) loamy-skeletal, clayey to clayey-skeletal Lithic Ustorthents and Typic Ustropepts with moderate to severe erosion.

6. Soils of hill ranges with scarp slopes : Moderately steeply sloping to very steeply sloping hill ranges and scarp slopes consist of very shallow to shallow, excessively to well drained, neutral (pH 7.5-8.5), loamy-skeletal Lithic Ustorthents with severe erosion ad moderate stoniness associated with rockout crops.

Moderately to gently sloping hills and ridges consist of shallow, well drained, neutral (pH 6.5-7.5), clayey Lithic Ustorthents and Ustochrepts with severe erosion and moderate stoniness. At places slightly deep, moderately well drained, neutral (pH 6.5 to 7.5) clayey cracking Vertic Ustropepts with moderate erosion.

7. Soils of plains and valleys : Gently sloping, plains and river valleys consist of moderately deep, deep to very deep, moderately well drained to well drained, neutral (pH 6.5-7.5) cracking Vertic Ustropepts and Typic Chromusterts with moderate erosion and high water holding capacity. At places, the soils are calcareous, alkaline (pH 7 .5 –8.5) Cracking Ustropepts and Vertic Ustropepts with moderate erosion and moderate water holding capacity. These soils have high CEC and high exchangeable bases.

Very gently sloping plains and river valleys consist of deep to very deep, moderately well drained, calcareous, neutral to alkaline (pH 6.5-8.5), cracking Typic Chromusterts and Vertic Ustropepts with slight to moderate salinity and alkalinity at places. High water holding capacity and high exchangeable bases. Owing to the lower permeability and low infiltration, they develop the salinity (EC > 4 mmhos) and alkalinity (pH > 8.5) under irrigated conditions. The cracking clay soils in central Maharashtra region are locally known as *"Black Cotton Soils"*.

Land Use : In the scarcity zone and western sector of the region pearl millet, sorghum, pulses, groundnut, safflower and gram are important crops.

In central and eastern parts of the region Jowar is mainly grown, followed by cotton, sorghum, pearl millet in kharif and gram, safflower in rabi. Kharif pulses like pigeonpea, green gram, black gram and rabi pulses like gram, lentil are also grown. The oilseeds like groundnut, sunflower, sesamum, niger, are also grown in kharif while safflower and sunflower are grown in rabi season. In summer, groundnut is grown under irrigated conditions.

In western district of the region both kharif and rabi cropping pattern is prevalent. In the eastern portion of the region kharif crops like sorghum, cotton, pigeon pea, soybean and rabi crops like wheat, gram are grown with partial irrigation. Paddy is grown under irrigated condition. Banana, pomegranate, guava and citrus are the main fruit crops in the region.

(c) Lower Maharashtra (Deccan) Plateau (Metamorphic) : The region includes Bhandara, Gadchiroli and part of Chandrapur and Nagpur districts. The soils are developed from granite, gneisses, schists and alluvium.

1. Soils of summits and spurs : Gently sloping summits and spurs consist of shallow, well drained, neutral to alkaline (pH 6.5-8.5) fine loamy to loamy, calcareous, Typic Ustorthents and Lithic Ustorthents with severe erosion and low water holding capacity.

2. Soils of undulating lands : Gently sloping undulating lands consist of shallow to moderately deep, well drained, neutral (pH 6.5-7.5) loamy, fine-loamy and fine, Lithic and Typic Ustorthents and Lithic Ustorthents with low water and nutrient holding capacity and moderate to severe erosion.

Very gently sloping undulating lands consist of deep to very deep, moderately well drained, neutral (pH 6.5-7.5) clayey Vertic Ustropepts and Typic Chromusterts with moderate erosion, high water and nutrient holding capacity.

3. Soils of hills and ridges with pediments : Moderately sloping hills and ridges consist of shallow, well drained, neutral (pH 6.5–7.5) loamy-skeletal, Lithic Ustorthents, Typic Ustorthents with severe erosion and moderate stoniness.

Gently sloping pediment surfaces consist of slightly deep, well drained, loamy Typic Ustropepts and Typic Ustorthents with severe erosion. At places deep, well drained, slightly acidic (pH 5.5-6.5) fine-loamy, Typic Haplustolls and Typic Ustropepts with moderate erosion are observed.

Very gently sloping pediment surfaces consist of very deep, well drained, calcareous, neutral to alkaline (pH 6.5-7.5), clayey, Typic Chromusterts and Typic Ustropepts and Vertic Ustropepts with high water holding and high CEC.

4. Soils of alluvial plains : Very gently sloping plains of alluvial origin consists of very deep, moderately well drained, neutral (pH 6.5-7.5), cracking, clayey Typic Chromusterts, Vertic Ustropepts, and Typic Ustropepts. These soils have high shrink swell potential, high water holding capacity and high exchangeable bases.

5. Soils of valleys : The gently sloping valleys consist of very deep, moderately well drained, fine-loamy, calcareous, neutral to alkaline (pH 6.5–8.5), Fluventic Ustochrepts and Vertic Ustochrepts with moderate erosion.

Land Use : Paddy is the predominant crop grown in kharif in the district of Bhandara, Chandrapur and Gadchiroli while pulses like gram and Lathyrus in rabi. In Nagpur district, cotton, soybean, sorghum, chillies are grown in kharif while gram and wheat in rabi in deep clayey soils with sustainable irrigation facility.

General cropping systems in the area are cotton-sorghum, sorghum-cotton-wheat/gram, sorghum-cotton, sorghum-cotton-safflower. In recent years soybean in encroaching the areas of cotton, sorghum and chillies in Umred tehsil of Nagpur district.

The vegetable like tomato, cabbage, cauliflower and at places fruit crops like citrus and guava are grown.

The teak plantation is famous in some tehsils of Chandrapur, Gadchiroli and Bhandara districts.

SOIL DISTRIBUTION AND CLASSIFICATION

The pictorial distribution of soils in Maharashtra under different orders, suborders, great groups, subgroups are given in Fig. 23.3.

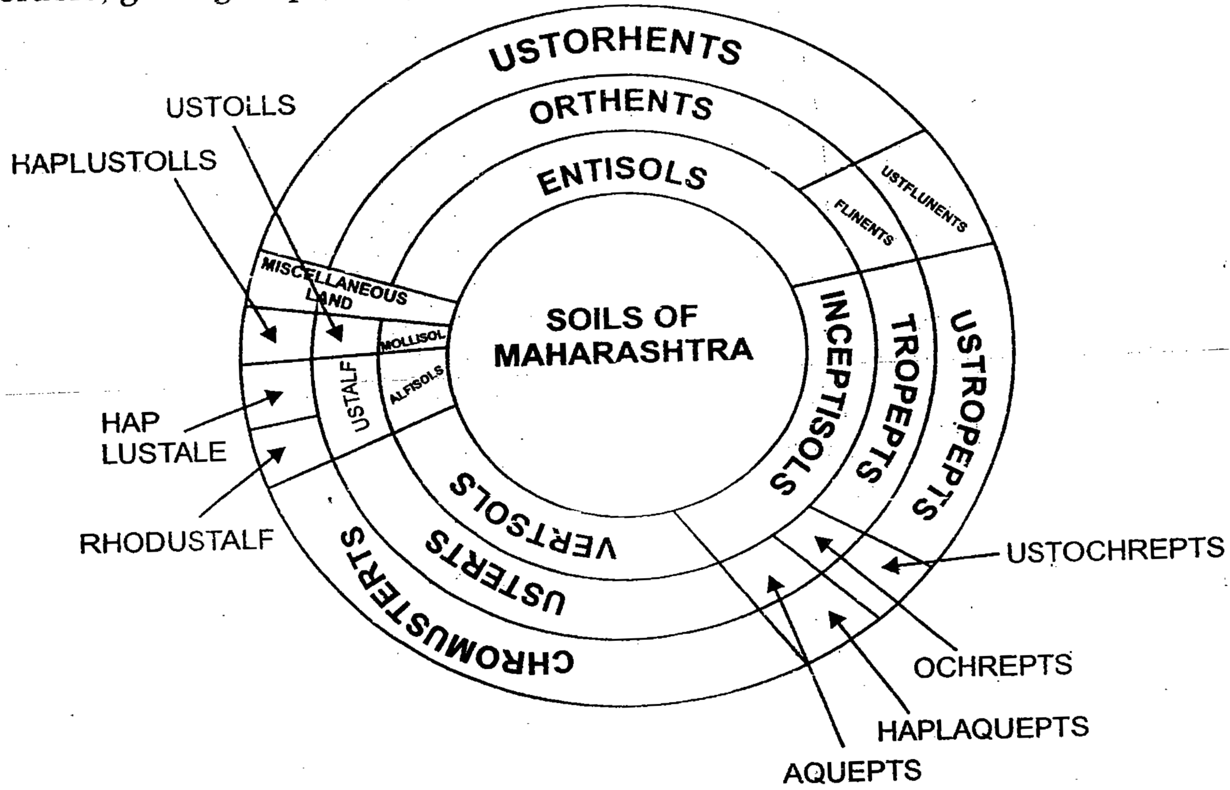

Fig. 23.1. Distribution of Soils in Maharashtra.

The total area under different soils is 99.6 per cent and the rest (0.4%) is occupied by miscellaneous lands. It has been observed that Entisols (36.77%), Inceptisols (30.9%) and Vertisols (26.3%) are the predominate soils following Alfisols (5.6%) and Mollisols (0.1%).

Table 23.1: Area under order, suborder, great group, subgroup (as per Soil Taxonomy) in Maharashtra

Order/Suborder	Great group	Subgroup
Alfisols (1731.4*; 5.6**) Ustalfs (1731.4 ; 5.6)	Rhodustalfs (1454.1 ; 4.7) Udic Rhodustalfs (1450.9 ; 4.7) Haplustalfs (277.3 ; 0.9)	Lithic Rhodustalfs (3.2 ; Neg) Udic Haplustalfs (81.0 ; 0.3) Ultic Haplustalf (196.3 ; 0.6)
Mollisols (19.4 ; 0.1) Ustolls (19.4 ; 0.1)	Haplustoll (19.4 ; 0.1)	Typic Haplustolls (19.4 ; 0.1)
Entisols (11321.4 ; 36.7) Fluvents (13.6 ; Neg) Orthents (11307.8; 36.7)	Ustifluvents (13.6 ; Neg) Ustorthents (11307.8 ; 36.7)	Typic Ustifluvents (13.6 ; Neg) Lithic Ustorthents (10059.3 ; 32.7) Typic Ustorthents (1248.5 ; 4.0)
Inceptisols (9463.6 ; 30.9) Aquepts (165.3 ; 30.9) Tropepts (9259.3 ; 30.2)	Halaquepts (165.3 ; 0.5) Ustropepts (9259.3 ; 30.2)	Vertic Halaquepts (165.3 ; 0.5) Typic Ustropepts (5237 .7 ; 17.0) Vertic Ustropepts (13322.2 ; 11.0) Lithic Ustropepts (659.2 ; 2.1) Fluventic Ustropepts (40.2 ; 0.1)
Ochrepts (39.0 ; 0.2)	Ustochrepts (39.0 ; 0.2)	Lithic Ustochrepts (21.2 ; 0.1) Vertic Ustochrepts (1.1; Neg) Fluventic Ustochrepts (16.7 ; 0.1)
Vertisols (8106.2 ; 26.3) Usterts (8106.2 ; 26.3)	Chromusterts (17463.8 ; 24.2)	Typic Chromusterts (8106.2 ; 26.3) Udic Chromusterts (39.1 ; 0.1) Entic Chromusterts (603.3 ; 2.0)

* Area in 000 ha., **Percentage of Total Geographical Area.

Based on the mapping the physiography, soil relationship is established. These mapped soils are classified as per the Taxonomy (Soil Survey Staff 1975) and given in table 23.1.

There are 356 soil family associations; each consisting of dominant and subdominant and inclusions.

EXERCISE

Q.1. Select the correct word :

1. ____________ in India have quite high base exchange capacity.
   (a) Red soils (b) Deep black soils
   (c) Laterite soils (d) Alluvial
2. There is no practically horizon differentiation in ________ type of soils in India.
   (a) Laterite (b) Red
   (c) Black (d) Alluvial
3. ________ soils in India are formed in depressions under submerged conditions.
   (a) Tarai (b) Peaty and marshy
   (c) Alluvial (d) Red
4. The soil is Western Konkan coast region are mostly formed from ______ rocks.
   (a) Basalt and granite (b) Deccan trap and granite
   (c) Basalt and schists (d) Deccan trap and basalt
5. _____________ form the major parent rock of soils in Western Ghat.
   (a) Basalt and gneisses (b) Deccan trap and granite
   (c) Deccan trap and laterite (d) Basalt and laterite
6. The soils of plain land form in Upper Maharashtra Deccan Plateau are ____ in reaction.
   (a) Acidic to neutral (b) Neutral
   (c) Neutral to alkaline (d) Alkaline
7. The lower Maharashtra Deccan Plateau is divided into __________ portions.
   (a) Eastern and Western (b) Eastern and Southern
   (c) Eastern and Northern (d) Western and Southern
8. In soils of valleys of lower Maharastra Plateau (metamorphic) ____ crop is prefominant.
   (a) Sugarcane (b) Cotton
   (c) Paddy (d) Wheat
9. In Maharashtra, teak plantation is famous in soils from __________ regions.
   (a) Western Konkan coast and Upper Maharashtra Deccan Plateau
   (b) Upper Maharashtra Deccan Plateau and Lower Maharasthra Deccan Plateau
   (c) Western Konkan coast and Lower Maharashtra Deccan Plateau
   (d) Western Konkan coast and Lower Maharashtra Deccan Plateau (metamorphic)
10. In Maharashtra the soils belonging to order _______ are highest in percentage to TGA.
    (a) Entisols (b) Inceptisols
    (c) Vertisols (d) Alfisols.

Q.2. Answer the questions to the points :

1. Why the laterite soils formed at low levels are darker in colour ?
2. What are main features of red soils in India ?

3. Why the marshy soils have blue colour ?

4. Why Tarai soils are highly productive

5. Name the three physiographic regions of the Maharashtra.

6. State the districts of Maharashtra comprising in Western Konkan coast regtion.

7. Name any three landform occurring in western Konkan coast region.

8. State the fruit corps grown is western Konkan coast region.

9. Which are the different land forms in western Ghat ?

10. Which crops are grown in kharif and rabi in soils from Western Ghat ?

11. Which are the three sub-region of Maharashtra Deccan Plateau ?

12. State two each of vegetable and fruit crops grown in upper Maharashtra deccanplateau.

13. Name the two dominant soil orders in Maharashtra.

Q.3. Match the suitable pairs :

1. Basalt and alluvium	1.The crops pearl millet, sorghum, pulses, ground nut safflower are grown
2. Soils of plains and valleys in Lower Maharashtra Deccan Plateau	2. 30.9% of TGA in Maharashtra
3. Entisols Maharashtra	3. Presence of various oxides of
4. Lower Maharashtra Deccan Plateau	4. 26.3% TGA in Maharashtra
5. Inceptisols grown	5. Banana, pomegranate, citrus are
6. Red colour soils topography	6. Developed due to Basin shaped
7. Scarcity Zone	7. Parent rock around Godavari river
8. Vertisols	8. Develop salinity under irrigation
9. Black soils of India	9. Foot hill soils of Himalayas
10. Western portion of lower Maharashtra	10. Soils of dissected table lands
	11. Soils occur at high elevation of Himalayas
	12. Basalt Rock
	13. 36.77 % TGA in Maharashtra
	14. Soils with pH 4.5 to 5.5.

Glossary of Soil Science Terms

A horizon The surface of a mineral soil having maximum organic matter accumulation, maximum biological activity and/or eluviation of materials such as iron and aluminium oxides and silicate clays.

ABC soil A soil with a distinctly developed profile, including A, B, and C horizons.

Absorption, active Movement of ions and water into the plant root as a result of metabolic processes by the root, frequently against an activity gradient.

Absorption, passive Movement of ions and water into the plant root as a result of diffusion along a gradient.

AC soil A soil having a profile containing only A and C horizons with no clearly developed B horizon.

Acid rain Atmospheric precipitation with pH values less than about 5.6, the acidity being due to inorganic acids such as nitric acid and sulfuric that are formed when oxides of nitrogen and sulfur are emitted into the atmosphere.

Acid soil A soil with a pH value <7.0. Usually applied to surface layer or root zone, but may be used to characterize any horizon. See also reaction, soil.

Acidity, active The activity of hydrogen ion in the aqueous phase of a soil. It is measured and expressed as a pH value.

Acidity, residual Soil acidity that can be neutralized by lime or other alkaline materials but cannot be replaced by an unbuffered salt solution.

Acidity, salt replaceable Exchangeable hydrogen and aluminium that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl.

Acidity, total The total acidity in a soil. It is approximated by the sum of the salt replaceable acidity plus the residual acidity.

Actinomycetes A group of organisms intermediate between the bacteria and the true fungi that usually produce a characteristic branched mycelium. Includes many, but not all, organisms belonging to the order of Actinomycetales.

Adhesion Molecular attraction that holds the surfaces of two substance (e.g. water and sand particles) in contact.

Adsorption The attraction of ion or compounds to the surface of a solid. Soil colloids adsorb large amounts of ions and water.

Adsorption complex The group of organic and inorganic substances in soil capable of adsorbing ions and molecules.

Aeration, soil The process by which air in the soil is replaced by air from the atmosphere. In a well-aerated soil, the soil air is similar in composition to the atmosphere above the soil. Poorly aerated soils usually contain more carbon dioxide and correspondingly less oxygen than the atmosphere above the soil.

Aerobic (1) Having molecular oxygen as a part of the environment. (2) Growing only in the presence of molecular oxygen, as aerobic organisms. (3) Occurring only in the presence of molecular oxygen (said of certain chemical or biochemical processes, such as aerobic decomposition).

Aggregate (soil) Many soil particles held in a single mass or cluster such as a clod, crumb, block, or prism.

Agric horizon See diagnostic subsurface horizons.

Air-dry (1) The state of dryness (of a soil) at equilibrium with the moisture content in the surrounding atmosphere. The actual moisture content will depend upon the relative humidity and the temperature of the surrounding atmosphere. (2) To allow to reach equilibrium in moisture content with the surrounding atmosphere.

Air porosity The proportion of the bulk volume of soil that is filled with air at any given time or under a given condition, such as a specified moisture potential; usually the large pores.

Alkali soil (Obsolete) A soil that contains sufficient alkali (sodium) to interfere with the growth of most crop plants. See also saline-sodic soil; sodic soil.

Alkaline soil Any soil that has pH > 7. Usually applied to surface layer or root zone but may be used to characterize any horizon or a sample thereof. See also reaction, soil.

Allophane An aluminosilicate mineral that has an amorphous or poorly crystalline structure and is commonly found in soils developed from volcanic ash.

Alluvial soil (Obsolete) A soil developing from recently deposited alluvium and exhibiting essentially no horizon development or modification of the recently deposited materials.

Alluvium A genera term for all detrital material deposited or in transi by streams, including gravel, sand, silt, clay, and all variations and mixtures of these. Unless otherwise noted, alluvium is unconsolidated.

Aluminosilicates Compounds containing aluminium, silicon, and oxygen as main constituents. An example is microcline, $KAlSi_3O_8$.

Amendment, soil Any substance other than fertilizers such as lime sulfur, gypsum, and sawdust, used to alter the chemical or physical properties of soil, generally to make it more productive.

Ammonification The biochemical process whereby ammoniacal nitrogen is released from nitrogen containing organic compounds.

Ammonium fixation The entrapment of ammonium ions by the mineral or organic fractions of the soil in forms that are insoluble in water and at least temporarily non-exchangeable.

Amorphous material Non-crystalline constituents of soils.

Anaerobic (1) Without molecular oxygen. (2) Living or functioning in the absence of air or free oxygen.

Andisols See soil classification.

Anion exchange capactity The sum total of exchangeable anions that a soil can adsorb. Expressed as centimoles per kilogram (cmol/kg) of soil (or of other adsorbing materials such as clay).

Antibiotic A substance produced by one species of organism that, in low concentrations, will kill or inhibit growth of certain other organisms.

Ap The surface layer of soil disturbed by cultivation or pasturing.

Apatite A naturally occurring complex calcium phosphate that is the original source of most of the phosphate fertilizers. Formula such as $[3Ca_3(PO_4)_2]\ CaF_2$ illustrate the complex compounds that make up apatite.

Argillic horizon See diagnostic subsurface horizons.

Arid climate Climate in regions that lack sufficient moisture for crop production without irrigation. In cool regions annual precipitation is usually less than 25 cm. It may be as high as 50 cm in tropical regions. Natural vegetation is desert shurbs.

Atterberg limits Water contents of find-grained soils at different states of consistency.

Autotroph An organism capable of utilizing carbon dioxide or carbonates as the sole source of carbon and obtaining energy for life processes from the oxidation of inorganic elements or compounds such as iron, sulfur, hydrogen, ammonium, and nitrites, or from raidant energy. Contrast with heterotroph.

Available nutrient That portion of any element or compound in the soil that can be readily absorbed and assimilated by growing plants ("Available" should not be confused with "exchangeable".)

Available water The portion of water in a soil that can be readily absorbed by plant roots. The amount of water released between the field capacity and the permanent wilting point.

B horizon A soil horizon usually beneath the A that is characterized by one or more of the following (a) a concentration of silicate clays, iron and aluminium oxides, and humus, alone or in combination (b) a blocky or prismatic structure , and (c) coatings of iron and aluminium oxides that give darker, stronger, or redder color.

Bar A unit of pressure equal to one million dynes per square centimeter (106 daynes/cm2)

Base saturation percentage The extent to which the adsorption complex of a soil is saturated with exchangeable cations other than hydrogen and aluminium. It is expressed as a percentage of the total cation exchange capacity.

BC soil A soil profile with B and C horizons but with little or no A horizon. Most BC sols have lost their A horizons by erosion.

Bedrock The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred feed.

Bench terrace An embankment constructed across sloping fields with a steep drop on the downslope side.

Beta particle A high-speed electron emitted in radioctive decay.

Biodegradable Subject to degradation by biochemical processes.

Biomass The amount of living matter in a given area

Blocky soil structure Soil aggregates with black-like shapes; common in B horizons of soils in humid regions.

Broad-base terrace A low embankment with such gentle slopes that is can be farmed, constructed across sloping fields to reduce erosion and runoff.

Buffering capacity The ability of a soil to resist changes in pH. Commonly determined by presence of clay, humus, and other colloidal materials.

Bulk blending Mixing dry individual granulated fertilizer materials to form a mixed fertilizer that is applied promptly to the soil.

Bulk density, soil The mass of dry soil per unit of bulk volume, including the air space. The bulk volume is determined before drying to constant weight as 105°C.

Buried soil Soil covered by an alluvial, loessal, or other deposit, usually to a depth greater than the thickness of the solum.

C horizon A mineral horizon generally beneath the solum that is relatively unaffected by biological activity and pedogenesis and is lacking properties diagnostic of an A or B horizon. It may or may not be like the material from which the A and B have formed.

Calcareous soil Soil containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly when treated with cold 0.1 N hydrochloric acid.

Calcic horizon See diagnostic subsurface horizons.

Caliche A layer near the surface, more or less cemented by secondary carbonates of calcium or magnesium precipitated from the soil solution. It may occur as a soft, thin soil horizon; as a hard, thick bed just beneath the solum; or as a surface layer exposed by erosion.

Cambic horizon See diagnostic subsurface horizons.

Capillary conductivity (Obsolete) See hydraulic conductivity.

Capillary water (Obsolete) The water held in the "capillary" or small pores of a soil, usually with a tension >60 cm of water. See also moisture potential.

Carbon cycle The sequence of transformations whereby carbon dioxide is fixed in living organisms by photosynthesis or by chemosynthesis, liberated by respiration and by the death and decomposition of the fixing organism, used by heterotrophic species, and ultimately returned to its original state.

Carbon/nitrogen ratio The ratio of the weights of organic carbon (C) to the weight of total nitrogen (N) in a soil or in organic material.

Carnivore An organism that feeds on animals.

"Cat" clays Wet clay soils high in reduced forms of sulfur that upon being drained, become extremely acid because of the oxidation of the sulfur compounds and the formation of sulfuric acid.

Catena A sequence of soils of about the same age, derived from similar parent material, and occurring under similar climate conditions, but having different characteristics because of variation in relief and in drainage.

Cation A positively charged ion; during electrolysis it is attracted to the negatively charged cathode.

Cation exchange The interchange between a cation in solution and another cation on the surface of any surface-active material such as clay or organic matter.

Cation exchange capacity The sum total of exchangeable cations that a soil can adsorb. Sometimes called "total-exchange capacity." "base-exchange capacity." Or "cation-adsorption capacity." Expressed in centimoles per kilogram (cmol/kg) of soil (or of other adsorbing material such as clay).

Cemented Indurated; having a hard, brittle consistency because the particles are held together by cementing substances such as humus, calcium carbonate, or the oxides of silicon, iron and aluminium.

Channery Thin, flat fragments of limestone, sandstone or schist upto 15 cm (6 in) in major diameter.

Chelate (Greek, claw) A type of chemical compound in which a metallic ion is firmly combined with an organic molecules by means of multiple chemical bonds.

Chert A structureless form of silica , closely related to flint, that breaks into angular fragments.

Chisel, subsoil A tillage implement with one or more cultivator-type feet to which are attached strong knife-like units used to shatter or loosen hard, compact layers, usually in the subsoil, to depths below normal plough depth. See also sub-soiling.

Chlorite A 2:1:1-type layer-structured silicate mineral having 2:1 layers alternating with a magnesium dominated octahedral sheet.

Class, soil A group of soils having a definite range in a particular property such as acidity, degree of slope, texture, structure, land-use capability, degree of erosion, or drainage. See also soil structure, soil texture.

Clastic composed of broken fragments of rocks and minerals.

Clay (1) A soil separate consisting of particles < 0.002 mm in equivalent diameter. (2) A soil textural class containing <40% clay, <45% sand, and < 40% silt.

Clay mineral Naturally occurring inorganic material (usually crystalline) found in soils and other earthy deposits, the particles being of clay size, that is, < 0.002 mm in diameter.

Claypan A dense, compact, slowly permeable layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary. Claypans are usually hard when dry and plastic and sticky when wet. See also hardpan.

Clod A compact, coherent mass of soil produced artifically, usually by such human activities as ploughing and digging, especially when these operations are performed on soils that are either too wet or too dry for normal tillage operations.

Coarse texture The texture exhibited by sands, loamy sands, and sandy loams except very fine sandy loam.

Cobblestone Rounded or partially rounded rock or mineral fragments 7.5-25 cm (3-10 in.) in diameter.

Cohesion Holding together force holding a solid or liquid together, owing to attraction between like molecules. Decreases with rise in temperature.

Colloid, soil (Greek, glue-like) Organic and inorganic matter with very small particle size and a correspondingly large surface area per unit of mass.

Colluvium A deposit of rock fragments and soil material accumulated at the base of steep slopes as a result of gravitational action.

Color The property of an object that depends on the wavelength of light it reflects Or emits.

Columnar soil structure See soil structure types.

Compost Organic residues, or a mixture of organic residues and soil, that have been piled, moistened, and allowed to undergo biological devcompoistion. Mineral fertilizers are sometimes added. Often called "artificial manure" or " synthetic manure" if producted primarily from plant residues.

Concretion A local concentration of a chemical compound, such as calcium carbonate or iron oxide, in the form of grains or nodules of varying size, shape, hardness and colour.

Conduction The transfer of heat of physical contact between two or more objects.

Conductivity, hydraulic See hydraulic conductivity.

Consistence The combination of properties of soil materials that determine its resistance to crushing and its ability to be molded or changed in shape. Such terms as loose, friable, firm, soft, plastic, and sticky describe soil consistence.

Constant charge The net surface charge of mineral particles, the magnitude of which depends only on the chemical and structural composition of the mineral. The charge arises from isomorphous substitution and is not affected by soil pH.

Consumptive use The water used by plants in transpiration and growth, plus water vapor loss from adjacent soil or snow, or from intercepted precipitation in any specified time. Usually expressed as equivalent depth of free water per unit of time.

Contour An imaginary line connecting points of equal elevation on the surface of the soil. A contour terrace is laid out on a sloping soil at right angles to the direction of the slope and nearly level throughout its course.

Crumb A soft, porous, more or less rounded natural unit of structure from 1 to 5 mm in diameter. See also soil structure types.

Crushing strength The force required to crush a mass of dry soil or, conversely, the resistance of the dry soil mass to crushing. Expressed in units of force per unit area (pressure).

Crust A surface layer on soils, ranging in thickness from a few millimeters to perhaps as much as 3 cm, that is much more compact, hard, and brittle, when dry, than the materials immediately beneath it.

Crystal A homogeneous inorganic substance of definite chemical composition bounded by plane surfaces that form definite angles with each other, thus giving the substance a regular geometrical form.

Crystal structure The orderly arrangement of atoms in a crystalline material.

Crystalline rock A rock consisting of various minerals that have crystallized in place from magma. See also igneous rock; sedimentary rock.

Deflocculate (1) To separate the individual components of compound particles by chemical and /or physical means. (2) To cause the particles of the disperse phase of a colloidal system to become suspended in the dispersion medium.

Delta An alluvial deposit formed where a stream or river drops its sediment load upon entering a quieter body of water.

Denitrification The biochemical reduction of nitrate or nitrite to gaseous nitrogen, either as molecular nitrogen or as an oxide of nitrogen.

Density See particle density; bulk density.

Desalinization Removal of salts from saline soil, usually by leaching.

Desert crust A hard layer, containing calcium carbonate, gypsum, or other binding material, exposed at the surface in desert regions.

Detritus Debris from dead plants and animals.

Desorption The removal of sorbed material from surfaces.

Diagnostic horizons (As used in Soil Taxonomy) : Combinations of specific soil characteristics that are indicative of certain classes of soils. Horizons that occur at the soil surface are called epipedons; those below the surface, diagnostic subsurface horizons.

Diagnostic subsurface horizons The following diagnostic subsurface horizons are used in Soil Taxonomy.

Agric horizon A mineral soil horizon in which clay, silt, and humus derived from an overlying cultivated and fertilized layer have accumulated. The wormholes and illuvial clay, silt, and humus occupy at least 5% of the horizon by volume.

Albic horizon A mineral soil horizon from which clay and free iron oxides have been removed or in which the oxides have been removed or in which the oxides have been segregated to the extent that the color of the horizon is determined primarily by the color of the primary sand and silt particles rather than by coatings on these particles.

Argillic horizon A mineral soil horizon characterized by the illuvial accumulation of layer-lattic silicate clays.

Calcic horizon A mineral soil horizon of secondary carbonate enrichment that is more than 15 cm thick, has a calcium carbonate equivalent of more than 15%, and has at least 5% more calcium carbonate equivalent than the underlying C horizon.

Cambic horizon A mineral soil horizon that has a texture of loamy very fine and or finer, contains some weatherable minerals, and is characterized by the alteration or removal of mineral material. The cambic horizon lacks cementation or induration and has too few evidences of illuviation to meet the requirements of the argillic or spodic horizon.

Duripan A mineral soil horizon that is cemented by silica, to the point that air-dry fragments will not slake in water or HCl.

Gypsic horizon A mineral soil horizon of secondary calcium sulfate enrichment that is more than 15 cm thick.

Kandic horizon A horizon having a sharp clay increase relative to overlying horizons and having low-activity clays.

Natric horizon A mineral soil horizon that satisfies the requirements of an argillic horizon, but that also has prismatic, columnar, or blocky structure and a sub-horizon having more than 15% saturation with exchangeable sodium.

Oxic horizon A mineral soil horizon that is at least 30 cm thick and characterized by the virtual absence of weatherable primary minerals or 2:1 lattice clays and the presence of 1:1 lattice clays and highly insoluble minerals such as quartz sand, hydrated oxides of iron and aluminium, low cation exchange capacity, and small amounts of exchangeable bases.

Petrocalcic horizon A continuous, indurated calcic horizon that is cemented by calcium carbonate and, in some places, with magnesium carbonate. It cannot be penetrated with a spade or auger when dry, dry fragments do not slake in water, and it is impenetrable to roots.

Petrogypsic horizon A continuous, strongly cemented, massive gypsic horizon that is cemented by calcium sulfate. It can be chipped with a spade when dry. Dry fragments do not slake in water and it is impenetrable to roots.

Placic horizon A black to dark reddish mineral soil horizon that is usually thin but that may range from 1 to 25 mm in thickness. The placic horizon is commonly cemented with iron and is slowly permeable or impenetrable to water and roots.

Salic horizon A mineral soil horizon of enrichment with secondary salts more soluble in cold water than gypsum. A salic horizon is 15 cm or more in thickness.

Sombric horizon A mineral subsurface horizon that contains illuvial humus but has low cation exchange capacity and low percentage base saturation. Mostly restricted to cool moist soils of high plateaus and mountainous areas of tropical and subtropical regions.

Spodic horizon A mineral soil horizon characterized by the illluvial accumulation of amorphous materials composed of aluminum and organic carbon with or without iron.

Sulfuric horizon A subsurface horizon in either mineral or organic soils that has a pH < 3.5, fresh straw-coloured mottles (called jarosite mottles). Forms by oxidation of sulfide- rich materials and is highly toxic to plants.

Ochric epipedon A surface horizon of mineral soil that is too light in color, too high in chroma, too low in organic carbon, or too thin to be a plaggen, mollic, umbric, anthropic, or histic epipedon, or that is both hard and massive when dry.

Plaggen epipedon A man-made surface horizon more than 50 cm thick that is formed by long-continued manuring and mixing.

Umbric epipedon A surface layer of mineral soil that has the same requirements as the mollic epipedon with respect to color, thickness, organic carbon content, consistence, structure, and P2O5 content, but that has a base saturation of less than 50%.

Diatoms Algae having siliceous cell walls that persist as a skeleton after death; any of the microscopic unicellular or colonial algae constituting the class Bacillariaceae. They occur abundantly in fresh and salt waters and their remains are widely distributed in soils.

Diatomaceous earth A geologic deposit of fine, grayish, siliceous material composed chiefly or wholly of the remains of diatoms. It may occur as a powder or as a porous, rigid material.

Diffusion The transport of matter as a result of the movement of the constituent particles. The intermingling of two gases or liquids in contact with each other takes place by diffusion.

Dioctahedral An octahedral sheet, or a mineral containing such a sheet, that has two thirds of the octahedral sites filled with trivalent ions such as aluminium or ferric iron.

Disintegration The breakdown of rock and mineral particles into smaller particles by physical forces such as frost action.

Disperse (1) To break up compound particles, such as aggregates, into the individual component particles. (2) To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water.

Drainage, soil The frequency and duration of periods when the soil is free from saturation with water.

Drift Material of any sort deposited by geological processes in one place after having been removed from another. Glacial drift includes material moved by the glaciers and by the streams and lakes associated with them.

horizon Horizon characterized by maximum illuviation (washing out) of silicate clays and iron and aluminium oxides; commonly occurs above the B horizon and below the A horizon.

Earthworms Animals of the Lumbricidae family that burrow into and live in the soil. They mix plant residues into the soil and improve soil aeration.

Ectotrophic mycorrhiza (ectomycorrhiza) A symbiotic association of the mycelium of fungi and the roots of certain plants in which the fungal hyphae form a compact mantle on the surface of the roots and extend into the surrounding soil and inward between cortical cells, but not into these cells. Associated primarily with certain trees. See also endotrophic mycorrhiza.

Edaphology The science that deals with the influence of soils on living things, particularly plants, including man's use of land for plant growth.

Electrokinetic potential A colloidal systems, the difference in potential between the immovable layer attached to the surface of the dispersed phase and the dispersion medium.

Eluviation The removal of soil material in suspension (or in solution) from a layer or layers of soil. (Usually, the loss of material in solution is described by the term "leaching.") See also leaching.

Endotrophic mycorrhiza (endomycorrhiza) A symbiotic association of the mycelium of fungi and roots of a variety of plants in which the fungal hyphae penetrate directly into roots hairs, other epidermal cells, and occasionally into cortical cells. Individual hyphae also extend from the roots surface outward into the surrounding soil. See also vesicular arbuscular mycorrhiza.

Entisols See soil classification.

Eolian soil material Soil material accumulated through wind action. The most extensive areas in the United States are silty deposits (loess), but large areas of sandy deposits also occur.

Epipedon A diagnostic surface horizons that includes the upper part of the soil that is darkened by organic matter, or the upper eluvial horizons or both. (Soil Taxonomy).

Erosion (1) The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. (2) Detachment and movement of soil or rock by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion.

Accelerated erosion Erosion much more rapid than normal, natural, geological erosion, primarily as a result of the activities of human or, in some cases of animals.

Gully erosion The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1-2 feet to as much as 23-30 m (75-100 ft).

Natural erosion Wearing away of the Earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, and so on, undisturbed by man. Synonymous with geological erosion.

Rill erosion An erosion process in which numerous small channels of only several centimeters in depth are formed; occurs mainly on recently cultivated soils. See als rill.

Sheet erosion The removal of a fairly uniform layer of soil from the land surface by run water.

Splash erosion The spattering of small soil particles caused by the impact of raindrops very wet soils. The loosened and separated particles may or may not be subsequently removed by surface runoff.

Essential element A chemical element required for the normal growth of plants.

Eutrophic Having concentrations of nutrients optimal(or) nearly so for plant or animal growth. (Said of nutrient solutions or of soil solutions).

Eutrophication A process of aging of lakes whereby aquatic plants are abundant and waters are deficient in oxygen. The process is usually accelerated by enrichment waters with surface runoff containing nitrogen and phosphorus.

Evapotranspiration The combined loss of water from a given area, and during a specifi period of time, by evaporation from the soil surface and by transpiration from plants.

Exchange capacity The total ionic charge of the adsorption complex active in the adsorption of ions. See also anion exchange capacity; cation exchange capacity

Exchangeable sodium percentage The extent to which the adsorption complex of a soil is occupied by sodium. It is expressed as follows:

$$ESP = \frac{\text{Exchangeable sodium (cmol / kg soil)}}{\text{Cation exchange capacity (cmol / kg soil)}} \times 100$$

Facultative organism An organism capable of both aerobic and anaerobic metabolism.

Fallow Cropland left idle in order to restore productivity, mainly through accumulation of water, nutrients, or both. Summer fallow is a common stage before cereal grain in regions of limited rainfall. The soil is kept free of weeds and other vegetation, thereby conserving nutrients and water for the next year crop.

Family, soil In soil classification, one of the categories intermediate between the great group and the soil series. Families are defined largely on the basis of physical and mineralogical properties of importance to plant growth.

Fauna The animal life of a region.

Ferrihydrite, $Fe_5HHO_8 \cdot 4H_2O$ A dark reddish brown poorly crystalline iron oxide that forms in wet soils.

Fertility, soil The quality of a soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specified plants.

Fertilizer Any organic or inorganic material of natural or synthetic origin added to a soil to supply certain elements essential to the growth of plants. The major types of fertilizers influde.

Bulk blended fertilizers Solid fertilizer materials blended together in small blending plants, delivered to the farm in bulk, and usually spread directly on the fields by truck or other special applicator.

Granulated fertilizers Fertilizers that are present in the form of rather stable granules of uniforms size, which facilitate ease of handling the materials and reduce undesirable dusts.

Liquid fertilizers Fluid fertilizers that contain essential elements in liquid forms either as soluble nutrients or as liquid suspensions or both.

Mixed fertilizers Two or more fertilizer materials mixed together. May be as dry powders, Granules, pellets, bulk blends, or liquids.

Fertilizer requirements The quantity of certain plant nutrients elements needed, in addition to the amount supplied by the soil, to increase plant growth to a designated optimum.

Fibric materials See organic soil materials.

Fine-grained mica A silicate clay having a 2:1-type lattice structure with much of the silicon in the tetrahedral sheet having been replaced by aluminium and with considerable interlayer potassium, which binds the layers together and prevents interlayer expansion and swelling, and limits interlayer cation exchange capacity.

Fine texture Consisting of or containing large quantities of the fine fractions, particularly of silt and clay. (includes clay loam, sandy clay loam, silty clay loam, sandy clay, silty clay, and clay textural classes.)

Fixation (1) For other than elemental nitrogen : the process or processesses in a soil by which certain chemical elements essential for plant growth are converted from a soluble or exchangeable form to a much less soluble or to a nonexchangeable form; for example, potassium, ammonium, and phosphate “fixation.” (2) For elemental nitrogen : process by which gaseous elemental nitrogen is chemically combined with hydrogen to form ammonia.

Biological nitrogen fixation Occurs at ordinary temperatures and pressures. It is commonly carried out by certain bacteria, algae, and actinomycetes, which may or may not be associated with higher plants.

Chemical nitrogen fixation Takes place at high temperatures and pressures in manufacturing plants; produces ammonia, which is used to manufacture most fertilizers.

Flagstone A relatively thin rock or mineral fragment 15-38 cm in length commonly composed of shale, slate, limestone, or sandstone.

Flocculate To aggregate or clump together individual, tiny soil particles, especially fine clay, into small clumps or floccules. Opposite of deflocculate or disperse.

Floodplain The land bordering a stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage. Sometimes called bottomland.

Flora The sum total of the kinds of plants in an area at one time.

Fluorapatite A member of the apatite group of minerals containing fluorine. Most common mineral in rock phosphate.

Fluvial deposits Deposits of parent materials laid down by rivers or streams.

Fragipan Dense and brittle pan or subsurface layer in soils that owe their hardness mainly to extreme density or compactness rather than high clay content or cementation. Removed fragments are friable, but the material in place is so dense that roots penetrate and water moves through it very slowly.

Friable A soil consistency term pertaining to the ease of crumbling of soils.

Fulvic acid A term of varied usage but usually referring to the mixture of organic substances remaining in solution upon acidification of a dilute alkali extract from the soil.

Fungi Simple plants that lack a photosynthetic pigment. The individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called hyphae, which may grow together to form a visible body.

Genesis, soil The mode of origin of the soil, with special reference to the processes responsible for the development of the solum, or true soil, from the unconsolidated parent material.

Geothite, FeOOH A yellow-brown iron oxide mineral that accounts for the brown colour in many soils.

Gibbsite, $(Al(OH)_3$ An aluminium trihydroxide mineral most common in highly weathered soils such as oxisols.

Gilgai The microreleif of soils produced by expansion and contraction with changes in moisture. Found in soils that contain large amounts of clay that swells and shrinks considerably with wetting and drying. Usually a succession of microbasins and microknolls in nearly level areas or of microvalleys and microridges parallel to the direction of the slope.

Glacial drift Rock debris that has been transported by glaciers and deposted, either directrly from the ice or from the meltwater. The debris may or may not be heterogenous.

Glaciofluvial deposits Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and may occur in the form of outwash plains, deltas, kames, eskers, and kame terraces.

Gley soil (Obsolete) Soil developed under conditions of poor drainage resulting in reduction of iron and other elements and in gray colours and mottles.

Granular structure Soil structure in which the individual grains are grouped into spherical aggregates with indistinct sides. Highly porous granules are commonly called crumbs. A well-granulated soil has the best structure for most ordinary crop plants. *See also soil structure types.*

Gravitational potential *See soil water potential.*

Gravitational water Water that moves into, through, or out of the soil under the influence of graivity.

Great group See soil classification.

Ground water Subsurface water in the zone of saturation that is free to move under th

Hardpan A hardened soil layer, in the lower A or in the B horizon, caused by cementation of soil particles with organic matter or with materials such as silica, seasquioxides, or calcium carbonate. The hardness does not change appreciably with changes in moisture content and pieces of the hard layer do not slake in water. See also caliche; claypan.

Heavy metals Metals with particle densities>5.0 Mg/m^3.

Hematite, Fe_2O_3 A red iron oxide mineral that contributes red colour to many soils.

Horizon soil A layer of soil, approximately parallel to the soil surface, differing in properties and characteristics from adjacent layers below or above it. See also diagnostic surface horizons.

Humic acid A mixture of variable or indefinite composition of dark organic substances, precipitated upon acidification of a dilute alkali extract from soil.

Humid climate Climate in regions where moisture, when distributed normally throughout the year, should not limit crop production. In cool climate annual precipitation may be as little as 25 cm; in hot climates, 150 cm or even more. Natural vegetation in uncultivated areas is forests.

Humification The processes involved in the decomposition of organic matter and leading to the formation of humus.

Humin The fraction of the soil organic matter that is not dissolved upon extraction of the soil with dilute alkali.

Hydraulic conductivity An expression of the readiness with which a liquid such as water flows through a solid such as soil in response to a given potential graident.

Hydrogen bond The chemical bond between a hydrogen atom in one molecule and a highly electronegative atom such as oxygen or nitrogen in another polar molecule.

Hydrologic cycle The circuit of water movement from the atmosphere to the Earth and back to the atmosphere through various stages or processes, as precipitation, interception, runoff, infiltration, perocolation, storage, evaporation and transpiration.

Hydroxyapatite A member of the apatite group of minerals rich in hydroxyl groups. A nearly insoluble calcium phosphate.

Hygroscopic coefficient The amount of moisture in a dry soil when it is in equilibrium with some standard relative humidity near a saturated atmosphere (about 98%), expressed in terms of percentage on the basis of oven-dry soil.

Hyperthermic See soil temperature classes.

Igneous rock Rock formed from the cooling and solidification of magma and that has not been changed apreciable since its formation.

Illite See fine-grained mica.

Illuvial horizon A soil layer or horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension. The layer of accumulation.

Immature soil A soil with indistinct or only slightly developed horizons because of the relatively short time it has been subjected to the various soil-forming processes. A soil that has not reached equilibrium with its environment.

Immobilization The conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues, thus rendering the element not readily available to other organisms or to plants.

Impervious Resistant to penetration by fluids or by roots.

Inceptisols *See soil classification.*

Indurated (soil) Soil material cemented into a hard mass that will not soften on wetting. See also consistence; hardpan.

Infiltration The downward entry of water into the soil.

Infiltration rate A soil characteristic determining or describing the maximum rate at which water can enter the soil under specified conditions including the presence of an excess of water.

Inoculation The process of introducing pure or mixed cultures of micro-organisms into natural or artificial culture media.

Inorganic compounds All chemical compounds in nature except compounds of carbon other than carbon monoxide, carbon dioxide and carbonates.

Interlayer (mineralogy) Materials between layers within a given crystal, including cations, hydrated cations, organic molecules and hydroxide groups or sheets.

Ions Atoms, groups of atoms, or compounds that are electrically charged as a result of the loss of electrons (cations) or the gain of electrons (anions).

Iron-pan An indurated soil horizon in which iron oxide is the principal cementing agent.

Flooding The water is released from field ditches and allowed to flood over the land.

Interstraitification Mixing of silicate layers within the structural framework of a given silicate clay.

Isomorphous substitution The replacement of one atom by another of similar size in a crystal lattice without disrupting or changing the crystal structure of the mineral.

Isotopes Two or more atoms of the same element that have different atomic massess because of different numbers of neutrons in the nucleus.

Kame A conical hill or ridge of sand or gravel deposited in contact with glacial ice.

Kaolinite An aluminosilicate mineral of the 1:1 crystal lattice group; that is, consisting of single silicon tetrahedral sheets alternating with single aluminium octahedral sheets.

Labile Descriptive of a substance in soil that readily undergoes transformation or is readily available to plants.

Lacustrine deposit Material deposited in lake water and later exposed either by lowering of the water level or by the elevation of the land.

Land A broad term embodying the total natural environmental of the areas of the Earth not covered by water. In addition to soil, its attributes include other physical conditions such as mineral deposits and water supply; location in relation to centers of commerce, populations, and other land; the size of the individual tracts or holdings; and existing plant cover, works of improvement, and the like.

Land capability classification A grouping of kinds of soil into special units, subclasses, and classes according to their capability for intensive use and the treatments required for sustained use. One such system has been prepared by the USDA soil Conservation Service.

Land classification The arrangement of land units into various categories based upon the properties of the land or its suitability for some particular purpose.

Land-use planning The development of plans for the uses of land that, over long periods, will best serve the general welfare, together with the formulation of ways and means for achieving such uses.

Laterite An iron-rich subsoil layer found in some highly weathered humid tropical soils that, when exposed and allowed to dry, becomes very hard and will not soften when rewetted. When erosion removes the overlying layers, the laterite is exposed and a virtual pavement results. *See also plinthite.*

Layer (clay mineralogy) A combination in silicate clays of (tetrahedral and octahedral) sheets in 1:1, 2:1, or 2:1:1 combination.

Leaching The removal of materials in solution from the soil by percolating waters. *See also eluviation.*

Liebig's law The growth and reproduction of an organism are determined by the nutrient substance (oxygen, carbon dioxide, calcium, etc.) that is available in minimum quantity, the *limiting factor.*

Light soil (Obsolete in scientific use) A coarse-textured soil; a soil with a low drawbar pull and hence easy to cultivate. *See also coarse texture; soil texture.*

Lime (agricultural) In strict chemical terms, calcium oxide. In practical terms, a material containing the carbonates, oxides and/or hydroxides of calcium and/or magnesium used to neutralize soil and acidity.

Lime requirement The mass of agricultural limestone, or the equivalent of other specified liming material, required to raise the pH of the soil to a desired value under field conditions.

Limestone A sedimentary rock composed primarily of calcite ($CaCO_3$). If dolomite ($CaCO_3$.$MGCO_3$) is present in appreciable quantities, it is called a dolomitic limestone.

Limiting factor *See Liebig's law.*

Liquid limit (LL) *See Atterberg limits.*

Loam The textural class name for soil having a moderate amount of sand, silt, and clay. Loam soils contain amount of sand, and clay. Loam soils contain 7-27% clay, 28-50% silt, and 23-52% sand.

Loamy intermediate in texture and properties between fine-textured and coarse-textured soils. Includes all textural classes with the words loam or loamy as a part of the class name, such as clay loam or loamy sand, see also loams; soil texture.

Loess Material transported and deposited by wind and consisting of predominantly silt-sized particles.

Luxary consumption The intake by a plant of an essential nutrient in amounts exceeding what it needs. For example, if potassium is abundant in the soil, alfalfa may take in more than it requires.

Lysimeter A device for measuring percolation and leaching and evapo-transpiration losses from a column of soil under controlled conditions.

Macronutrient A chemical element necessary in large amounts (usually 50 mg/kg in the plant) for the growth of plants. Includes C, H, O, N, P, K, Ca, Mg, and S. ("Macro" refers to quantity and not to the essentiality of the element.) See also micronutirent.

Marsh Periodically wet or continually flooded area with the surface not deeply submerged. Covered dominantly with sedges, cattails, rushes, or other hydrophytic plants. Sub-classes include freshwater and saltwater marshes.

Mature soil A soil with well-developed soil horizons produced by the natural processes of soil formation and essentially in equilibrium with its present environment.

Maximum water-holding capacity The average moisture content of a disturbed sample of soil, 1 cm high, which is at equilibrium with a water table at its lower surface.

Mechanical analysis (Obsolete) See particle-size analysis; particle-size distribution.

Metamorphic rock A rock that has been greatly altered from its previous condition through the combined action of heat and pressure. For example, marble is a metamorphic rock produced from limestone, gneiss is produced from granite, and slate from shale.

Micas Primary alumino silicate minerals in which two silica tetrahedral sheets alternate with one alumina/magnesia octahedral sheet with entrapped potassium atoms fitting between sheets. They separate readily into thin sheets or flakes.

Microflora That part of the plant population which consists of individuals too small to be clearly distinguished without the use of a microscope. Includes actinomycetes, algae, bacteria, and fungi.

Micronutrient A chemical element necessary in only extremely small amounts (<50 mg/kg in the plant) for the growth of plants. Examples are B, Cl, Cu, Fe, Mn, and Zn. ("Micro" refers to the amount used rather than to its essentiality). *See also macronutrient.*

Microrelief Small-scale local differences in topography, including mounds, swales, or pits that are only a meter or so in diameter and with elevation differences of upto 2 m. See also gilgai.

Mineralization The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Mineral soil A soil consisting predominantly of, and having its properties determined predominantly by mineral matter. Usually contains <20% organic matters, but may contain an organic surface layer upto 30 cm thick.

Moisture equivalent The weight percentage of water retained by a previously saturated sample of soil 1 cm in thickness after it has been subjected to a centrifugal force of 1000 times gravity for 30 min.

Montromorillonite An aluminosilicate clay mineral in the smectite group with a 2:1 expanding crystal lattice, with two silicon tetrahedral sheets enclosing an aluminium octahedral sheet. Isomorphous substitution of magnesium for some of the aluminium has occurred in the octahedral sheet. Considerable expansion may be caused by water moving between silica sheets of contiguous layers.

Moraine An accumulation of drift, with an initial topographic expression of its own, built within a glaciated region chiefly by the direct action of glacial ice. Examples are ground, lateral, recessional, and terminal moraines.

Morphology, soil The constitution of the soil including the texture, structure, consistence, color, and other physical, chemical, and biological properties of the various soil horizons that make up the soil profile.

Muck soil (1) A soil containing 20-50% organic matter. (2) An organic soil in which the organic matter is well decomposed.

Mulch Any material such as straw, sawdust, leaves, plastic film, and loose soil that is spread upon the surface of the soil to protect the soil and plant roots from the effects of raindrops, soil crusting, freezing evaporation, etc.

Mulch tillage *See tillage, conservation.*

Mycorrhiza The association, usually smbiotic, of fungi with the roots of seed plants. See also ectotrophic mycorrhiza; endotrophic mycorrhiza; vesicular arbuscular mycorrhiza.

Neutral soil A soil in which the surface layer, at least to normal plow depth, is neither acid nor alkaline in reaction. In practice this means the soil is within the pH range of 6.6-7.3. *See also acid soil; alkaline soil; pH, reaction, soil.*

Nitrification The biochemical oxidation of ammonium to nitrate, predominantly by autotrophic bacteria.

Nitrogen assimilation The incorporation of nitrogen into organic cell substances by living organisms.

Nitrogen cycle The sequence of chemical and biological changes undergone by nitrogen as it moves from the atmosphere into water, soil, and living organisms, and upon death of these organisms (plants and animals) is recycled through a part or all of the entire process.

Nitrogen fixation The biological conversion of elemental nitrogen (N_2) to organic combinations or to forms readily utilize in biological processes.

Organic soil A soil that contains at least 20% organic matter (by weight) if the clay content is low and at least 30% if the clay content is as high as 60%.

Organic soil materials (As used in Soil Taxonomy in the United States) (1) Saturated with water for prolonged periods unless artificially drained and having 18% or more organic carbon (by weight) if the mineral fraction is more than 60% clay, more than 12% organic carbon if the mineral fraction has no clay, or between 12 and 18% carbon if the clay content of the mineral fraction is between 0 and 60%. (2) Never having more than 20% organic carbon. Histosols develop on these organic soil materials. There are three kinds of organic materials.

Oven-dry soil Soil that has been dried at 105°C until it reaches constant weight.

Pans Horizons or layers, in soils, that are strongly compacted, indurated, or very high in clay content. See also caliche; claypan; fragipan; hardpan.

Parent material The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic processes.

Particle density The mass per unit volume of the soil particles. In technical work, usually expressed as metric tons per cubic meter (Mg/m^3) grams per cubic centimeter (g/cm^3).

Particle size The effective diameter of a particle measured by sedimentation, sieving, or micro-metric methods.

Particle-size analysis Determination of the various amounts of the different separates in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods.

Particle-size distribution The amounts of the various soil separates in a soil sample, usually expressed as weight percentages.

Peat Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter accumulated under conditions of excessive moisture. See also organic soil materials; peat soil.

Peat soil An organic soil containing more than 50% organic matter. Used in the United States to refer to the stage of decomposition of the organic matter,"peat" referring to the slightly decomposed or undecomposed deposits and "muck" to the highly decomposed materials. See also muck soil; peat.

Ped A unit of soil structure such as an aggregate, crumb, prism, block, or granule, formed by natural processes (in contrast to a clod, which is formed artificially).

Pedon The smallest volume that can be called "a soil." It has three dimensions. It extends downward to the depth of plant roots or to the lower limit of the genetic soil horizons. Its lateral cross section is roughly hexagonal and ranges from 1 to 10 m2 in size depending on the variability in the horizons.

Penetrability The ease with which a probe can be pushed into the soil. May be expressed in units of distance, speed, force, or work depending on the type pf penetrometer used.

Percolation The downward movement of water through soil. Especially, the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

pH, (soil) The negative logarithm of the hydrogen ion activity (concentration) of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quainhydrone, or other suitable electrode or indicator at a specified moisture content or soil/ water ratio, and expressed in terms of the pH scale.

pH-dependent charge That portion of the total charge of the soil particles that is affected by, and varies with, changes in pH.

Phase, (soil) A sub-division of a soil series or other unit of classification having characteristics that affect the use and management of the soil but do not vary sufficiently to differentiate it as a separate series. Included are such characteristics as degree of slope, degree of erosion, and content of stones.

Physical properties (of soils) Those characteristics, processes, or reactions of a soil that are caused by physical forces and that can be described by, or expressed in, physical terms or equations. Examples of physical properties are bulk density, water-holding capacity, hydraulic conductivity, porosity, pore-size distribution and so on.

Platy Consisting of soil aggregates that are developed predominantly along the horozontal axis, laminated; flaky.

Pore size distribution The volume of the various sizes of pores in a soil. Expressed as percentages of the bulk volume (soil plus pore space).

Porosity, (soil) The volume percentage of the total soil bulk not occupied by solid particles.

Primary mineral A mineral that has not been altered chemically since deposition and crystallization from molten lava.

Prismatic soil structure A soil structure type with prism like aggregates that have a vertical axis much longer than the horizontal axis.

Productivity, (soil) The capacity of a soil for producting a specified plant or sequence of plants undre a specified system of management. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields.

Profile, (soil) A vertical section of the soil through all its horizons and extending into the parent material.

Puddled (soil) Dense, massive soil artificially compacted when wet and having no aggregated structure. The condition commonly results from the tillage of a clayey soil when it is wet.

Regolith The unconsolidated mantle of weathered rock and soil materials on the earth's surface; loose earth materials above solid rock. (Approximately equivalent to the term "soil" as used by many engineers).

Residual material Unconsolidated and partly weathered mineral materials accumulated by disintegration of consolidated rock in place.

Rhizobia Bacteria capable of living symbiotically with higher plants, usually in nodules on the roots of legumes, from which they receive their energy, and capable of converting atmospheric nitrogen to combined organic forms; hence, the term symbiotic nitrogen-fixing bacteria. (Derived from the generic name Rhizobium.).

Rhizosphere That portion of the soil in the immediate vicinity of plant roots in which the abundance and composition of the microbial population are influenced by the presence of roots.

Rock The material that forms the essential part of the Earth's solid crust, including loose incoherent masses such as sand and gravel, as well as solid masses of granite and limestone.

Saline soil A nonsodic soil containing sufficient soluble salts to impair its productivity. The conductivity of a saturated extract is >4 dS/m, the exchangeable sodium adsorption ratio is less than about 13, and the pH is < 8.5.

Salinization The process of accumulation of salts in soil.

Saltation Particle movement in water or wind where particles skip or bounce along the stream bed or soil surface.

Sand A soil particle between 0.02 and 2.0 mm in diameter, a soil textural class.

Saturation extract The solution extracted from a saturated soil paste.

Saturation percentage The water content of a saturated soil paste, expressed as a dry weight percentage.

Secondary mineral A mineral resulting from the decomposition of a primary mineral or from the reprecipitation of the products of decomposition of a primary minerals. (*See also primary mineral*).

Sedimentary rock A rock formed from materials deposited from suspension or precipitated from solution and usually being more or less consolidated. The principal sedimentary rocks are sandstones, shales, limestones, and conglomerates.

Semiarid Term applied to regions or climates where moisture is more plantiful than in arid regions but still definitely limits the growth of most crop plants. Natural vegetation in uncultivated areas is short grasses.

Separate, (soil) One of the individual-sized groups of mineral soil particles-sand, silt, or clay.

Sheet (mineralogy) A flat array of more than one atomic thickness and composed of one or more levels of linked coordination polyhedra. A sheet is thicker than a plane and thinner than a layer. Examples; tetrahedral sheet, octahedral sheet.

Silica/alumina ratio The molecules of silicon dioxide (SiO_2) per molecules of aluminum oxide (Al_2O_3) in clay minerals or in soils.

Silica/sesquioxide ratio The molecules of silicon dioxide (SiO_2) per molecules of aluminium oxide (Al_2O_3) plus ferric oxide (Fe_2O_3)in clay minerals or in soils.

Silt A soil separate consisting of particles between 0.02 and 0.002 mm in equivalent diameter. A soil textural class.

Silting The deposition of water-borne sediments in stream channels, lakes, reservoirs, or on floodplains, usually resulting from a decrease in the velocity of the water.

Site index A quantitative evaluation of the productivity of a soil for forest growth under the existing or specified environment.

Smectite A group of silicate clays having a 2:1 type lattice structure with sufficient isomorphous substitution in either or both the tetrahedral and octahedral sheets to give a high interlayer negative charge and high cation exchange capctiy and to permit significant interlayer expansion and consequent shrinking and swelling of the clay. Montmorillonite, beidellite, and saponite are in the smectite group.

Sodic soil A soil that contains sufficient sodium to interfere with the growth of most crop plants, and in which the sodium adsorption ratio is 13 or greater.

Sodium adsorption ratio (SAR)

$$\text{SAR} = \frac{[\text{Na}^{+}]}{\sqrt{\frac{1}{2}[\text{Ca}^{2+}] + [\text{Mg}^{2+}]}}$$

Where the cation concentrations are in millimoles per liter (mmole/L).

Soil A dynamic natural body composed of mineral and organic materials and living forms in which plants grow. The collection of natural bodies occupying parts of the earth's surface that support plants and that have properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief, over periods of time.

Soil air The soil atmosphere; the gaseous phase of the soil, being that volume not occupied by solid or liquid.

Soil alkalinity The degree or intensity of alkalinity of a soil, expressed by a value > 7.0 on the pH scale.

Soil amendment Any material, such as lime, gypsum, sawdust, or synthetic conditioner, that is worked into the soil to make it more amenable to plant growth.

Soil classification (Soil Taxonomy) The systematic arrangement of soils into groups or categories on the basis of their characteristics.

Order The cateogry at the highest level of generalization in the soil classification system. The properties selected to distinguish the orders are reflections of the degree of horizon development and the kinds of horizons present. The eleven orders are as follows.

Andisols Soils developed from volcanic ejecta. The colloidal fraction is dominated by allophane and/or Al-humus compounds.

Alfisols Soils with gray to brown surface horizons, medium to high supply of bases, and B horozons of illuvial clay accumulation. These soils form mostly under forest or savanna vegetation in climates with slight to pronounced seasonal moisture deficit.

Aridisols Soil of dry climates. They have pedogenic horizons, low in organic matter, that are never moist as long as 3 consecutive months. They have an ochric epipedon and one or more of the following diagnostic horizons; argillic, natric, cambic, calcic, petrocalcic, gypsic, salic, or a duripan.

Entisols Soils have no diagnostic pedogenic horizons. They may be found in virtually climate on very recent geomorphic surfaces.

Histosols Soils formed from materials high in organic matter. Histosols with essentially no clay must have at least 20% organic matter by weight (about 78% by volume). This minimum organic matter content rises with increasing clay content to 30% (85% by volume) in soils with at least 60% clay.

Inceptisols Soils that are usually moist with pedogenic horizons of alteration of parent material but not of illuviation. Generally, the direction of soil development is not yet evident from the marks left by various soil forming processes or the marks are too weak to classify in another order.

Mollisols Soils with nearly back, organic-rich surface horizons and high supply of bases. They have mollic epipedons and base saturation greater thatn 50% in any cambic or argillic horizon. They lack the characteristics of Vertisols and must not have oxic or spodic horizons.

Oxisols Soils with residual accumulations of low-activity clays, free oxides, kaolin and quartz. They are mostly in tropical climates.

Spodosols Soils with subsurface illuvial accumulations of organic matter and compounds of aluminum and usually iron. These soils are formed in acid, mainly coarse-textured materials in humid and mostly cool or temperate climates.

Ultisols Soils that are low in bases and have subsurface horizons of illuvial clay accumulations. They are usually moist, but during the warm season of the year some are dry part of the time.

Vertisols: Clayey soil with high shrink-swell potential that have wide, deep cracks when dry. Most of these soils have distinct wet and dry periods throughout the year.

Suborder This category narrows the ranges in soil moisture and temperature regimes, kinds of horizons, and composition, according to which of these is most important.

Great group The classes in this category contain soils that have the same kind of horizons in the same sequence and have similar moisture and temperature regimes.

Subgroup The great groups are subdivided into central concept subgroups that show the central properties of the great group, integrade subgroups that show properties of more than one great group, and other subgroups for soils with a typical properties that are not characteristic of any great group.

Family Families are defined largely on the basis of physical and mineralogical properties of importance to plant growth.

Series The soil series is a subdivision of a family and consists of soils that are similar in all major profile characteristics.

Soil complex A mapping unit used in detailed soil surveys where two or more defined taxonomic units are so intimately intermixed geographically that it is undesirable or impractical, because of the scale being used, to separate them. A more intimate mixing of smaller areas of individual taxonomic units than that described under soil association.

Soil conditioner Any material added to a soil for the purpose of improving its physical condition.

Soil conservation A combination of all management and land-use methods that safeguard the soil against depletion or deterioriation caused by nature and/or humans.

Soil correlation The process of defining, mapping, naming, and classifying the kinds of soils in a specific soil survey area, the purpose being to ensure that soils are adequately defined, accurately mapped, and uniformly named.

Soil monolith A vertical section of a soil profile removed from the soil and mounted for display or study.

Soil morphology The physical constitution, particularly the structural properties, of a soil profile as exhibited by the kinds, thicknesses, and arrangement of the horizons in the profile, and by the texture, structure, consistence, and porosity of each horizon.

Soil profile See, profile (soil).

Soil organic matter The organic fraction of the soil that includes plant and animal residues at various stages of decompoistion, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic materials contained in a soil sample passed through a 2 mm sieve.

Soil structure The combination or arrangement of primary soil particles into secondary particles, units, or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The secondary units are characterized and classified into classes, types, and grades, respectively.

Soil structure classes A grouping of soil structural units or peds on the basis of size from the very fine to very coarse.

Soil structure grades A grouping or classification of soil structure on the basis of inter and intra aggregate adhesion, cohesion, or stability within the profile. Four grades of structure, designated from 0 to 3, are recognized.

0 : structureless – no observable aggregation.
1: weakly durable peds.
2 : moderately durable peds.
3: strong, durable peds.

Soil structure types A classification of soil structure based on the shape of the aggregates or peds and their arrangement in the profile, including platy, prismatic, columnar, blocky, subangular blocky, granulated, and crumb.

Soil survey The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to the kind and intensity of field examination.

Soil temperature classes (Soil Taxonomy) Classes are based on mean annual soil temperature and on differences between summer and winter temperatures at a depth of 50 cm.

(a) Soil with 5oC and greater difference between summer and winter temperatures are classsed on the basis of mean annual temperatures.

1. Frigid : <8°C mean annual temperature.
2. Mesic : 8-15°C mean annual temperature.
3. Thermic :15-22°C mean annual temperature.
4. Hyperthermic : >22°C mean annual temperature.

(b) Soils with < 5°C difference between summer and winter temperatures are classed on the basis of mean annual temperatures.

1. Isofrigid : < 8°C mean annual temperature.
2. Isomesic : 8-15°C mean annual temperature.
3. Isothermic : 15-22°C mean annual temperature.
4. Isohyperthermic : < 22°C mean annual temperature.

Soil textural class A grouping of soil textural units based on the relative proportions of the various soil separates (sand, silt, and clay). These textural classes, listed from the coarsest to the finest in texture, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy, clay loam, clay loam, silty clay loam, sandy clay, silty clay and clay. There are several subclasses of the sand, loamy sand, and sandy loam classes based on the dominant particle size of the sand fraction (eg. Loamy fine sand, coarse sandy loam).

Soil water potential (total) A measure of the difference between the free energy state of soil water and that of pure water. Technically it is defined as "that amount of work that must be done per unit quantity of pure water in order to transport reversibly and isothermically an infinitestimal quantity of water from a pool of pure water, at a specified elevation and at atmospheric pressure to the soil water (at the point under consideration)." This total potential consist of the following potentials.

Matric potential That portion of the total soil water potential due to the attractive forces between water and soil solids as represented through adsorption and capillarity. It will always be negative.

Osmotic potential That portion of the total soil water potential due to the presence of solutes in soil water. It will generally be negative.

Gravitational potential That portion of the total soil water potential due to differences in elevation of the reference pool of pure water and that of the soil water. Since the soil water elevation is usually chosen to be higher than that of the reference pool, the gravitational potential is usually positive.

Solum (plural sola) The upper and most weathered part of the soil profile; the A,, E, and B horizons.

Trace element (Obsolete) See micronutrient.

Universal soil loss equation (USLE) An equation for predicting the average annual soil loss per unit area per year, A = RKLSPC, where R is the climatic erosivity factor (rainfall plus runoff), K is the soil erodibility factor, L is the length of slope, S is the percent slope. C is the cropping and management factor and P is the soil erosion practice factor.

Unsaturated flow The movement of water in a soil that is not filled to capacity with water.

Vermiculite A 2:1-type silicate clay usually formed from mica that has a high net negative charge stemming mostly from extensive isomorpohous substitution of aluminum for silicon in the tetrahedral sheet.

Vertisols See soil classification.

Vesicular arbuscular mycorrhiza A common endomycorrhizal association produced by phycomycetous fungi of the genus Endogone and characterized by the deveolopment of two types of fungal structures : (a) within root cells small structures known as arbuscles and (b) between root cells storage organs known as vesicles. Host range includes many agricultural and horticultural crops. *See also endomycorrhiza.*

Virgin soil A soil that has not been significantly disturbed from its natural environment.

Water-stable aggregate A soil aggregate stable to the action of water such as falling drops, or agitation as in wet-sieving analysis.

Water table The upper surface of groundwater or that level below which the soil is saturated with water.

Water table, (perched) The surface of a local zone of saturation held above the main body of groundwater by an impermeable layer of stratum, usually clay and separated from the main body of groundwater by an unsaturated zone.

Water use efficiency Dry matter or harvested portion of crop produced per unit of water consumed.

Weathering All physical and chemical changes produced in rocks, at or near the Earth's surface, by atmospheric agents.

Wilting point (permanent wilting point) The moisture content of soil, on an oven-dry basis, at which plants wilt and fail to recover their turgidity when placed in a dark humid atmosphere.

Xerophytes Plants that grow in or on extremely dry soils or soil materials.