Study Guide
BS Rural Development

INTRODUCTORY SOIL SCIENCE

COURSE CODE: 7902



Department of Agricultural Sciences
ALLAMA IQBAL OPEN UNIVERSITY

INTRODUCTORY SOIL SCIENCE

Course Code: 7902

DEPATMENT OF AGRICULTURAL SCIENCES
ALLAMA IQBAL OPEN UNIVERSITY
ISLAMABAD

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PREFACE

Soil science plays a vital role in agriculture, and its significance can be highlighted as through the understanding of soil properties and nutrient management that ensures optimal crop growth and productivity, knowledge of soil characteristics helps in selecting suitable crops, optimizing yields, and reducing soil degradation, soil science informs practices that maintain soil health, reduce erosion, and promote environmental sustainability, understanding soil-water relationships helps in efficient irrigation management, reducing waste, and conserving this precious resource and soil science helps mitigate environmental issues like soil pollution, salinization, and desertification.

This **Introductory Soil Science** book highlights the importance of soil science in agriculture by emphasizing the relevance of soil science in modern agriculture and inspiring students to appreciate the significance of soil science in ensuring food security and environmental sustainability.

By introducing the importance of soil science, this book can spark curiosity and motivate readers to explore the subject further.

Soil Science has a crucial role to play in the context of agricultural growth, especially when agriculture is facing numerous challenges restricting agricultural production in the country with a rapidly increasing population, and when drastic changes are continuously taking place with the advancement of science and technology. It is the soil that provides a medium of growth to emerging seeds. Soils not only provide a medium of growth to roots as well as shoots but are also a source of nutrition, water and air supply too young seedling. Hence, it can be said without any hesitation that the presence of soil is mandatory for plant growth. Soils have much potential to supply macro and micro nutrients to plants, and this potential has to be explored by the soil scientists to achieve the desired goal of higher crop production to meet the demands of ever-increasing population in the country.

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Unit:1

BASICS OF SOIL SCIENCE

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INTRODUCTION

This is an introductory unit designed to introduce the concept and significance of soil and its related terms for agriculture students at the undergraduate level. It provides information to the students about soil and its related terms, with their environmental significance. This introductory unit is designed for undergraduate agriculture students, aiming to introduce the concept of soil and its significance, familiarize students with soil-related terminology, and highlight the environmental importance of soil. Students can gain a foundational understanding of soil science, enabling them to appreciate its role in agriculture and environmental sustainability.

OBJECTIVES

This unit is designed to introduce the concept and importance of soil and its related terms for agriculture students at undergraduate level. This unit lays the groundwork for further exploration of soil science and its applications in agriculture. This unit aims to:

1. Understand soil's importance in agriculture
2. Familiarize with soil-related terminology
3. Appreciate soil's impact on crop production and environmental sustainability

LEARNING OUTCOMES

The students will be able to understand soil and related terms and their relationship with crop production and the environment. This knowledge will help students appreciate the significance of soil conservation and sustainable agricultural practices. The learning objectives include:

1. Students will grasp the importance of soil in agriculture and ecosystems.
2. They will understand how soil properties affect crop growth and productivity.
3. Students will recognize the role of soil in environmental sustainability.

1. Introduction to Soil

Soil is the loose and unstratified portion present on the surface of Earth that serves as a medium for growing plants. In nature, soil is considered a dynamic entity. It is a naturally found material that is composed of many constituents like minerals, organic matter, liquids, and gases. Soil provides cover to the surface of land. Soil is an essential component of the earth's ecosystem that supports all types of plant life, controls water and nutrient cycles, and contains many microorganisms. Soil performs many functions in a natural ecosystem. It provides basic support to growing plants, along with water and essential elements as a source of nutrition, to help them maintain life. Soil acts as a reservoir for water storage and filtration. Numerous kinds of microorganisms are present, playing a vital role in nutrient cycling, organic matter decomposition, and maintaining soil health. Many biogeochemical cycles, such as the carbon, nitrogen, and phosphorus cycles, take place in soil. Soil exhibits diverse physical and chemical properties that vary greatly from place to place.

Due to the above facts, understanding the importance of soil is mandatory for managing this important natural land resource to boost agricultural productivity and finally conserve the natural environment. In other situations, soils are degraded quickly by erosion, salts, and other pollutants. To understand soils in a better way, some basic definitions are given below:

1.1 Soil

It is the unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for plant growth. The unconsolidated mineral material on the surface of Earth. This material has been subjected to so many physical, chemical, and biological processes. All these processes are affected by many genetic and environmental/climatic factors. Some of the common factors are parent material, climate, topography, and many types of living organisms. All these factors are interacting with each other for long periods of time. The result of all these interactions is the product called soil.

Soil is freely movable and loose matter which covers the earth's surface and consists of minerals, organic fractions, water, and gases. It provides a foundation for human life and global ecosystems. Minerals found in soil are named as separates, and their percentage in any specific soil is called texture. Weathering plays its significant role in soil formation under the interaction of climate, topography, various organisms, and parent materials over a long period of time. Hence, every soil is different from others in respect of its basic physical (like texture, structure, consistency, colour), chemical (pH, EC, SAR, and CEC, etc.), and biological characteristics.

Soils act as a sink for carbon storage. Soils are made up of 04 constituents like minerals, organic fraction, soil air, and water. Most of the soils are composed of

minerals like quartz and feldspars in combination with secondary minerals like clays and different oxides of iron.
The basic role of soil is to offer backing to growing plants along with a supply of water and various nutrients. Soil has various layers called horizons, which can be distinguished from each other, and each of these has unique properties. In this regard, the organic/O horizon is dark brown or black in colour and is the has enriched with humus, and the mineral horizon is the topmost soil layer composed of organic matter. On the other hand, mineral soil layers are designated as A, B, and C horizons. All these horizons are identified by their specific composition, colour, and properties.

1.2 Earth

Earth is the third planet with reference to distance from the sun. It is situated between Venus and Mars. The word earth has many definitions, like the planet/place on which we are living, the material/stuff which makes surface of the earth, and likewise an assembly to connect to electrical devices. Water covers about 71% of the Earth's surface. From these huge quantities of water, about 96.5 % is found in oceans.
As a planet, Earth is the 3rd one from the sun, which is large enough and round in shape. It is covered in land, water, and air. It contains many volcanoes, mountains, and valleys. The lithosphere of Earth is distributed in large-sized regularly moving plates. Among the whole solar system, Earth is the single planet that contains and supports life. This unique feature of supporting life makes the soil unique among all the planets.
Earth as a material is a loose/free substance or stuff from which a large portion of the surface of the ground is prepared. It provides a solid foundation for the soil.
The term "earth" is also used by engineers. In this context, earth refers to an unconsolidated mass that can be dug, moved, compacted, and formed by any means. It can come from shallow or deep layers of the Earth's mantle.

1.3 Land

Land is a commonly used word to describe the non-water portion of the earth, commonly in situations to an enormous external part. In some contexts, it is similar to soil. Land can be classified into various types based on its use. For example,

Agricultural Lands

These are used for growing crops, vegetables, fruits, and raising animals.

Commercial Lands

These are used for various commercial purposes like buildings, malls, and plazas, etc.

Recreational Lands

These are used for various outdoor activities meant for enjoyment to relax people from various tensions.

Residential Lands

These are used for the construction of houses for single and multifamily homes, apartments, etc.

Industrial Lands

These are used for various industrial purposes, like business parks, and light, medium, and heavy industrial zones.

Transportation Lands

These are used for the construction of roads, bus stops, and railway stations.

2. Soil Science

It is the branch of agriculture that deals with different aspects, types, and properties of soil. Soils have various physical, chemical, biological, and fertility-related characteristics. All these properties are working simultaneously and have a significant part in soil management for the plant's growth. The composition of any soil at a specific location has its direct impact on growing plants.

Soil Science has an important and basic role in evaluating and subsequently alleviating the negative impact of the environment on human activities like excavating, construction, and various land usage alterations. It elaborates on the mechanism of various soil properties and their management for the ideal growth of plants, forest, range, and wetland soils. It also provides basic information about urban land use, as well as the disposal and management of waste materials. Soil science is studied by agronomists, pedologists, and soil classifiers in addition to soil scientists.

2.1 Volumetric Components of Soil

Soil is made up of 04 constituents like minerals, organic fraction, soil air, and water. All these components are very important and play their significant role in plant growth. Air and water present in soil control different voids between soil particles. The percentage of all these components on the basis of soil volume is as under in Table No. 1.1 and Figure No. 1.1:

Table 1.1: Components of soil

Sr. No.	Soil Component	Percentage
1	Minerals	40-45
2	Carbon-based or organic fraction	5
3	Air	20-30
4	Water	20-30
5	Microorganisms	Found in large amounts, but not more than 1% of soil volume
6	Gases	NH_3, N_2O, CO_2 and CH_4

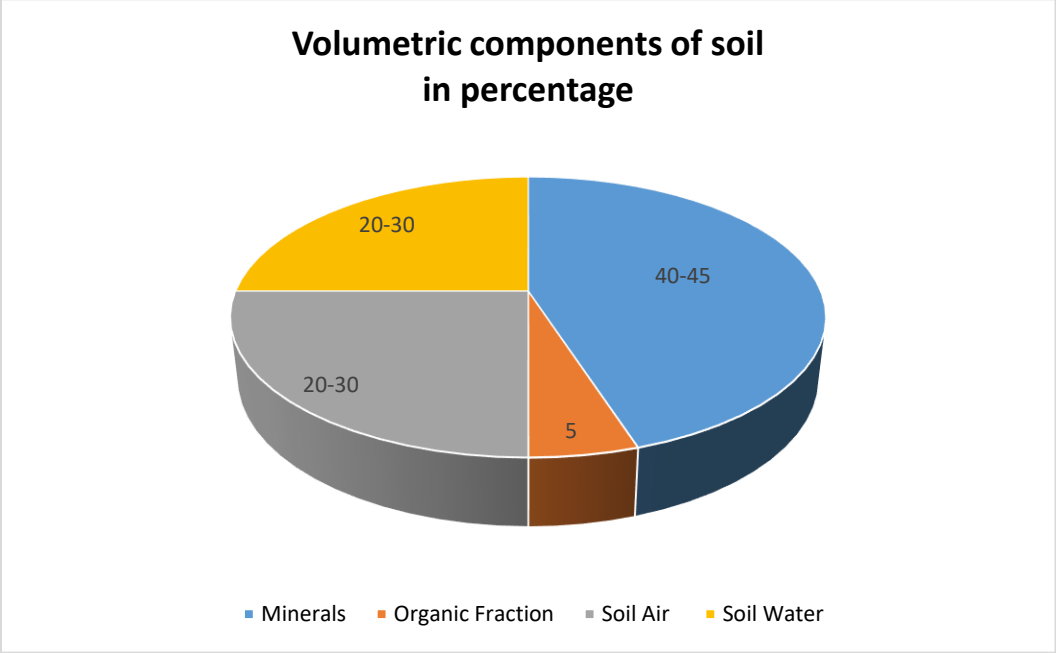


Figure No. 1.1

The composition of soil is not easy but very complex it is dynamic in nature. It changes from time to time depending upon so many internal and external factors. e.g., volume of water in the soil can change depending upon season, temperature, rainfall, and irrigation.

2.2 Important Components of Earth

Earth is composed of 4 major parts, namely lithosphere, hydrosphere, atmosphere, and biosphere, as shown in Figure No. 1.2. Brief descriptions of these 4 parts are as under:

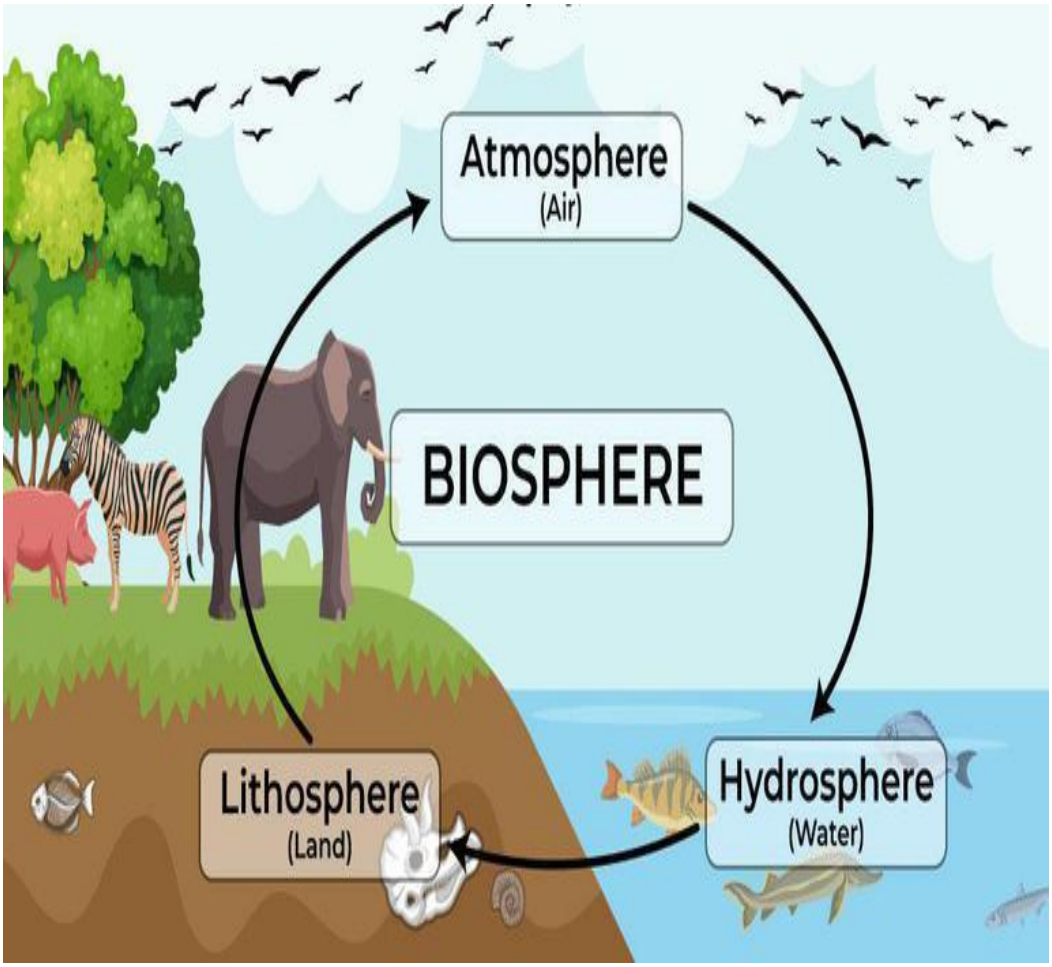


Figure No. 1.2

1. Lithosphere

It is the hard/compact/solid / rock type part of the earth which is flattened at the poles owing to rotation (Figure No. 1.3). About 289 million km^2 lies below the sea, and 86 million km^2 is land.

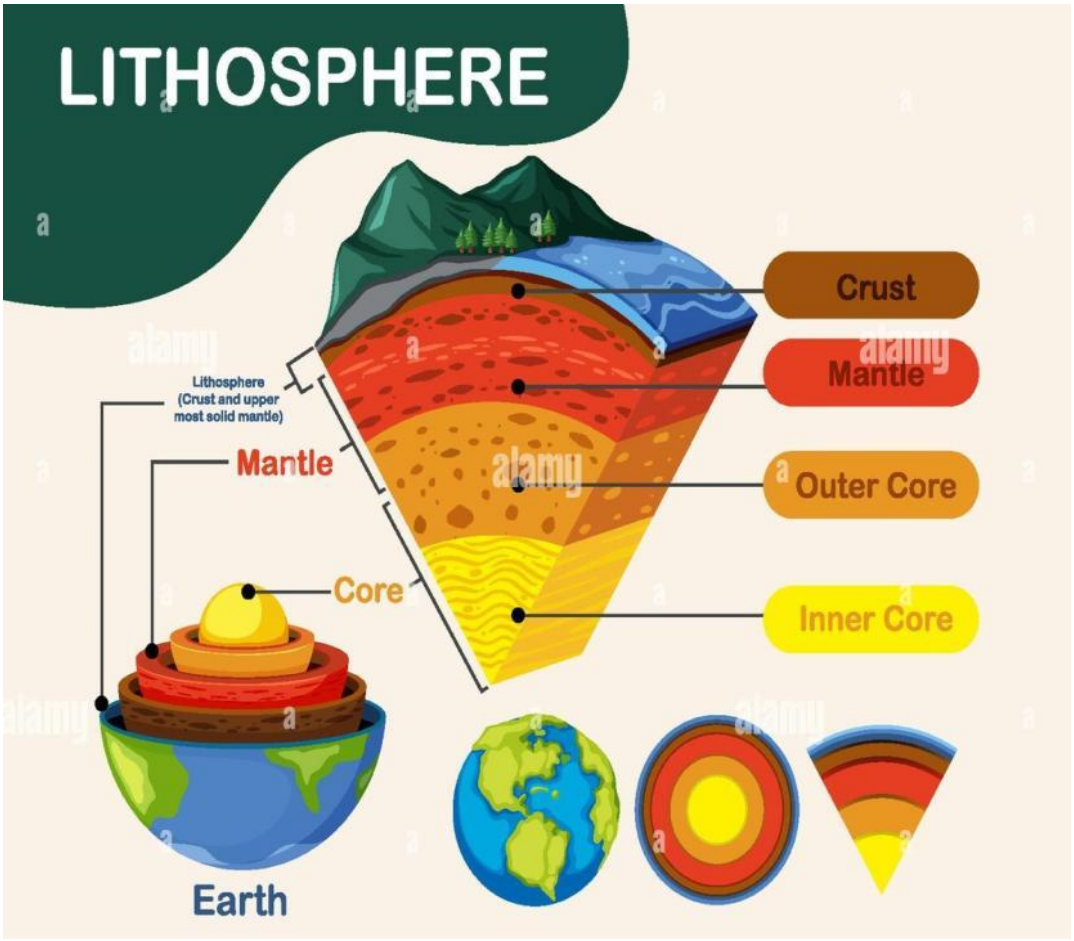


Figure No. 1.3

2. Hydrosphere

The hydrosphere is the part of the Earth that contains various water sources altogether (oceans, seas, lakes, and rivers, etc.). The greater part of the water of the hydrosphere is in the ocean. The ocean is about 10 km deep with an average depth of 4 km. The surface of the ocean is about 289 million km^2. This is the water that supports plants, weathering of rocks, soil formation, and ultimately serves as the medium for most of the soil chemical reactions (Figure No. 1.4).

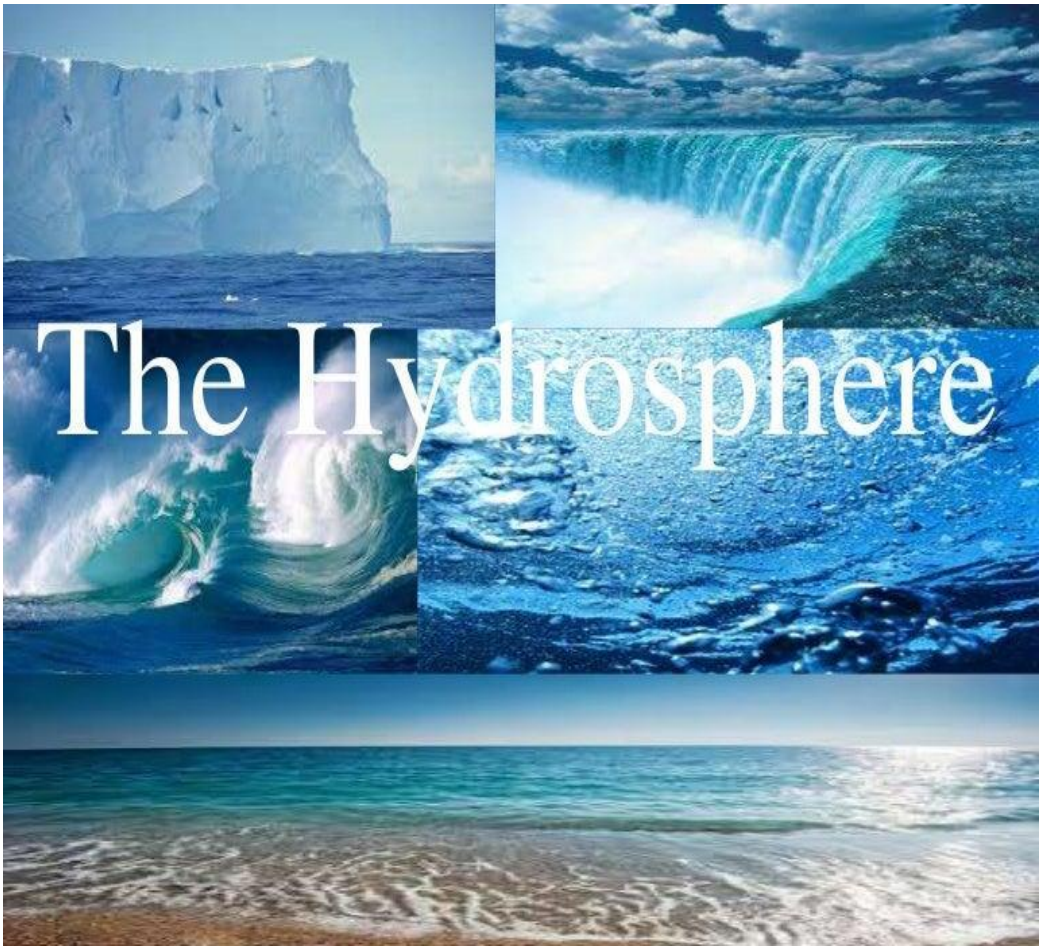


Figure No. 1.4

3. Atmosphere

Atmosphere is a mixture of various gases which are retained by the earth under the direct impact of gravitational force. The composition of various gases present in the atmosphere is given in Table 1.2. At sea level, such an envelope of gases is highly thick and compressed. This thickness declines quickly with increasing height. The mass of atmosphere is 1/1200000 the mass of Earth (6×10^{21} tons), and the pressure at sea level is 1.013 bars. The atmosphere extends to about 320 kilometers above the Earth's surface. It is an important geological agent and acts as a thermal blanket (Figure No. 1.5). It captures heat from the solar system and supplies snow and rainwater. The composition of the atmosphere is as under:

Table 1.2: Composition of Gases in Atmosphere

Nitrogen (N_2)	78%
Oxygen (O_2)	21%
Argon (Ar)	0.93%
Carbon dioxide (CO_2)	0.03%
Ne, He, Kr, Xe, H_2O vapors, dust particles, hydrocarbons etc.	Traces

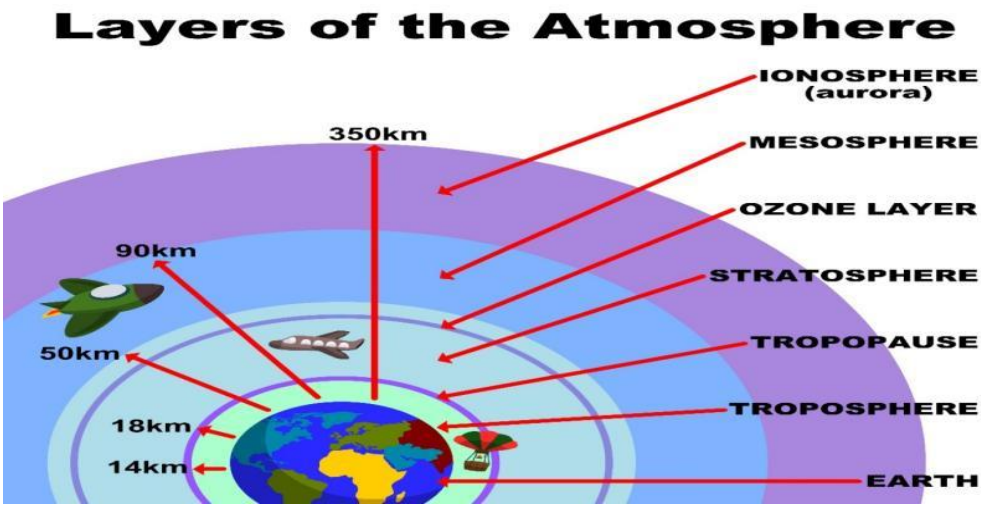


Figure No. 1.5

4. Biosphere

Biosphere is the part of Earth that comprises all living things, like microorganisms, animals, plants, and human beings. This part deals with the habitats of all living creatures and their interactions with other components of Earth (Figure 1.6).

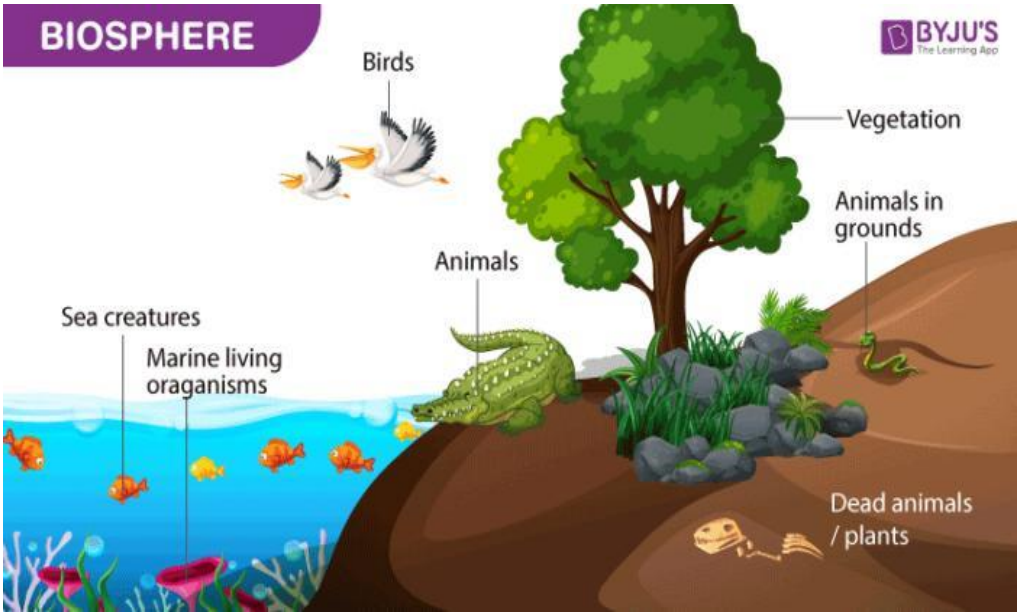


Figure 1.6

3. Different Elements Present on the Surface Earth

On average, more than 100 elements are known to exist on Earth's surface (Figure 1.7). The average amount of these elements is given in Table 1.3 as under:

Table 1.3: Percentage of Elements Present on Earth's Surface

Sr. No.	Name of Element	Amount (%)
1	O	46.7
2	Si	27.7
3	Al	8.1
4	Fe	5.1
5	Ca	3.7
6	Na	2.8
7	K	2.6
8	Mg	2.1
9	H	0.1
10	Others	1.3
Total		**100**

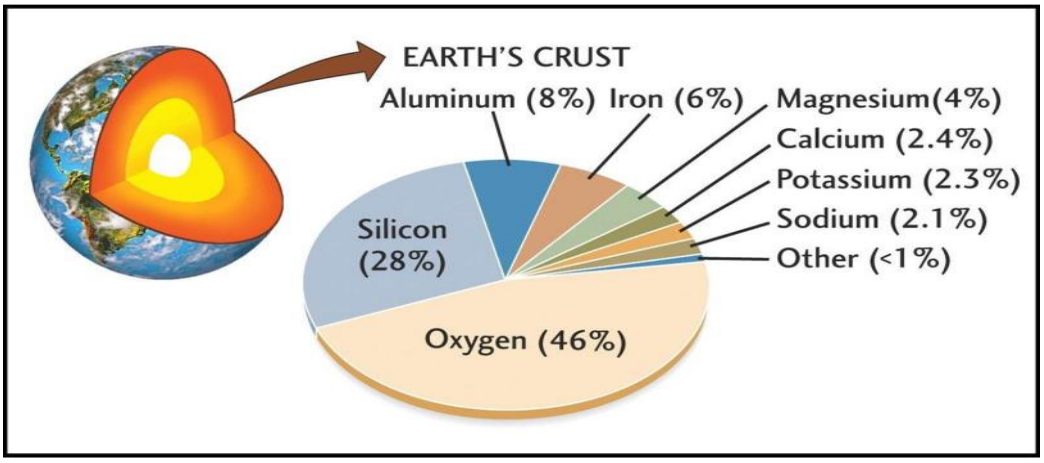


Figure 1.7

SELF ASSESSMENT QUESTIONS

Question No. 1: Differentiate between soil and earth.
Question No. 2: Define land. Explain various types of land.
Question No. 3: Define and explain the concept of soil science.
Question No. 4: Write a note on volumetric components of soil.
Question No. 5: Define Earth and explain its major components of earth.
Question No. 6: Define atmosphere. Write a composition of atmosphere.
Question No. 7: Write a note on the different elements present on the surface of Earth.

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Unit:2

DISCIPLINES OF SOIL SCIENCE

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INTRODUCTION

This unit is designed to introduce the concept and significance of soil science and its Various disciplines for agriculture students at the undergraduate level. It provides information to the students about soil science and its branches, as well as their environmental significance. This unit aims to understanding of soil science and its branches, an appreciation of soil's role in agriculture and environmental sustainability, and a foundation for further study in soil science and its applications. This unit provides a comprehensive introduction to soil science, setting the stage for deeper exploration and application in agriculture and environmental fields.

OBJECTIVES

This unit introduces the concepts of soil science and its various branches for agriculture students at the undergraduate level. This unit provides an introduction to the definition and scope of soil science and the importance of soil in agriculture and ecosystems. Some of the branches of Soil Science include soil physics, soil chemistry, soil biology and soil fertility, and management, etc. This unit lays the groundwork for understanding soil science and its applications in agriculture.

LEARNING OUTCOMES

The students will be able to understand various disciplines of soil science and their relationship with crop production and the environment. After studying this unit:

1. Students will grasp the importance of soil science in agriculture and ecosystems.
2. They will understand how soil properties and management practices affect crop growth and productivity.
3. Students will recognize the role of soil science in maintaining environmental quality and sustainability.

1. Soil Science

It is the branch of agriculture that deals with different aspects, types, and properties of soil. Soils have various properties and characteristics (physical, chemical, biological, and fertility). All these properties are working simultaneously and have their significant part in soil management for the plant's growth. The composition of any soil at a specific location has its direct impact on growing plants.

Soil Science has an important and basic role in evaluating and subsequently alleviating the negative impact of the environment on human activities like excavating, construction, and various land usage alterations. It elaborates on the mechanism of various soil properties and their management for the ideal growth of plants, forest, range, and wetland soils. It also provides basic information about urban land use, as well as the disposal and management of waste materials. Soil science is studied by agronomists, pedologists, and soil classifiers in addition to soil scientists.

2. Important Branches of Soil Science

A short description of important branches of soil science is given below:

2.1 Soil Chemistry

Soil chemistry may be defined as a branch of soil science that deals with chemical properties, reactions, and various developments taking place in the soil. It also deals with the delivery of different elements and compounds in solid, liquid, and gaseous phases of soil. In this way, the chemical configuration of soil is described through its chemistry. Chemical characteristics of any soil are very important as these have a direct impact on soil fertility status, growth of plants, and various ecological methods (Figure 2.1).

In this branch of soil sciences, chemical composition, chemical reactions, nature of soil solution, soil reaction and buffering capacity, cation exchange capacity, and density and movement of different pollutants in soil are studied in detail. Therefore, it can be said that soil chemistry is important for sustainable agriculture, protection of the environment, and soil genesis/formation. It also covers the different nutrient cycles in addition to soil buffering capacity and redox reactions.

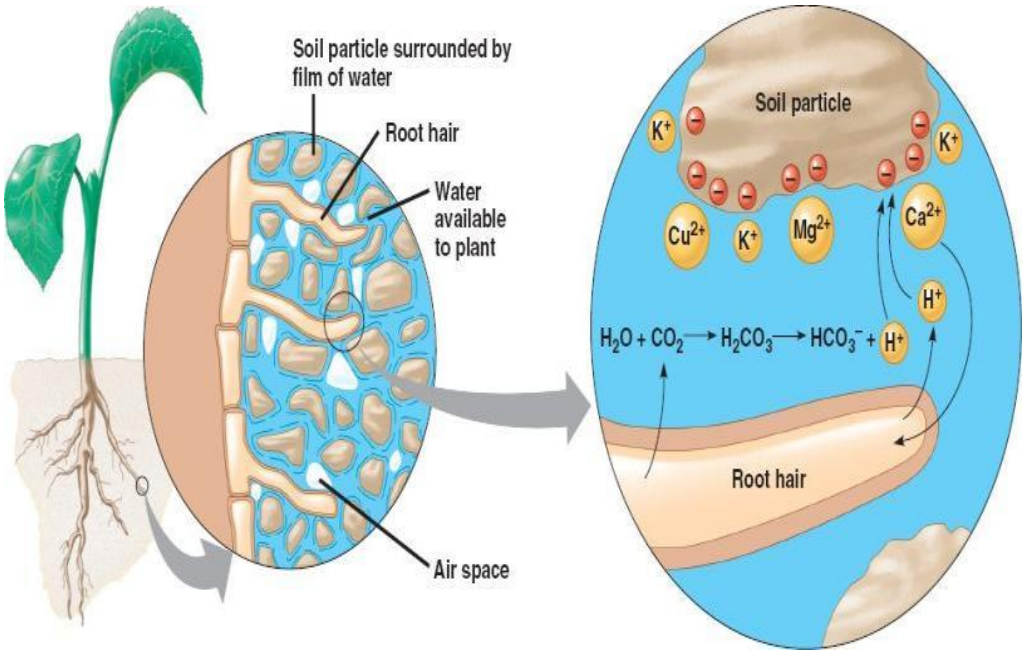


Figure 2.1

2.2 Soil Survey

Soil survey is the branch of soil science that deals with investigation, grouping, explanation, and drawings/mapping of soil in an organized and orderly manner. Information regarding basic soil properties like structure, texture, colour, drainage, pH, salt level, and erosion hazard etc., is presented in a systematic and organized/orderly manner (Figure 2.2). Important components of soil survey are systematic examination, description of soil parameters, soil classification based on described properties, classification of soils based on the basis of studied properties, preparation of maps of different soils as per their characteristics, interpretation of soils on the basis of described properties and finally planning for using particular lands.

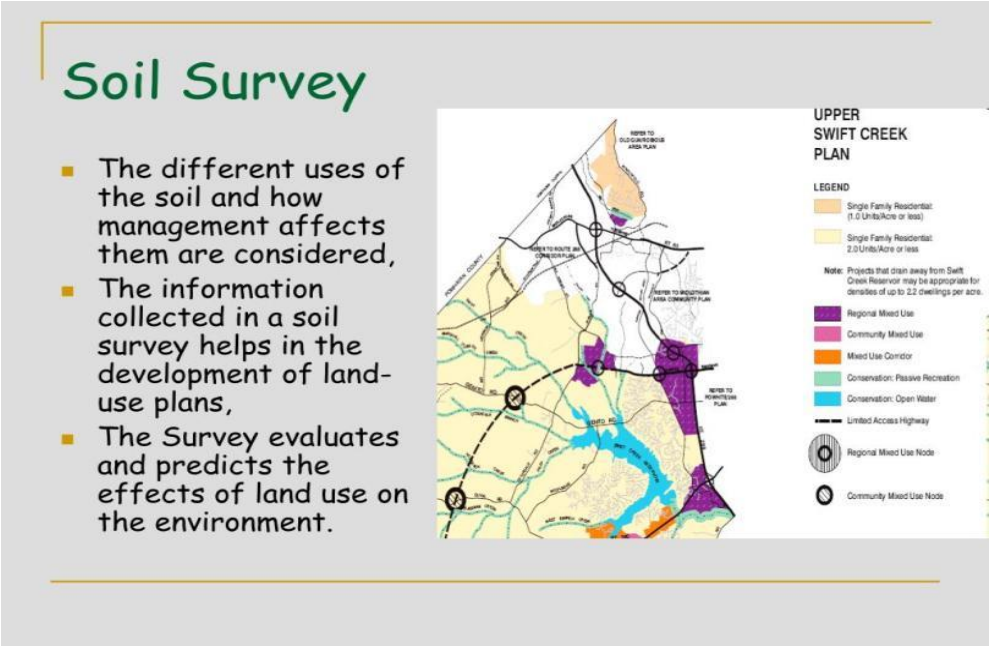


Figure 2.2

2.3 Soil Genesis/Formation

Soil genesis is the branch of soil science that deals with various methods and processes of soil formation. This branch is concerned with the weathering of rocks/parent material, which results in prominent/distinct soil horizons. These horizons are formed after many physical, chemical, and biological reactions that occur over time in combination with different climatic factors (Figure 2.3). Soil genesis is also referred to as soil formation or pedogenesis. Hence, it is the study of soil origin and subsequent formation through many agents and factors like parent material, topography of the region, biotic and abiotic factors, and climate. Some important components of soil genesis are parent material, climate, relief/topography, organisms, and time. All these components play their vital role in the formation of any specific soil.

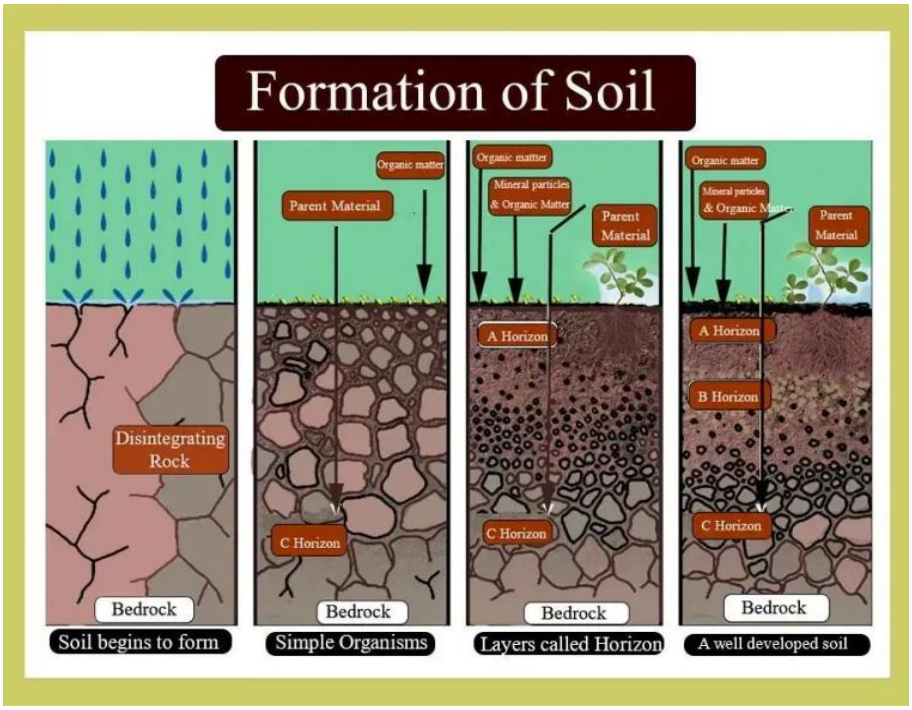


Figure 2.3

2.4 Soil Morphology

Soil morphology is the visual observation of soil structure, shapes, and the arrangement of soil horizons in the soil profile. It is the branch of soil science that deals with the explanation of different physical properties of soil. These physical soil characteristics are texture, structure, colour, and consistency. These characteristics can be seen in the field while studying soil profiles (Figure 2.4). These characteristics are also called components of soil morphology. Knowledge of soil morphology is essential to understand various processes of soil genesis/formation, their classification, and management, and subsequently application of these processes to agriculture, engineering, and environmental sciences.



Figure 2.4

2.5 Soil Classification

Soil classification is the branch of soil science that deals with the grouping of soils into various classes/categories through organized, orderly, and systematic procedures that are based on specific characteristics (Figure 2.5). These characteristics may be chemical, physical, biological, mineralogical, or genetic in nature, etc. Sometimes geotechnical soil properties are also used to classify the soils, and this classification is made to understand mapping and soil resource management. Some important components of soil classification are systematic description of soil parameters, predictive tools being used for classification, organized knowledge behind the classification, and basic information behind the land use for various purposes. It is also known as soil taxonomy.



Figure 2.5

2.6 Soil Conservation

Soil conservation is a branch of soil science that deals with different management approaches designed to prevent soil erosion, salinity, acidity, or other similar types of pollution caused due to any reason.

Hence, it is a grouping of altogether controlling and land usage systems which maintain soil from being exhausted or declining due to environmental and/or human factors. It is a system of husbandry that aims at getting maximum production from the soil on a sustained basis. In other words, the conservation of the soil is a matter of using the land as it should be used. i.e., some soils are too steep to be farmed, some are too erodible to be cultivated, and some are climatically unsuited to intensive cultivation (Figure 2.6). Considering the above points, soil conservation can be defined as the sustainable use of soil based on cost-effective practices that align with its capabilities and requirements, ensuring its long-term productivity.



Figure 2.6

2.7 Soil Fertility

Soil fertility is the branch of soil science that deals with the capability of any particular soil to provide all essential (macro and micro) nutrients to the growing plants, besides a favorable growing environment. This will ensure the growth of high-quality crops on a consistent and sustained basis. Hence, it can be said that soil fertility is the ability of any soil to support plant growth and high yield on a sustained basis. Soil fertility also includes soil's potential to supply water, essential nutrients, and a good physical environment for vigorous plant growth. Important components of soil fertility are soil pH, nutrient availability, quantity of soil organic matter, soil textural class, and mineral composition of the soil (Figure 2.7). Conservation of soil fertility is mandatory for food security, environmental sustainability, and economic stability. This target of soil fertility conservation can be achieved through the addition of organic matter, nutrient management, soil conservation, proper crop rotation, and soil testing.

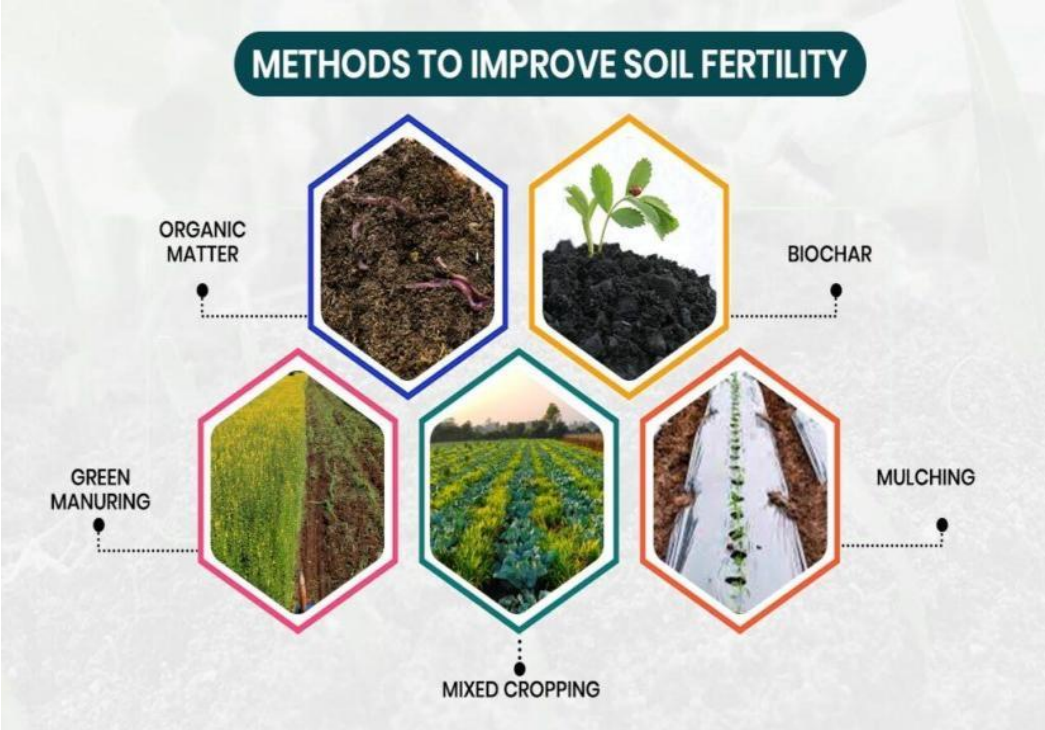


Figure 2.7

2.8 Soil Microbiology

Soil microbiology is the branch of soil science that deals with the study of various microorganisms present in the soil. It also deals with the proper roles and actions played by microorganisms in the soil. Microorganisms play their role in the growth of plants by keeping a healthy soil environment on a sustainable basis. Hence, it can be said that microbiology is the study of different microorganisms present in soil, their actions, and their relationship with relevant soil properties (Figure 2.8). Important microorganisms are bacteria and viruses. Some microorganisms are also toxic to plant growth.



Figure 2.8

2.9 Soil Mineralogy

Soil mineralogy is the branch of soil science that deals with the study of various minerals present in any particular soil. It is an important branch of soil science. Knowledge of basic structure, configuration, chemistry, and physical characteristics of minerals is mandatory for a good understanding of rocks and ores (Figure 2.9). Feldspar, micas, and quartz are major minerals found in most soils. Soil mineralogy is very important as it controls the presence and amounts of all nutrients found in any soil. Nutrient availability to plants at a proper rate is also governed by soil minerals. About half (50%) of soil volume is made up of minerals. These minerals not only provide physical support to growing plants but also boost growth by providing water and air-filled pores. Weathering of minerals releases many types of important nutrients that are required by plants.



Figure 2.9

2.10 Soil Physics

Soil physics is the branch of soil science that deals with different physical properties and processes taking place in the soil. The important processes include structure, texture, movement of water, and dynamic actions of these properties with each other (Figure 2.10). Soil physics also explains the role of these properties for growing plants in relation to other functions of the natural ecosystem. Important physical properties are texture, structure, bulk density, porosity, consistency, colour, water movement, and temperature etc. Similarly, important physical processes are water percolation, infiltration, drainage, heat transfer, movement of solutes and gases, etc.

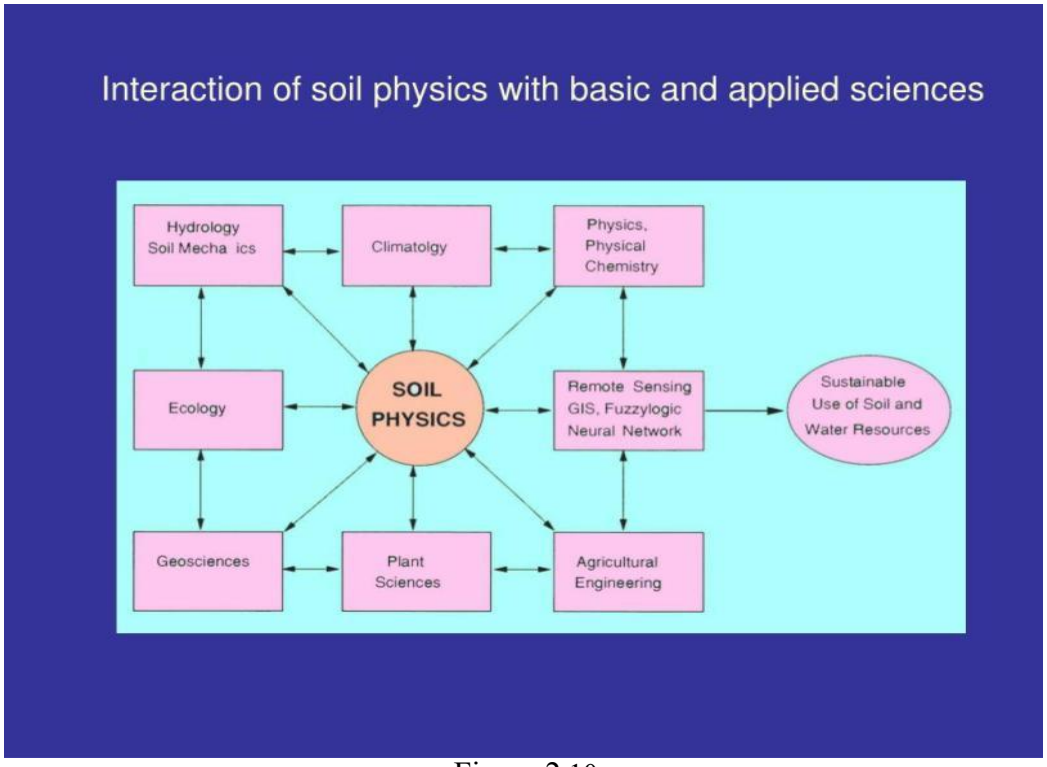


Figure 2.10

2.11 Soil Salinity

Soil salinity is the branch of soil science that deals with the knowledge of salt-affected soils in relation to plant growth and water stress caused due to excess salts. Salinity deals with the accumulation of high concentrations of water-soluble salts to the extent of hindering plant growth (Figure 2.11). Important salts which contribute to salinity are sodium sulphate, sodium chloride, calcium chloride, and magnesium sulphate. Salinity can be measured by using an EC meter. As a result of high salt uptake, plants are unable to absorb water in sufficient amounts and many essential nutrients due to the interference of salinity. Plants growing in such an environment show ion toxicity. Basic causes of high salinity are natural and artificial (due to human activities).

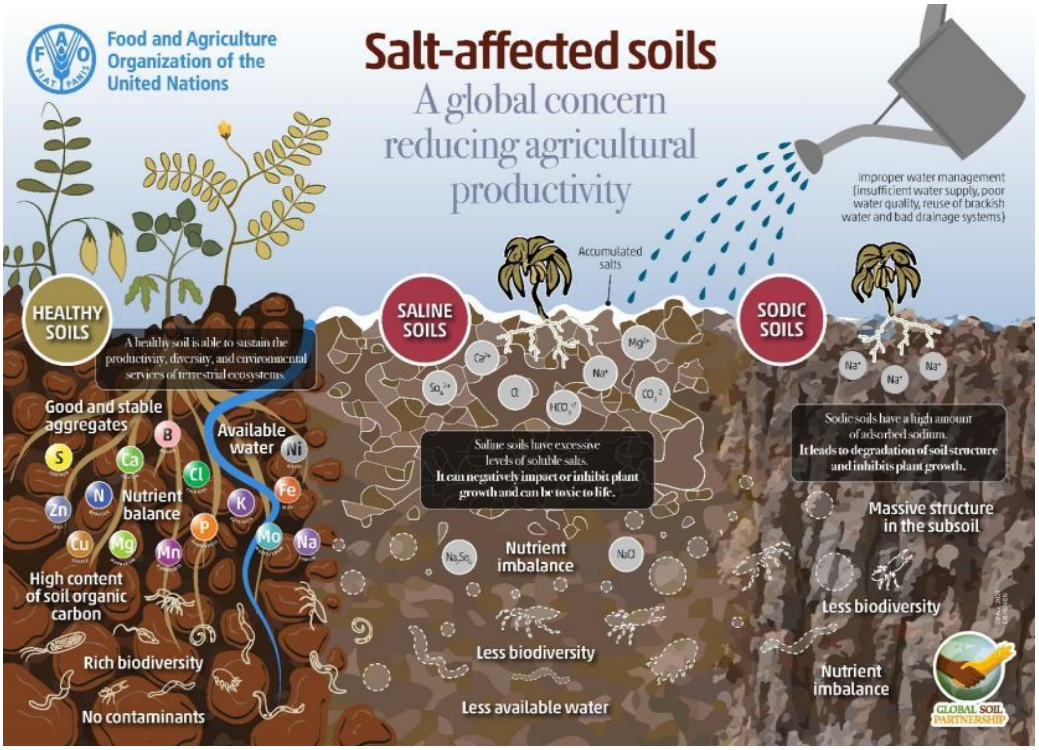

Food and Agriculture Organization of the United Nations
Salt-affected soils
A global concern reducing agricultural productivity
Improper water management (insufficient water supply, poor water quality, reuse of brackish water and bad drainage systems)
Accumulated salts
HEALTHY SOILS
A healthy soil is able to sustain the productivity, diversity, and environmental services of terrestrial ecosystems.
SALINE SOILS
SODIC SOILS
Good and stable aggregates
Available water
Nutrient balance
High content of soil organic carbon
Rich biodiversity
No contaminants
Saline soils have excessive levels of soluble salts. It can negatively impact or inhibit plant growth and can be toxic to life.
Nutrient imbalance
Less biodiversity
Less available water
Sodic soils have a high amount of adsorbed sodium. It leads to degradation of soil structure and inhibits plant growth.
Massive structure in the subsoil
Less biodiversity
Nutrient imbalance
GLOBAL SOIL PARTNERSHIP

Figure 2.11

2.12 Soil Biology

Soil biology is the subdivision of soil science that deals with the study of many creatures living in the soil, their relationships with each other, as well as their interaction with the environment. These living organisms play their main part in conserving soil productivity and health. It can be said that it is the learning of soil infectious organisms, faunal action, and the soil ecosystem (Figure 2.12). These microorganisms play a significant role in all soil processes, like decomposition of organic materials and different nutrient cycles. Soil biology is an important contributor to the diversified ecosystem and its proper functioning.

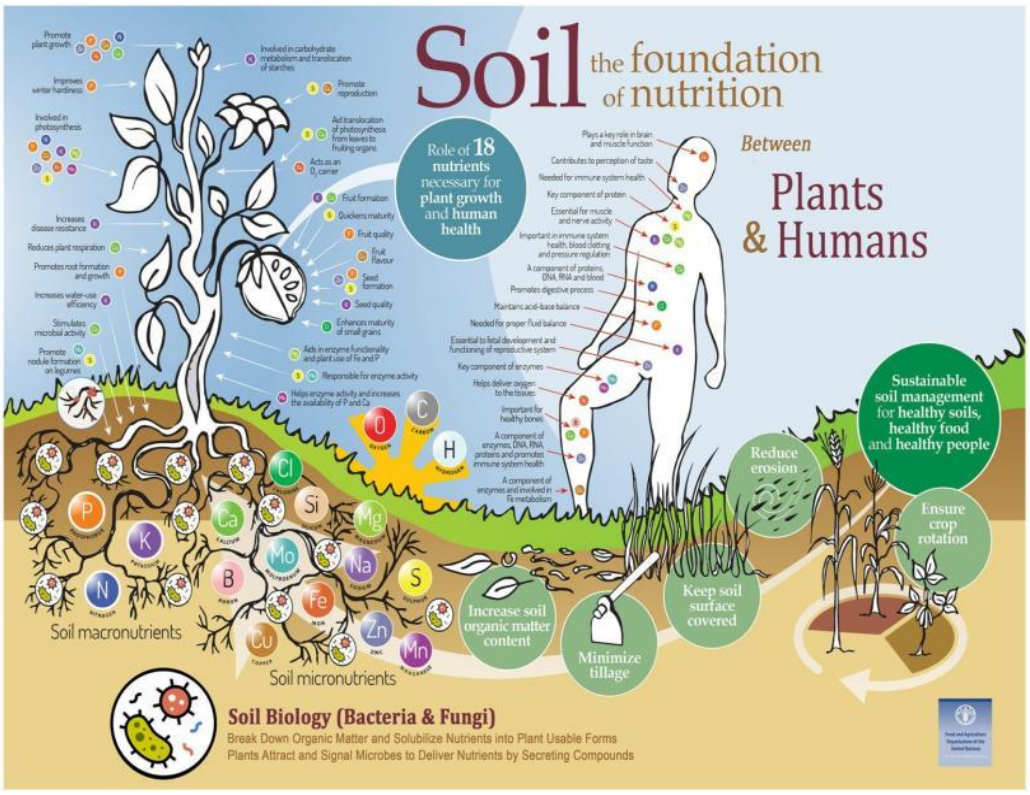


Figure 2.12

SELF ASSESSMENT QUESTIONS

Question No. 1: Define soil science and explain its importance in agriculture.
Question No. 2: Enlist various branches of soil science.
Question No. 3: Differentiate between soil chemistry and soil physics.
Question No. 4: How can you compare soil salinity and soil fertility?
Question No. 5: Differentiate between soil genesis and soil morphology.
Question No. 6: What is the difference between a soil survey and soil classification?
Question No. 7: Define and explain soil conservation.
Question No. 8: Differentiate between soil mineralogy and soil microbiology.
Question No. 9: Define and explain soil biology.

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Unit:3

SOIL FORMING ROCKS AND MINERALS

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INTRODUCTION

This is an introductory unit designed to introduce the concept and significance of various types of rocks and minerals, as well as their classification. This introductory unit covers types of rocks (igneous, sedimentary, metamorphic), classification and properties of minerals, and the significance of rocks and minerals in geology and soil science. Students will gain a foundational understanding of rocks and minerals, setting the stage for further exploration in geology, soil science, and related fields.

OBJECTIVES

This unit is designed to introduce the concept and importance of different types of rocks and minerals with special relation to soil science at the undergraduate level. This unit introduces undergraduate students to:

1. Understand the formation and classification of rocks and minerals.
2. Recognize the role of rocks and minerals in soil formation and fertility.
3. Appreciate the significance of rocks and minerals in soil science and agriculture

LEARNING OUTCOMES

The students will be able to understand the concept and importance of different types of rocks and minerals, with special relation to soil science and their relationship with crop production and the environment. Learning outcomes of this unit will be:

1. Students will understand how rocks and minerals influence soil formation and properties.
2. They will recognize the role of rocks and minerals in nutrient cycling and availability for crops.
3. Students will appreciate the environmental significance of rocks and minerals in soil and ecosystem health.

1. Soil Forming Rock and Minerals

Minerals and rocks are the most common materials on Earth. It is obvious to everyone that mountains are made of rocks, and these rocks are composed of various types of minerals.

2. Mineral

Mineral is a naturally occurring inorganic substance with a definite chemical composition with physical characteristics that are identical or flexible within certain restrictions. It is possible to express the chemical composition of a mineral with a chemical formula (Figure 3.1).



Figure 3.1

3. Types of Minerals

Minerals are of two types

3.1 Primary Minerals

Primary minerals are such minerals that are not changed or altered within their chemical composition or configuration from the time when these were deposited and crystallized from magma/lava (Figure 3.2). e.g., quartz, mica, and feldspar, etc.

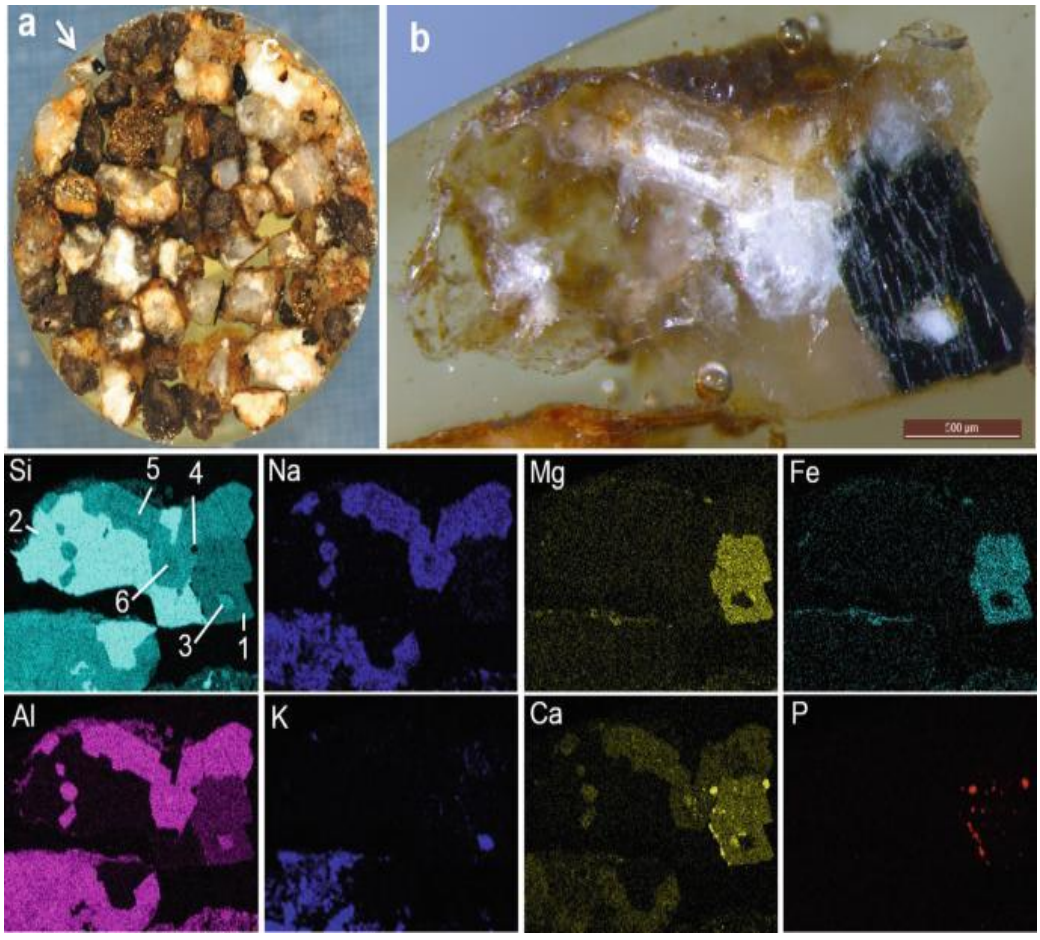


Figure 3.2

3.2 Secondary Minerals

Secondary minerals are formed from the breakdown and disintegration of primary minerals. They result from the precipitation of the decomposed parts of primary minerals (Figure 3.3). e.g., calcite, halite, and gypsum, etc.



Figure 3.3

4. Rocks

Rocks are the most familiar objects of the earth, made up of minerals. Rock is an assembly of many mineral grains. According to geologists, any mass of inorganic substance that forms a fragment of earth is called rock (Figure 3.4). Rock may consist of only one mineral species or an aggregation of many minerals. A rock with having single mineral is called a **monomineralic rock**. The minerals group themselves naturally and assemble to form rocks. These minerals possess definite chemical and physical characteristics with distinct composition and atomic configuration. Rocks are always identified, characterized, and classified based on the types and composition of various minerals that form them.

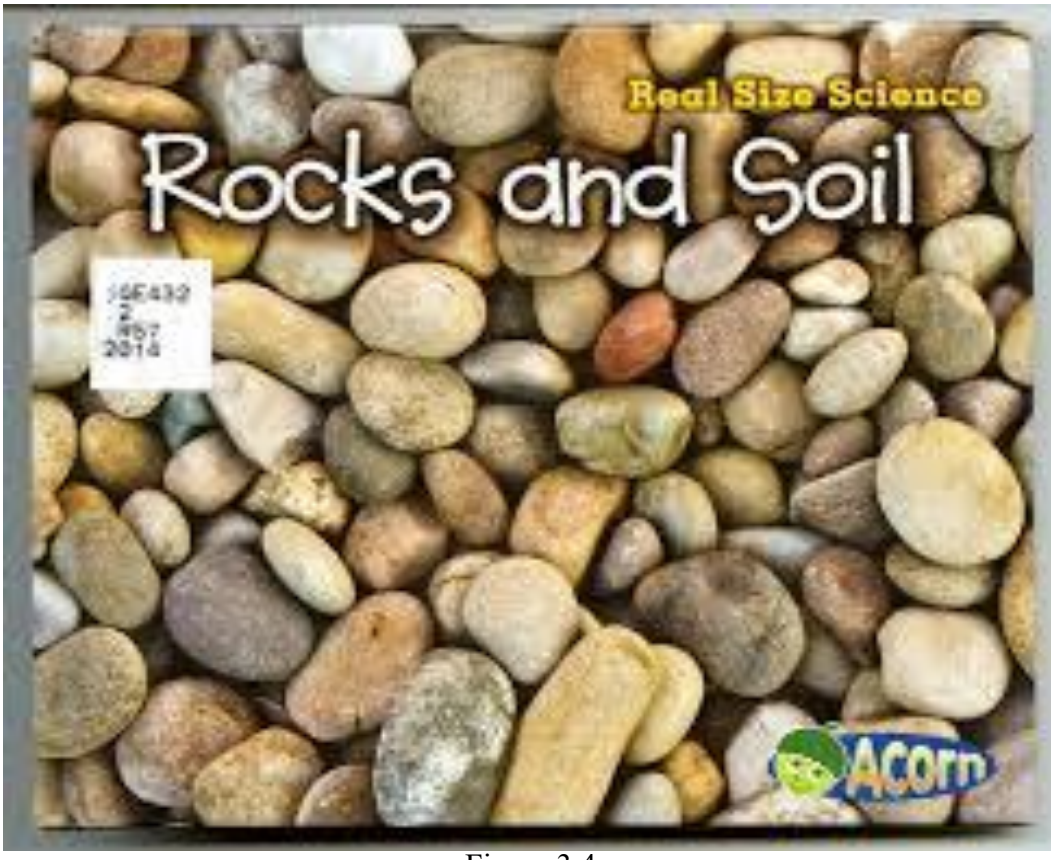


Figure 3.4

5. Significance of Rocks

Rocks are of much significance in natural ecosystems and society.

1. Rocks provide materials which are used for the construction of buildings, roads, and bridges, etc.
2. Rocks are an actual and real source of soil formation. Soils are formed of parent materials derived from different rocks. Weathering of these parent materials leads to soil formation.
3. Rocks are a source of many minerals of economic importance. Among these minerals, some are very costly, like iron, silver, and gold, etc.
4. Rocks presence is mandatory for earth stability.
5. Rocks are a rich source of nutrients for plants. During the process of weathering, a large number of nutrients are released, which are highly valuable for plant growth.
6. Rocks contain many explosive elements, which are used as a source of energy, like uranium.

6. Types/Forms of Rocks

Rocks are normally distributed into 3 main types like igneous rocks, sedimentary rocks, and metamorphic rocks.

6.1 Igneous Rocks

Igneous rocks are made from the chilling and subsequent crystallization of magma/lava material. The origin of the word igneous is from Latin word “ignis” means fire (Figure 3.4). These rocks require quite high temperatures for their formation. The range of desired temperature to form igneous rocks is 700-1200 °C. It covered 64.7% area of the Earth's crust.

Hence, it can be said that these are made from making cold and solidification of tremendously warm materials, which are called magma. These rocks include granite and diorite. These rocks are composed of primary minerals such as quartz, feldspar, and dark colored minerals like biotite and augite. According to geologists, igneous rocks were the first rocks to form on the surface of Earth (Figure 3.5). After many chemical changes, sedimentary and metamorphic rocks developed from igneous rocks.



Figure 3.4



Figure 3.5

Types of Igneous Rocks

a) Intrusive Igneous Rocks

These are also called plutonic igneous rocks. If cooling of magma takes place slowly beneath the Earth's crust, coarse-grained intrusive or plutonic igneous rocks are formed (Figure 3.6). e.g., granite, diorite, etc.



Figure 3.6

b) Extrusive Igneous Rocks

When magma or lava is forced into cooler regions near Earth's surface, it cools very rapidly to form good-grained rocks (Figure 3.7). These rocks formed exterior to the Earth's crust are called extrusive igneous rocks. e.g., basalt, rhyolite, etc.

Extrusive Igneous Rocks



Figure 3.7

Composition of Igneous Rocks

- All igneous rocks contain silica ranging in content from ~45% to ~80%
- Based on the contents of silica, igneous rocks are grouped into the following:
  - ✓ Felsic
  - ✓ Mafic
  - ✓ Intermediate
  - ✓ Ultra

6.2 Sedimentary Rocks

Sedimentary rocks are formed from the deposition and re-cementation of materials that originated from the weathering of other rocks. e.g., quartz and sand formed from the weathering of granite and dumped on the surface of the shoreline or coastline. Later on, this material is changed geologically to constitute a new cemented solid mass known as sandstone (Figure 3.8). Likewise, re-cemented muds/clays are called shale. The confrontation of these rocks to weathering is assessed through their specific main raw materials and binding substances.

Hence, these rocks are made up of elements resulting from earlier present rocks, which are deposited subsequently and transported by streams, waves or tidal currents, wind, or ice. In addition, cementation may result from chemical reactions and precipitation. As solid articles settle out, a layer is formed. When the size of these particles is changed, a series of layers of varied types is formed. Because of pressure, compaction, driving out water, and chemical deposits of $CaCO_3$ or SiO_2, cementing of particles takes place. These layers harden over time into rocks. These cover 7.6% area of the earth's crust out of which 75% are exposed to the process of weathering.

Forms of Sedimentary Rocks

Important forms of sedimentary rocks are discussed below:

a) **Chemical Sedimentary Rocks**

These are also called non-clastic rocks. Many minerals are present in aqueous solution. These minerals undergo a lot of chemical and biological reactions under various agents. As a result of these reactions, these precipitates form new products called chemical sedimentary rocks. An example of these rocks is limestone.

Limestone

- Composed of calcium carbonate ($CaCO_3$)
- $CaCO_3$ produced by tiny marine organisms for shell development
- As organisms die, shells fall to the basin floor, accumulate, and eventually compact to form chemical sedimentary rock (limestone)

b) **Clastic**

Clastic sedimentary rocks are formed when existing rocks are broken down into smaller pieces or fragments due to the weathering process. These fragments of broken pieces are moved and transported from one place to another. At new places, these are settled and cemented through some binding agents. Such a newly formed product is called clastic sedimentary rock. Examples are conglomerate and sandstone.

Conglomerate

- Composed of large particles (pebble size) held within a matrix of finer-grained sediments
- Indicative of a high-energy environment

Sandstone

- Composed mostly of sand-sized particles
- Indicative of a moderate-energy environment

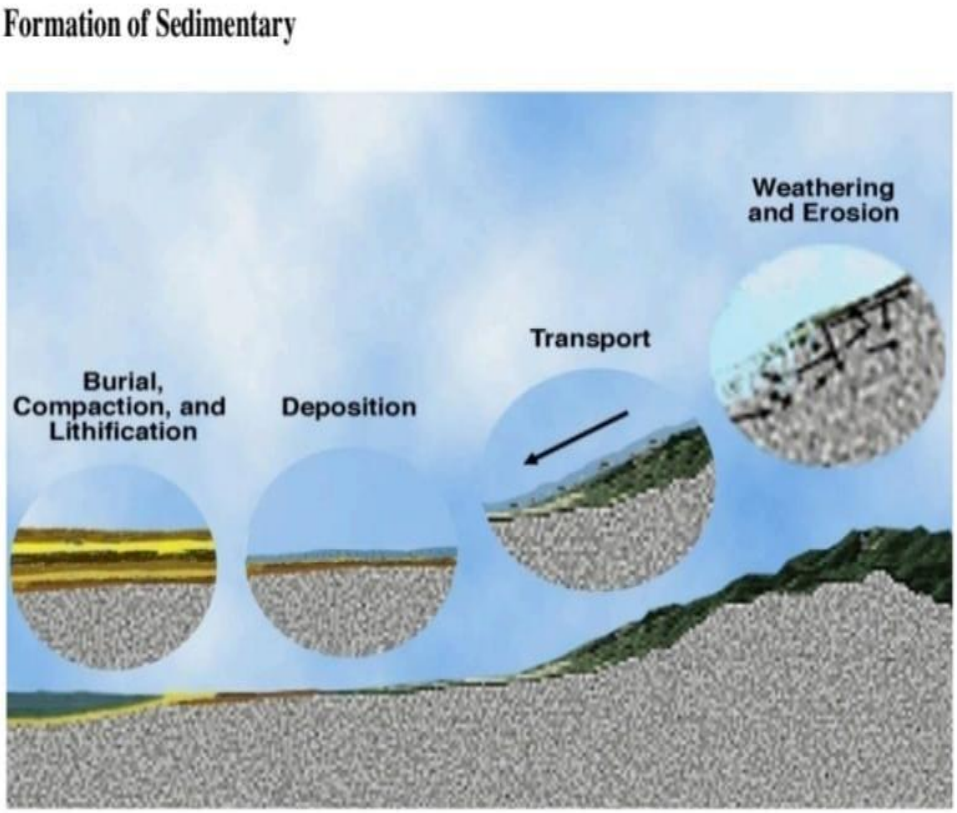


Figure 3.8

6.3 Metamorphic Rocks

These rocks are derived from preexisting igneous or sedimentary rocks by alterations due to tremendous pressure and high temperature. Metamorphic rocks are usually harder and have more compact structures (Figure 3.9). e.g., quartzite and marble. When existing materials of any rock type undergo continuous changes over time, something new is formed. The application of extremely high pressure and heat makes this material stressed. Many new substances also combine with this material, and in this way, metamorphic rocks are formed as a consequence of constant and regular changes.

Hence, these are such rocks that are made through the practice of metamorphism or changes in other rocks. Igneous and sedimentary rocks, when exposed to marvelous pressure and high heat, transform into metamorphic rocks. The method through which these rocks are shaped is called metamorphism. It covers 27.4% area of Earth's crust.

Important Types of Metamorphic Rocks

Metamorphic Rocks are also classified into two types (Figure 3.10).

I. Foliated Metamorphic Rocks: Examples are slate and schist.

Slate

- Composed primarily of tiny mica flakes
- Exhibits very noticeable cleavage (i.e., splits easily into sheets)
- Often confused with shale
- Low-grade metamorphism

Schist

- Platy rocks that can be split into thin flakes
- Commonly has visible sheets of mica
- Moderate-high grade metamorphism

II. Non-Foliated Metamorphic Rocks: Examples are quartzite and marble.

Quartzite

- Formed from sandstone
- Quartz grains fuse under high-grade metamorphic conditions
- Very hard

Marble

- Formed from limestone
- Composed of large interlocking calcite crystals
- Impurities (trace elements) may alter the color

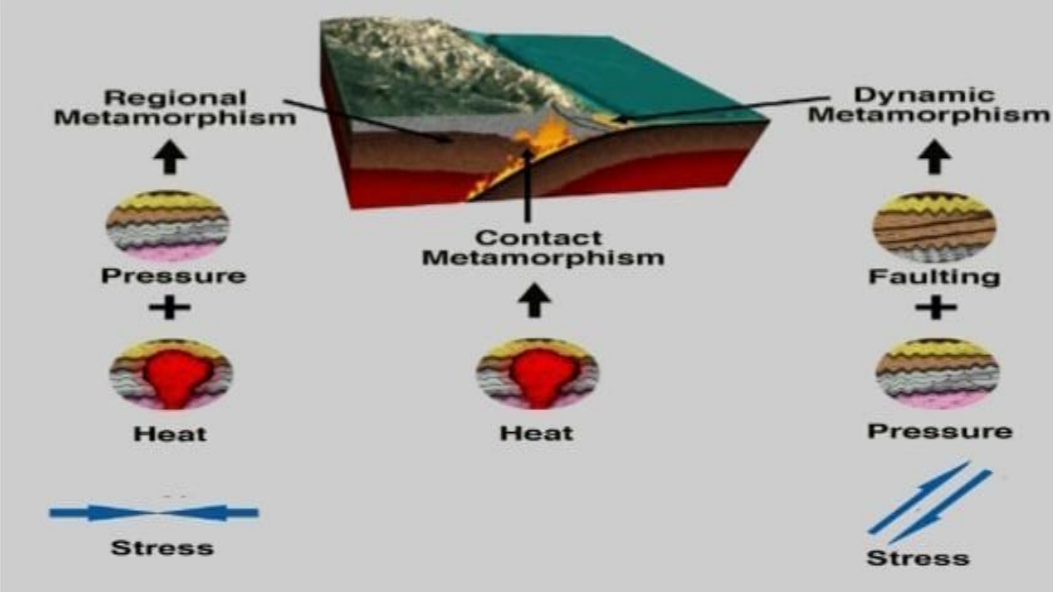


Figure 3.9

Classification of metamorphic Rocks

Rock Name	Texture	Grain Size	Comments	Parent Rock
Slate	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite	Foliated	Fine	Breaks along wavey surfaces, glossy sheen	Slate
Schist	Foliated	Medium to Coarse	Micas dominate, scaly foliation	Phyllite
Gneiss	Foliated	Medium to Coarse	Compositional banding due to segregation of minerals	Schist, granite, or volcanic rocks
Marble	Nonfoliated	Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite	Nonfoliated	Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Anthracite	Nonfoliated	Fine	Shiny black organic rock that may exhibit conchoidal fracture	Bituminous coal

Increasing Metamorphism

Figure 3.10

7. Rock cycle

The rock cycle illustrates the dynamic transformation of the three primary rock types:

i. Igneous (formed from molten magma or lava)
ii. Sedimentary (formed from compressed sediments)
iii. Metamorphic (formed through alteration under heat and pressure)

These transformations occur through geological processes such as:

a) Melting and cooling
b) Weathering and erosion
c) Heat and pressure

Driven by Earth's internal heat and solar energy, the rock cycle continuously reshapes the planet's surface over millions of years.

The rock cycle is a dynamic, continuous process where rocks transform into different types through various geological processes (Figure 3.11). Here's a breakdown:

Rock Cycle Process

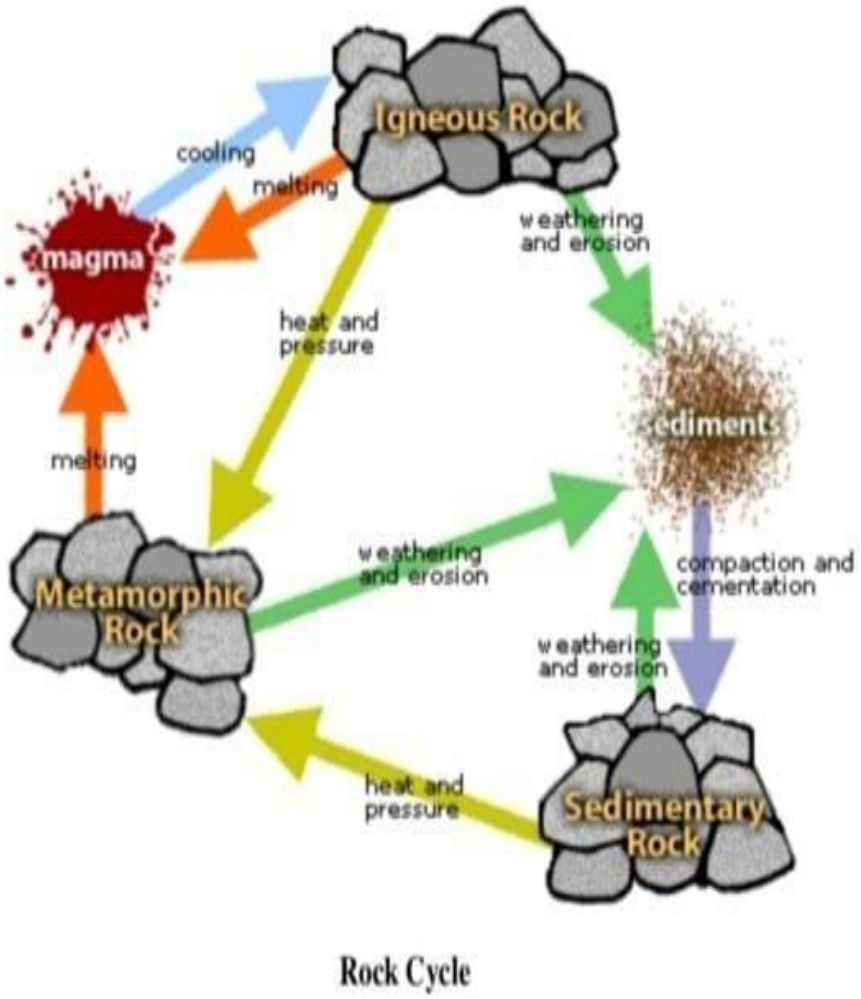
1. **Igneous to Sedimentary**: Igneous rocks are weathered, eroded, and deposited as sediments, which compact and cement to form sedimentary rocks.

2. Sedimentary to Metamorphic: Sedimentary rocks are subjected to heat and pressure, transforming them into metamorphic rocks.

3. Metamorphic to Igneous: Metamorphic rocks can melt, forming magma, which cools and solidifies into new igneous rocks.

- The rock cycle recycles Earth's materials, reshaping the planet's surface and crust.
- It's a continuous process driven by geological forces like heat, pressure, and erosion.
- Rocks can transform into different types and even back into the same type through various geological processes.

The rock cycle plays a crucial role in shaping our planet's geology and landscape over millions of years.



Rock Cycle

Figure 3.11

SELF ASSESSMENT QUESTIONS

Question No. 1: Define a mineral and explain its types.
Question No. 2: Define rocks and explain the significance/importance of rocks.
Question No. 3: Enlist and explain different types of rocks.
Question No. 4: Define igneous rocks and explain the different types of igneous rocks.
Question No. 5: What is the composition of igneous rocks?
Question No. 6: Define sedimentary rocks and explain their various types.
Question No. 7: Define metamorphic rocks and explain their various types.
Question No. 8: Write a short note on the rock cycle.
Question No. 9: Write in detail the processes of the rock cycle.
Question No. 10: Differentiate between rocks and minerals.

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Unit:4

WEATHERING OF ROCKS AND MINERALS

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INTRODUCTION

This unit aims to enable students to understand different types of weathering and its various agents. Further, this unit will enable students to learn about parent material, its types, factors, and mode of formation. This unit will enable students to understand different types of weathering (mechanical, chemical, biological) and various agents of weathering (temperature, water, wind, organisms). This unit will equip students with knowledge regarding parent material and its significance, types of parent material (residual, transported), factors influencing parent material formation, and the mode of formation. By covering these topics, students will gain a comprehensive understanding of weathering and parent material, laying the groundwork for further study in soil science and agriculture.

OBJECTIVES

This unit is designed to introduce the concept of different types of weathering and its various agents. This unit provides foundational knowledge on weathering and parent material, essential for understanding soil science and its applications in agriculture. This unit aims to:

1. Importance of parent material in soil formation
2. Types of parent material (residual, transported)
3. Factors influencing parent material formation
4. Mode of formation

LEARNING OUTCOMES

Students will gain insights into the processes shaping soil formation, fertility, and ecosystem health, ultimately informing sustainable agricultural practices. The students will be able to:

1. Understand the concept of weathering (mechanical, chemical, biological)
2. Identify various agents of weathering (temperature, water, wind, organisms)
3. Recognize the relationship between weathering, crop production, and environmental sustainability
4. Apply knowledge to understand parent material types (residual, transported), factors influencing formation, and mode of formation.

1. Weathering and Soil Formation

Weathering

Weathering is a method of fragmentation and breakdown of rocks and minerals to new constant formulae under distinctive environments. This method changes the inventive rock (parent rock) into soil parental materials. Weathering does not cease after giving rise to parent material; it continues within the soil solum, like A and B horizons, or underneath it in the C horizon. Intensity and nature of reactions vary depending upon conditions of moisture, temperature, and biological activity. Two types of weathering, geochemical and pedochemical, can be recognized during soil development.

Geochemical weathering takes place during rock alteration and below the soil solum.

Pedochemical weathering is the continuous disintegration or alteration/ decomposition of minerals in the soil solum. It is very obvious that weathering is mostly a breakdown practice. Nevertheless, simultaneously, a constructive process or synthesis may take place. Definite elements become free through the process of weathering. These elements can rejoin with others to form secondary minerals, including clays.

Weathering processes include physical, chemical, and biological actions. This division, however, is an academic one, and in nature, these weathering types overlap or operate concurrently.

2. Physical Weathering

Physical weathering is the method through which rocks and minerals are fractured, crushed, crumpled, and expanded. Product of physical weathering is new mass which differs in physical appearance but no or little change in chemical or mineralogical configuration. Factors accountable to physical weathering are overload weight/pressure and cutting pressure (e.g., grinding of particles under an ice sheet), expansion forces due to temperature change and growth of crystals (e.g., ice), animal or plant activity, or water pressure, which may be important in processes controlled by wetting and drying cycles.

These forces produce stress either within the bedrock, causing it to break along fracture and cleavage planes, and usually resulting in large blocks or sheets, or along mineral grains or boundaries, creating the small-sized materials of sand and silt.

Such types of weathering occur due to the activities of various factors on rocks and further movement of these broken materials. It is carried around by the practices of delivery by erosion, expansion of freezing water, or crystallizing salt in cracks along grain boundaries. Agencies that move rocks consist of glacier ice, water movement, the impact of gravitational force, and wind.

Unloading by erosion. Fractures can be formed by the enlargement of rock expansion after the confining forces are reduced through uplift and erosion. Ultimate rock strength is higher under the conditions of increased pressure caused by the overlying rock mass. When the overlying rock mass is decreased by surface erosion, the confining pressure is also decreased. The internal stress then set up in the rock is relieved by elastic expansion of the rock. This expansion eventually causes rupture, and a series of cracks is formed parallel to the surface of the rock.
Crystal growth. Volume changes due to crystal growth set up pressures inside rocks, which go to breakdown and thus constitute a part of physical weathering. These volume changes occur because of the icing of water, mineral development, or chemical alteration of pre-existing minerals.

A. FROST WEATHERING. Water enlarges 9% when it freezes at 0 °C. This great change in volume has a potentially great disruptive effect, and frost-shattering is an important mechanical agent in weathering. When water freezes in a confined space, tremendous pressure is exerted on the enclosing rock. A theoretical pressure of several thousand pounds per square inch is possible at lower temperatures (30,000 Ib/sq in at - 22 °C), which is far greater than the compressive strength of rock. Frost-shattering of rock also takes place in unconfined cracks or crevices.

B. SALT WEATHERING. The growth of salt crystals from solution in porous rocks may lead to the disintegration of these rocks either into blocks or individual grains. Salt weathering causes rock breakup in several ways. (1) Crystal growth from solution creates rupturing pressure. Examples are the crystallization of calcium carbonate and gypsum from saline solution. (2) The thermal expansion properties of crystalline salts are much higher than those of common rocks, and in desert climates where daily temperature fluctuations are extreme, weathering may occur through this process. (3) Volume increase of salts and clay upon hydration creates stress sufficient to disintegrate rocks.

Thermal expansion and contraction. Diurnal fluctuation in surface temperature, if great enough, can cause external cracking or granulated fragmentation of certain rocks. Differential expansion upon heating and shrinkage upon cooling is an important weathering process in heterogeneously composed rocks. With surface temperature fluctuation, each mineral expands and contracts at a different rate, especially in desert and high mountain areas. Some scientists, however, have expressed doubt about the efficacy of weathering by this process. Laboratory experimental evidence is inconclusive because the elastic strength of the granite rock measured was more than the stresses set up by these processes, which did not affect the breakup of the rocks in the experimental setting.
Fire. It is perhaps an imperative cause of physical weathering of rocks in forestry zones. Rocks are not so good at transferring heat; therefore, during fires, very steep temperature gradients develop from the rock surface to its interior. Repeated fires

in forest areas, even after 100 or more years, can weaken the rock surface, and over thousands of years the effects of this process become very significant.
Among the physical weathering processes mentioned above, unloading by erosion and crystal growth are especially significant. Other processes have minor roles in weathering overall; their role in specific environments for some rocks should not be overlooked. Physical weathering contributes to chemical weathering of rocks by reducing particle size, thus increasing specific surface area for chemical reactivity. Sand is produced exclusively by physical weathering, while silt-sized particles are, to a large extent, the products of the same process.

3. Chemical Weathering

Chemical weathering comprises processes that change rocks and minerals that are stable at high temperatures and compressions at Earth's surface.
Different processes responsible for chemical weathering are hydration, hydrolysis, oxidation, reduction, carbonation and solution. The kinds of reactions and combination of reactions in soils depend on environmental factors such as temperature, water content, presence or absence of oxygen, and leaching intensity.
Solution and Carbonation: In rock soil organization, water plays the main role as being universal solvent. The solution impact of water on rock minerals depends on the water due to its dipole property that quickly permits the suspension of ionic entities like salts of sodium, potassium, and magnesium with chlorides and sulfates to produce a stable ionic solution. Gypsum is less soluble, while $CaCO_3$, and SiO_2 are sparingly soluble. Solubility of some elements, such as iron and manganese, depends upon redox potential, while that of silica is to some extent pH dependent (much higher at pH above 9). Water is never pure in a weathering system, and nearly all the substances are soluble to varying degrees. The activity of H_2O is augmented by the existence of CO_2 to produce H_2CO_3. The effect of H_2CO_3 is especially effective on limestones. The carbonic acid-containing water dissolves $CaCO_3$ readily in the reaction:

$$\mathbf{CaCO_3 + H_2CO_3 \rightarrow Ca(HCO_3)_2}$$

The effect of the partial CO_2 pressure of the atmosphere on the dissolution of limestone indicates that the solubility of $CaCO_3$ increases markedly (2-18 times) with increasing CO_2 content (up to 100%) of the atmosphere.
The power of water is more amplified by the existence of organic and various acids. It then becomes one of the most potent factors in the decomposition of rocks, provided the water is continuously renewed. Mineral contents of spring water, well water, and flowing rivers confirm the dissolving power of water whenever it comes in contact with solid material. Over geological time, the ocean water has become too saline (35 g L^{-1}) for drinking or irrigation purposes.

4. Processes of Chemical Weathering

4.1 Hydrolysis: Hydrolysis is an imperative practice in the chemical weathering of alumino-silicates, general rock-forming minerals. It is a chemical reaction in a mineral and H_2O. Actually, hydrolysis is the attack of an acid in water on a mineral. Common acids are carbonic acid and other acid byproducts of the decay of organic matter. In hydrolysis, cations that are part of the crystal lattice of alumino-silicate minerals are replaced by $H^+(H_3O^+)$, with resulting distortion and disintegration of the mineral structure. Simultaneously, H_2O dissociates into H^+ and OH^- ions, which then combine with Al, Si, O, and OH on the mineral surface, breaking the Si-O and Al-O bonds. Common byproducts are H_4SiO_4, HCO_3, OH^-, and cations, along with clay minerals if conditions are favorable. The silicic acids formed are partly leached, recombined with Al, or further decomposed. A general reaction is:

Alumino-silicate $+H_2O$ $+H^+$(from acids) → Clay Mineral +Cations $+OH^-$ $+HCO_3^-$ $+H_4SiO_4$

A specific example is the hydrolysis of orthoclase.

$$KAlSi_3O_8 + HOH \rightarrow HAlSi_3O_8 + KOH \qquad \textbf{(i)}$$

The formation of KOH can be recognized by the fact that an aqueous suspension of orthoclase powder reacts alkaline. The alumino-silicate formed is unstable, and hydrolyzes further, changing either into a kaolinite or into silica and aluminum hydroxide as given below:

$$2HAlSi_3O_3 + HOH \rightarrow Al_2Si_2O_5(OH)_4 + SiO_2 \qquad \textbf{(ii)}$$

Kaolinite

or

$$HAlSi_3O_8 + HOH \rightarrow Al(OH)_3 + 3SiO_2 \qquad \textbf{(iii)}$$

The crystal lattice of orthoclase is completely decomposed. Potassium in mica is gradually displaced by H, and after complete removal of K, mica decomposes, however, very slowly. The alteration of ferromagnetic minerals most commonly occurs through simultaneously occurring hydrolysis and oxidation.

4.2 Oxidation: From the point of view of simple weathering, the term oxidation describes the reaction of any element with oxygen to produce its oxides. When water is also combined, then the reaction is called hydrolysis. In a strict sense, oxidation means the loss of electrons. Oxidation affects especially the Fe (I) and Mn (II) containing minerals, mainly ferromagnetic ones. The oxidation of iron alters the structure of such minerals, causing disintegrative weathering. Oxidation of Fe^{2+} to Fe^{3+} dislocates the electrostatic detachment of the crystal. Pure oxidation is represented by the transformation of magnetite to hematite in the presence of air.

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

Hydrolysis results in the weathering of Fe^{2+} containing minerals and discharge of soluble Fe^{2+}, along with other byproducts. Then, in the presence of oxygen, Fe^{2+} is

converted into Fe^{3+}; thus, oxidation follows the hydrolysis process, as in the oxidation of olivine.

$$Fe_2SiO_4 + 2H_2CO_3 + 2H_2O \rightarrow 2Fe^{2+} + 2HCO^{3-} + H_4SiO_4 + 2OH^-$$

(hydrolysis)

$$2Fe^{2+} + 4HCO^{-3} + ½O_2 + 2H_2O \rightarrow Fe_2O_3 + 4H_2CO_3$$

(oxidation)

Similarly, ilmenite weathers into goethite and rutile.

$$4FeTiO_3 + O_2 + 2H_2O \rightarrow 4FeOOH + 4TiO_2$$

Pyrite, frequently present in acid rocks, is oxidized into goethite and sulfuric acid.

$$4FeS_2 + 15O_2 + 10H_2O \rightarrow 4FeOOH + 8H_2SO_4$$

4.3 Reduction: Reduction, the gain of electrons, is the opposite of oxidation and takes place in geochemical environments where the material remains saturated with water. In this case, the biological oxygen demand (BOD) is more, but its supply is less. Where seasonal wetting and drying are the climatic pattern, soils often undergo many oxidation-reduction cycles during formation; in waterlogged conditions, on the other hand, they remain in a permanently reduced anaerobic state. Iron and polyvalent elements are reduced to more soluble and mobile forms, which either react to form sulfides or are likely to be lost by leaching. Reduction of Fe^{3+} to Fe^{2+} conveys typical green and blue-green colors to various reduced substances.

4.4 Hydration: It is the relationship of water and a mineral, deprived of definite disintegration or alteration of the mineral itself. Sorption of water particles mainly occurs on the external surfaces of minerals, besides the cracked boundaries of silicate minerals. Dehydration, the exclusion of water, is the inverse of hydration. An example of a hydration-dehydration phenomenon is the development of gypsum and anhydrite by the addition or elimination of water, respectively.

$$CaSO_4 + 2H_2O \rightarrow CaSO_4 + 2H_2O$$

Anhydrite Gypsum

Another example is the conversion of hematite to goethite.

$$Fe_2O_3 + H_2O \rightarrow 2FeOOH$$

Hematite Goethite

Gibbsite ($Al_2O_3.3H_2O$) is a hydrated mineral of Al_2O_3. Muscovite easily converts into hydro muscovite.

Hydration is an example of an exothermic chemical reaction, which encompasses a significant volume change (average 50%). This situation or condition is essential

for physical weathering. The sorbed water in silicate minerals permits the entrance of hydronium (H_3O^+) ions to violate the configuration of minerals. Thus, hydration prepares the mineral surface for oxidation and hydrolysis practices.

5. Biotic/Biological Weathering

When physical and chemical weathering takes place through certain biological agents, it is called biotic or biological weathering. In this case, plants, animals, and microorganisms play their role to accelerate the disintegration of minerals. Physical effects are produced especially by crop roots, which enter into the cracks and crevices of rocks. Pressure exerted by roots as they grow is occasionally capable of breaking the rock, or causing broader crashes. Lichen (a symbiotic association of algae and fungi) rising on rock surfaces also adds to physical weathering. Loose mineral and rock particles are attached to the underside of lichens and are pulled away from the surface when the lichens contract during dry conditions. Large plants covering the surface of a rock alter the micro environment by alleviating the surface and monitoring temperature and soil erosion.

6. Parent Material

Parent material is the result and product of weathering processes. It is the material from which soil is developed. Hence, it can be defined as unconsolidated/free material which is more or less weathered and is composed of minerals and organic fraction from which the solum of earth is established through various processes of soil genesis.

7. Classification of Parent Material

Basically, parent material is classified into two groups/classes.

1. **Residual parent material**
   Parent material is called residual type if it is found at the original site of its formation without any further movement. Hence, if parent material is deposited at its original state/site of production, it is known as residual parent material.
2. **Transported parent material**
   Parent material is considered transported when it moves from its original site of formation and is deposited after some movement somewhere else. In this class, parent material is moved and transported from one place to another under the action of some agents like water, gravity, wind, and ice, etc.

8. Classification of Transported Parent Material

Transported parent material is classified into four classes based on transportation agents like gravity, water, ice, and wind.

8.1 Parent material transported under the force of gravity
8.2 Parent material transported under the force of water
8.3 Parent material transported under the force of ice
8.4 Parent material transported under the force of wind

A brief description of all four classes is given below:

8.1 Parent material transported under the force of gravity (Colluvium)

When parent material moves under the force of gravity, it is called colluvium. Hence, when the dominant transport agency is gravity, the material is called colluvium. e.g., if 30% material is moved by water, wind, and ice but 70% under the force of gravity, it will be known as colluvium. Sometimes it is also called colluvial debris. Its important characteristics are given below:

1. Colluvial debris is composed of rock trash separated from elevations above. Then this is moved down the slope by the force of gravity.
2. This material is mainly formed as a result of physical weathering. Therefore, it is generally stony and coarse in nature.
3. Due to roughness and stony format, soils developed from this material have little agricultural importance.
4. However, some useful and grazing lands in every mountainous region have colluvial materials.

8.2 Parent material transported under the force of water (Alluvial)

When parent material is moving under the action of flowing water, it is called alluvial. e.g., if 30% material is moved by gravity, wind, and ice but 70% under the force of water, it will be known as alluvial.

Classification of Alluvial Material

Alluvial material is of three types.

1. Flood Plains

Streams commonly overflow their banks and flood the surrounding area. A portion of a valley that is drowned by floodwater is called a flood plain. Residues moved by the enlarged watercourse are placed through the flood. In this case, coarse materials are left down near the river passage and finer materials for their away. The nutrients derived from the sediments are generally rich in nutrients. However, these might require drainage and shelter from overflow. Correspondingly, useful soils originate in the valleys of many countries. Some of these floodplain deposits are used for the wetland rice.

2. Alluvial Fans

Stream leaving a thin valley in a highland zone and quickly inclining to an abundant, larger valley beneath settled deposits in the gradient of a fan. This material is commonly stony and rough in nature. Some of it may be porous and show good drainage. Such fans are present on big extent in mountains and mountainous areas. Soils resulting from such remains are often show very productive/useful.

3. Delta Deposits

A lot of fine sediments moved by watercourses are not placed in the flood plains. These are settled into the stream basin or sea. More or less deposited material accumulates near the entrance of the waterway, making a delta. These are found very rarely and are a continuation of floodplains. It is clayey in nature. A river delta is formed from the deposition of sediments carried by a river and enters slower-moving standing water. This happens when a river enters a sea, ocean, or lake, etc.

8.3 Parent material transported under the force of ice (Glacial Deposits)

When parent material is moving under the action of ice accompanied by water, it is called glacial deposits.

8.4 Parent material transported under the force of wind (Aeolian)

When parent material is moving under the action of blowing wind, it is called aeolian. Parent materials conveyed by wind are classified as dune sand, loess, and aerosolic dust.

1. Dune Sand

These are fine grains of sand which are found on the beaches of the world's oceans. These are picked up through strong winds.

2. Loess

It is the material mainly blown and moved by wind. It comprised mostly silt particles with some fine nature of sand and coarse clay. It can move hundreds of kilometers by wind.

3. Aerosolic Dust

These are very fine particles blown by the wind and can move up to thousands of kilometers. These are normally settled with rainfall. As these particles remain suspended in the air for a long time, so are called aerosolic dust.

9. Marine Sediments

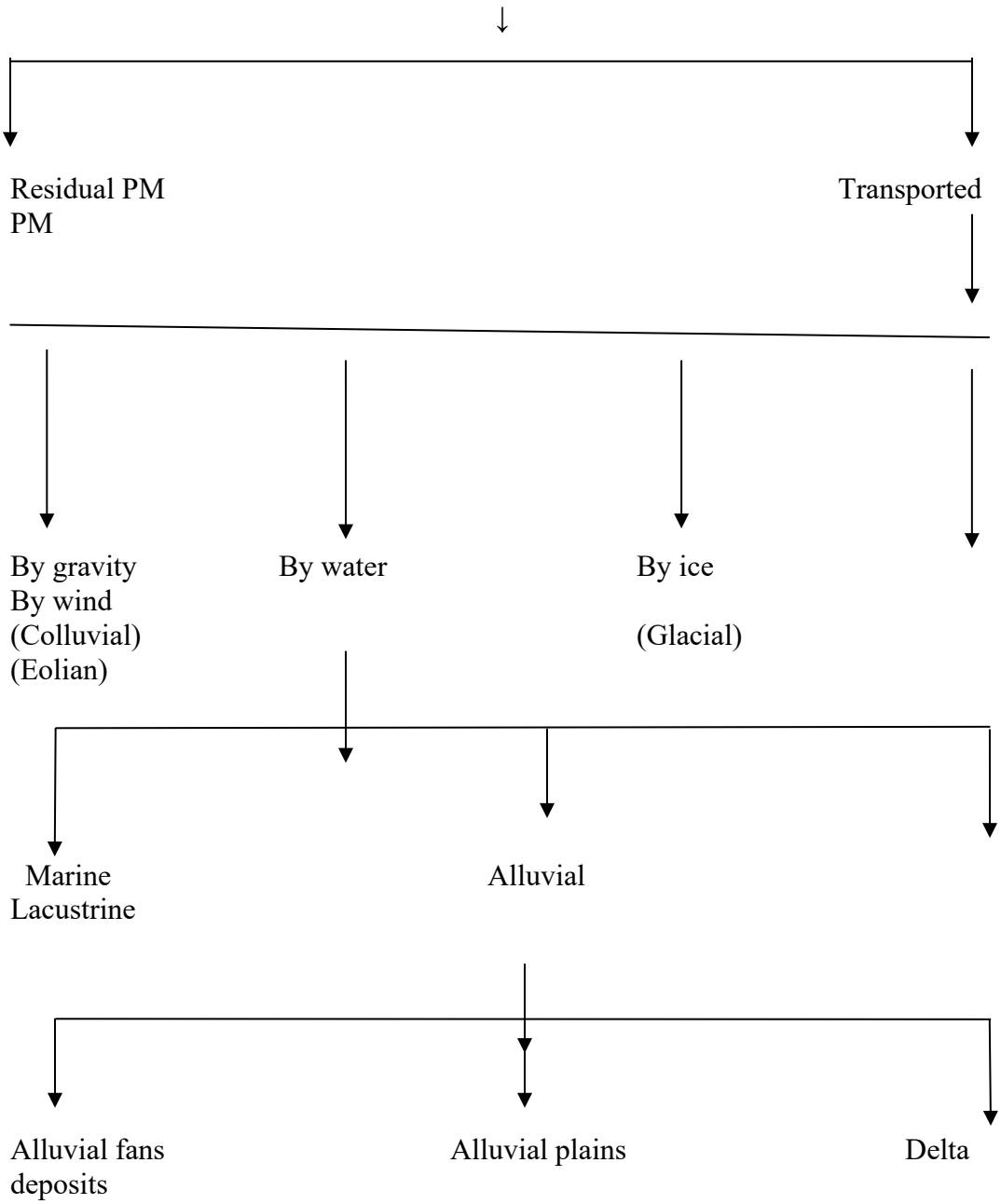
A considerable portion of the deposits moved by streams is eventually placed in water sources (oceans, seas, gulf, and lakes). Coarser fragments are deposited near

the shoreline, while finer quality particles settle farther away. After some time, under water deposits are formed which may develop somewhat deep. These deposits are then subjected to weathering and to soil formation, giving rise to valuable agricultural soils in some cases. These deposits are reasonably different in texture. Some of these deposits are sandy, while others are rich in clay. With proper management and fertilization, soils developed on certain marine deposits can be quite productive.

10. Lacustrine Deposits

Lacustrine deposits refer to the sedimentary layers that accumulate in lake environments, often consisting of clay, silt, sand, and organic materials. These deposits are crucial for understanding past climates and ecosystems, as they preserve fossils and other geological records. Materials in lakes are deposited by water and wind from the surrounding upland areas. So nature of these deposits is generally unleached and requires drainage before cultivation can be carried out.

11. Classification of Parent Materials



SELF ASSESSMENT QUESTIONS

Question No. 1: Define weathering. Also differentiate between geochemical weathering and pedochemical weathering.

Question No. 2: Define and explain physical weathering.

Question No. 3: Differentiate between frost and salt weathering.

Question No. 4: Define chemical weathering. Also, explain the different processes responsible for chemical weathering.

Question No. 5: Enlist and explain various processes of chemical weathering.

Question No. 6: Differentiate between hydrolysis and hydration of chemical weathering.

Question No. 7: Differentiate between oxidation and reduction of chemical weathering.

Question No. 8: Write a short note on biotic/biological weathering.

Question No. 9: Define parent material. Also, write different basic classes of parent material.

Question No. 10: Describe the classification of transported parent material.

Question No. 11: Differentiate between colluvial and alluvial types of parent materials.

Question No. 12: Define alluvial parent material. Also, write a classification of alluvial parent materials.

Question No. 13: Differentiate between glacial deposits and aeolian types of parent materials.

Question No. 14: Differentiate between marine sediments and lacustrine deposits.

Question No. 15: What do you understand by aeolian and its classes?

Question No. 16: Sketch the systemic classification of parent materials.

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Unit:5

SOIL FORMATION

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INTRODUCTION

This unit is based on a morphogenetic system that utilizes both quantitative factors and soil genesis themes and assumptions to guide soil groupings. Factors and processes of soil formation, interpretative soil morphology, local pedogenic processes, and an introduction to the USDA soil classification system will be discussed in this unit. The students will be able to understand and describe morphological features and taxonomic relations of different soils. Soil genesis, with special reference to soil-forming factors, time, parent material, topography, climate, and organisms, is the main course content. The students will know how the properties of soils affect their uses, and be able to evaluate alternative treatments, amendments, and/or location of different uses of soil/substrate.

OBJECTIVES

Students will gain insights into soil formation, morphology, and classification, enabling them to better understand soil science and its applications in agriculture and environmental management. This unit aims to:

1. Understand factors and processes of soil formation
2. Interpret soil morphology
3. Recognize local pedogenic processes

LEARNING OUTCOMES

This unit will enable students to understand and describe morphological features and taxonomic relations of different soils. This unit will provide students with a comprehensive understanding of soil characteristics and classification. Students will be able to:

1. Understand the morphological features of different soils
2. Describe taxonomic relations between various soils
3. Apply knowledge of soil morphology and taxonomy in soil science and agriculture

1. Soil Formation

It deals with the manufacture of parent material by means of weathering processes and the subsequent development of the soil profile. In fact, both these processes of weathering and changes within the soil mass occur instantaneously.

2. Processes of Soil Formation

Basically, the following four processes are involved in all changes that occur during soil formation, as shown in Figures 5.1 and 5.2.

2.1 Additions
2.2 Losses
2.3 Transformation
2.4 Translocation

A brief description of all these processes is given below:

2.1 Additions

Additions means adding something. These additions are done through water, either rainfall or irrigation, nitrogen through fixation by bacteria, energy as sunlight, sediments from wind or water, salts, organic substances/residues, and fertilizers of different types (Figure 5.3).

2.2 Losses

Losses mean the removal of something. Losses may result from different chemicals, which are solubilized in soil water, erosion of soil particles, nutrients in harvested plants, removal of water, and carbon depletion in the form of CO_2 and nitrogen losses (Figure 5.4).

2.3 Transformation

Transformation may take place because of numerous chemical and biological reactions which disintegrate organic matter, form insoluble constituents from soluble elements, and change or dissolve some mineral deposits (Figure 5.5).

2.4 Translocation

Translocation means the movement of water and many creatures within the soil body. Numerous elements are translocated within the soil to various depths. e.g., clay to deeper depths, soluble salts to the soil surface after evaporation of water (Figure 5.5).

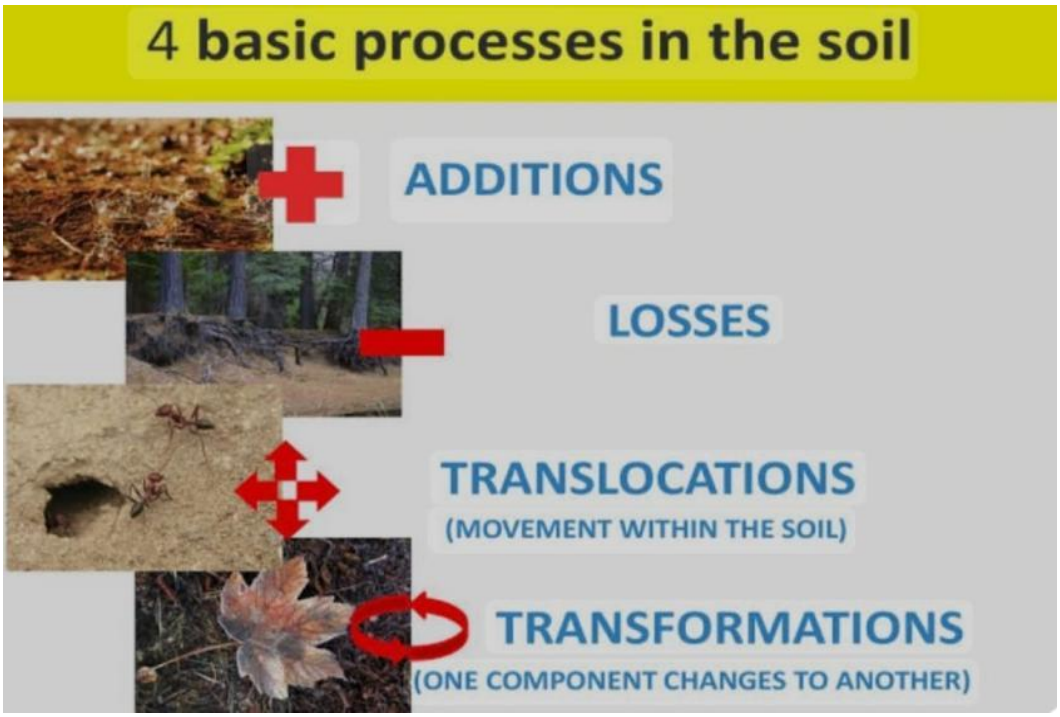


Figure 5.1



Figure 5.2



Figure 5.3

Losses



Figure 5.4

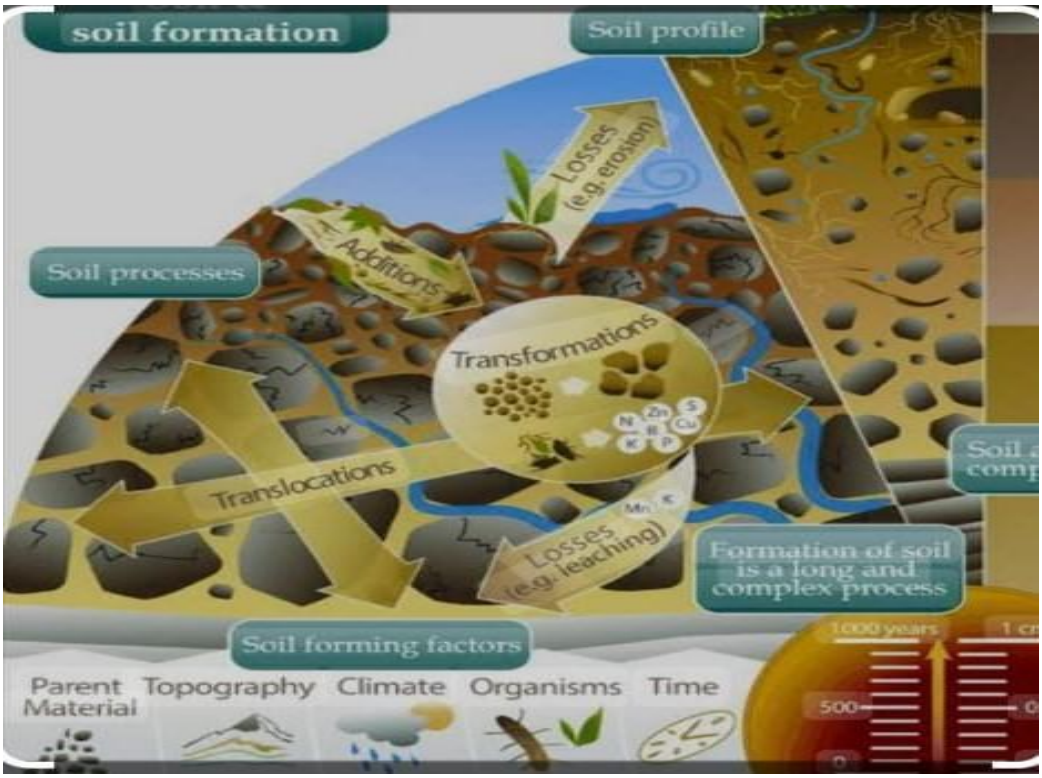


Figure 5.5

3. Various Factors of Soil Formation

Soil formation/development is a miscellaneous and multifaceted procedure that is affected by several factors occurring in combination with each other. Factors of soil formation can be defined as variables that are usually related to some natural agencies, which are dynamic in nature and accountable for soil formation.

These factors of soil formation are grouped into 5 major categories listed below and shown in Figure 5.6:

3.1 Climate
3.2 Parent Material
3.3 Living Organisms
3.4 Topography
3.5 Time

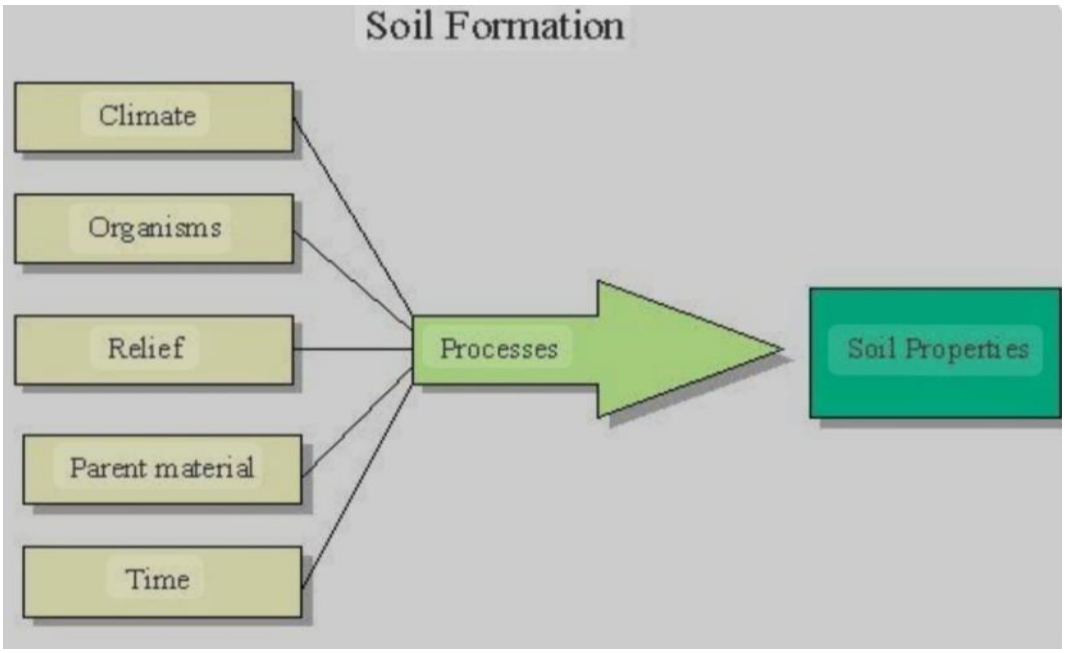


Figure 5.6

All these factors of soil formation are discussed one by one in the given section.

3.1 Climate

It is an increasingly dominant factor in soil formation mechanisms due to its impact on rainfall, temperature, and winds. All these components of climate or sub-factors have their significant impact on proportions of chemical, physical, and biological practices which are accountable for the formation of soil profile (Figure 5.7). A brief detail of these components is given below:

I. Temperature

Temperature plays its significant role in all processes (physical, chemical, biochemical, and biological) occurring in soil. All biochemical alterations are sensitive to temperature. These changes/alterations are favored by a wide range of temperatures. This range extends from 20-30 degrees Celsius. Temperature also affects the contents of carbon-based material in the soil. The decomposition of this material is greater at higher temperatures as compared to lower ones. e.g., organic matter is generally lower in the soils of dry areas such as those found in Pakistan.

II. Moisture

Water or moisture remains a significant cause of soil formation. Rainfall is the main source of providing moisture. In regions of less rainfall, there is a low concentration of carbonates in the soil. On the other hand, in humid regions having high rainfall, acid soils are formed under

conditions of intense weathering and leaching. Erosion caused by water may remove the upper portion of soils and may deposit it in some other place. Hence, a soil is called "developed" after this has visible and distinguished horizons. e.g., clays, organic colloids, or soluble salts transported through water.

III. Wind

It can affect the soil development process through erosion. Wind can lessen the depth of soil developed, and it can damage lower vegetation. e.g., in sandy areas like Cholistan, destruction impacts of wind destruction are much pronounced and prominent.

IV. Vegetation

Climate also affects the natural vegetation of any location. In humid regions, high rainfall delivers a favorable environment for plant growth. In contrast, grasslands are dominant native vegetation in semi-arid regions, while shrubs of different types in arid regions. In these regions, vegetation is not dense enough to protect the soil from wind and water erosion.

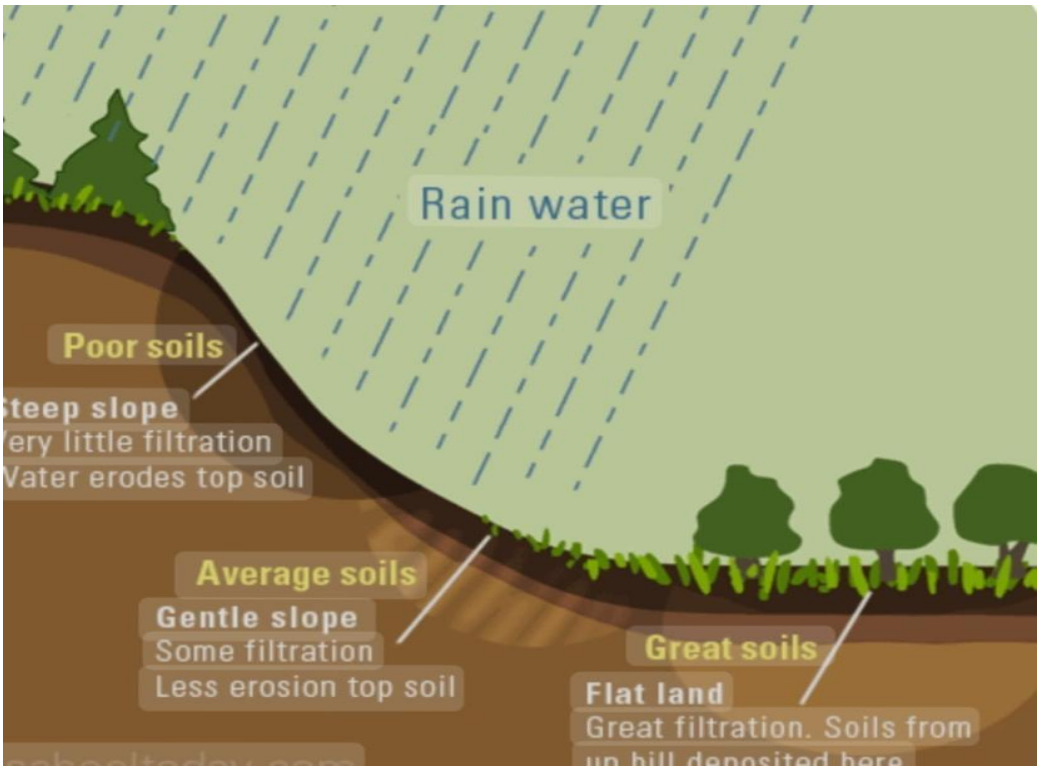


Figure 5.7

3.2 Parent Material

Soil characteristics are mainly affected by the nature and types of parent material. Parent material affects the process of soil formation through:

i. their different rates of weathering
ii. concentration of nutrients it contains for the utilization of plants
iii. size of different soil individual particles. e.g., sandstone results in sandy soils, conglomerate in rocky and shales in clayey soils.

Parent material will have a greater impact on soil properties when a soil is less developed and vice versa. However, characteristics of well-developed soils are also much affected by the type and nature of parent materials (Figure 5.8). When parent material is different, all soils at the lowest category of soil classification (soil series) are grouped into separate series.

Parent material can be prominent in determining or assessing soil characteristics. e.g., soil formed from weakly cemented sandstones is differentiated as sandy, and soils from shale are considered to be fine-textured. It also affects the amount and kind of different clay minerals found in any soil profile. e.g., soils developed or formed from potassium-enriched parent material can have **illite** as a prominent clay mineral.

3.3 Living Organisms

Soil formation processes are greatly affected by the activities of all living organisms, like plants and animals. Residues and organic wastes of different types, originating from the decomposition of these organisms, also have a marked effect on soil development. Soil living organisms have a vital role in the differentiation of profile, the buildup of organic matter, profile mingling, cycles of different nutrients, and structural stabilities. Living organisms present in soil affect all these factors. The existence of burrowing animals like moles, earthworms, termites, and ants in sufficient amounts is of much significance for soil development. Soils having these animals in large numbers have fewer but deeper horizons/layers due to constant mixing within the soil profile

Various types of microorganisms found in the soil attack plant and animal residues and produce different types of organic substances. These substances, in combination with plant roots, are helpful in binding soil particles for stable aggregates. Similarly, some of the microorganisms may fix nitrogen from the atmosphere into common usable compounds by the plants. It enhances nitrogen contents in the soil (Figure 5.9).

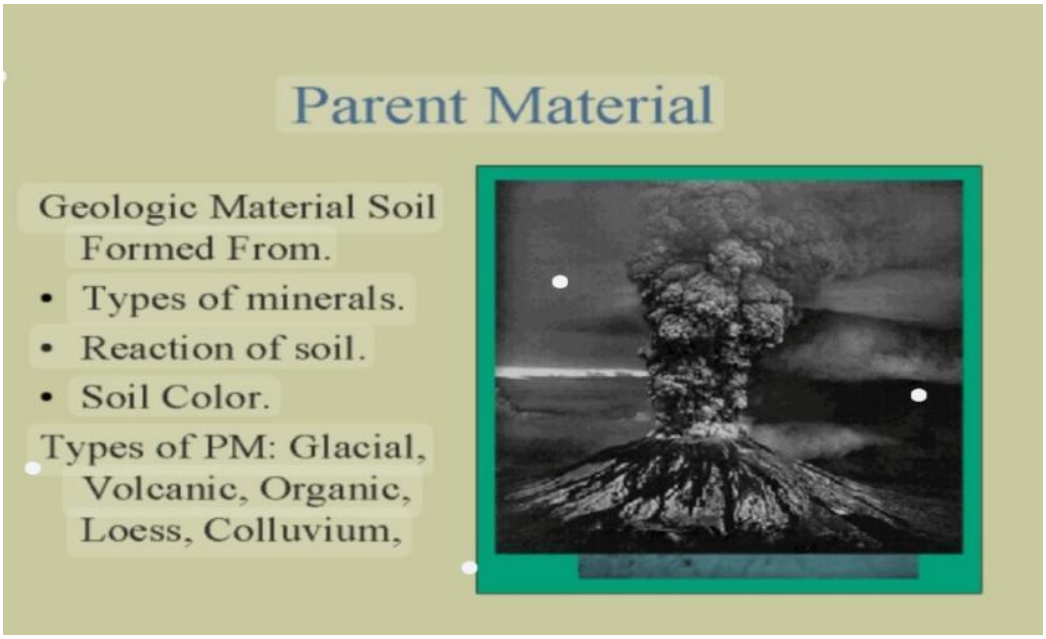


Figure 5.8

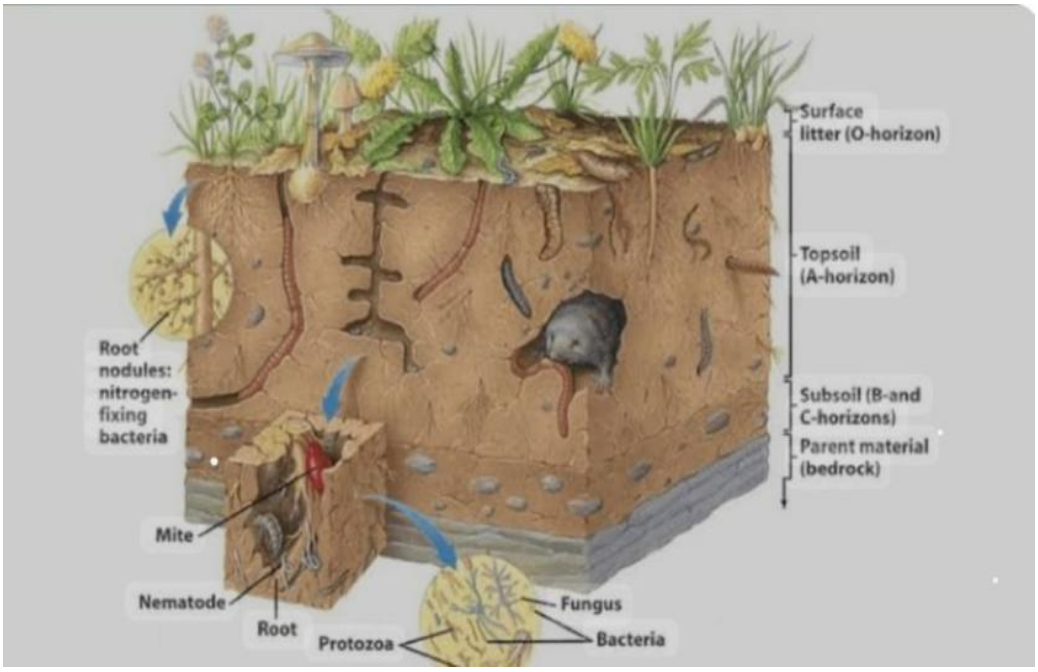


Figure 5.9

3.4 Topography

The contour of the earth's surface is called topography, which is also known as relief. Topography refers to the formation of the land surface and is defined in terms of variations in elevation, slope, and related features.

Features of any land may accelerate or postpone the working capabilities of environmental factors. In case of smooth and flat surfaces, excessive water is removed less quickly as compared to areas having steep slopes. Topography having steep slopes encourages natural erosion of soil surfaces, which decreases the possibility of development or formation of a deep soil. On the other hand, if water remains standing for a long time, depression can form deposition of salts after water evaporation.

Topography also determines the kind and content of vegetation. e.g., in the northern hemisphere, high plants and more vegetation are found on north-facing slopes. But scarce, small, and less shrubs are found on the southern face slopes. Slopes may be of convex or concave types.

Convex Slope: Soil formation is minimal

Concave Slope: Soil formation is maximum

3.5 Time

Duration and extent of time to things that are exposed to weathering and necessary changes occurring in the soil mass can affect the soil formation process. Time required for a specific soil to grow into distinct and distinguished layers or horizons depends on all four other factors of soil formation like environment, type of parent material, living organisms, and structure. Soil layers have a tendency to improve much quickly when the climate is warm, humid, and forested. In this situation, there is sufficient water available to transfer or move clays, humus, and other similar colloids downward through the soil depth. Under an ideal situation, a recognized soil profile can form within about 200 years. On the other hand, when conditions are less favorable, this time can prolong to many thousands of years (Figure 5.10).



Figure 5.10

4. **Soil Morphology**

It remains the optical reflection of different soil characteristics like soil structure, shapes, and arrangement of soil constituents in any soil profile. Comprehensive morphological interpretations can be capable by the usage of different stages of evaluation (Figures 5.11 and 5.12). It may remain prominent in the ground by nude eye (macro morphology), through the assistance of a hand lens and a binocular stereoscope (meso morphology), and by means of electron microscopy-3D (called micro morphology).

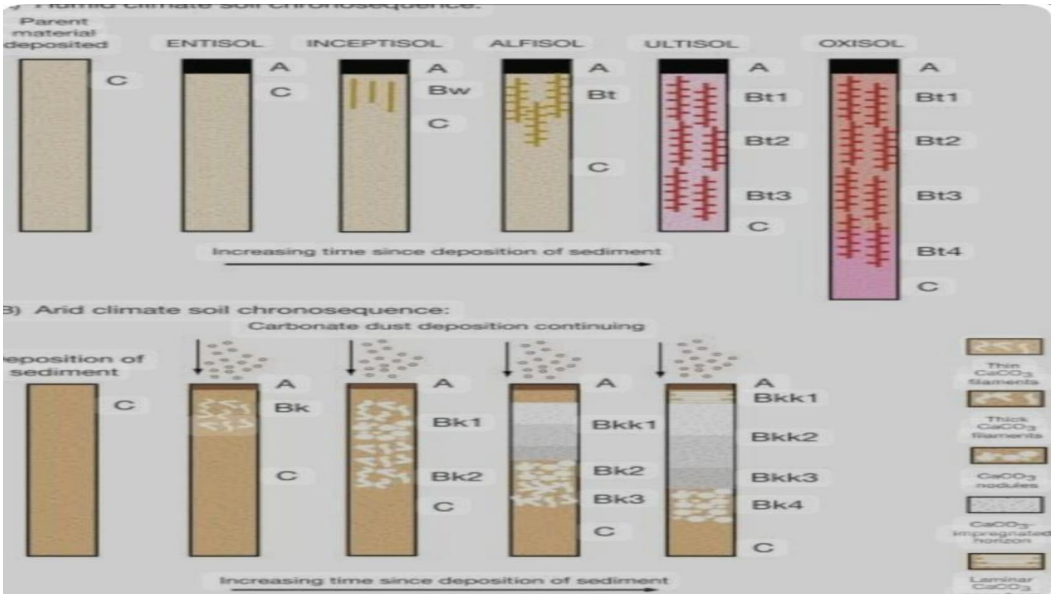


Figure 5.11

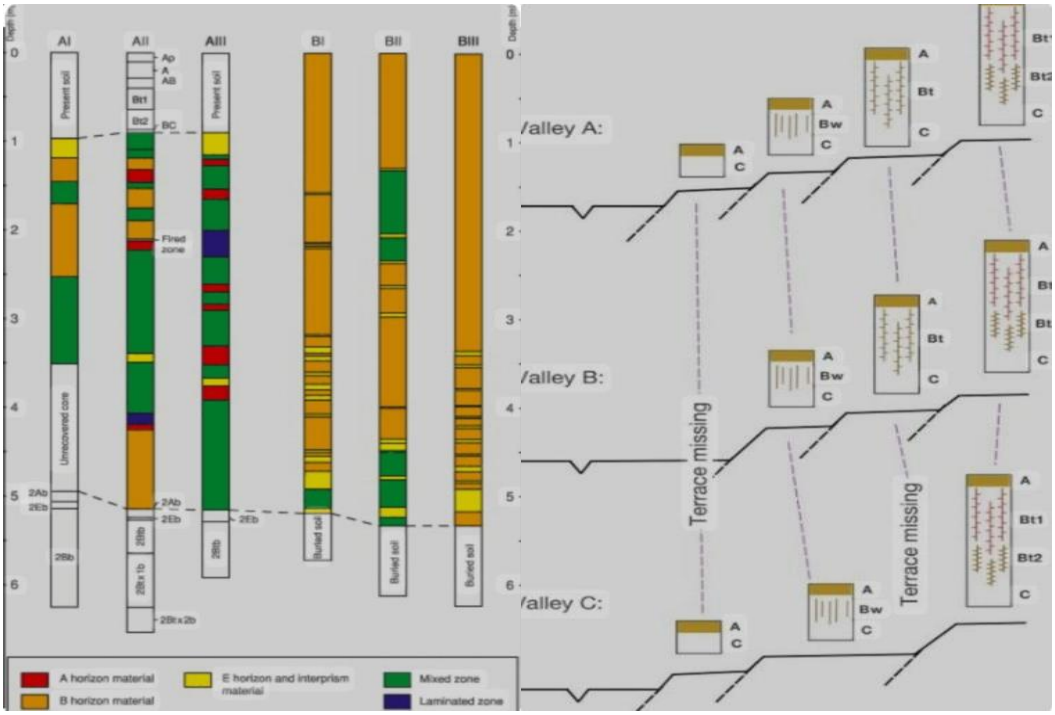


Figure 5.12

5. Soil Profile

It is a vertical section of soil through its different horizons, which are extended into the C horizon. So, profile is the appearance of soil from a vertical section.

6. Description of Typical Soil Profile

The general order of horizons or layers present within a profile consists of 5 master horizons. These master horizons are labeled as O, A, E, B, and C or R (parent rock). All five master horizons are differentiated from each other by the different subscripts to show subordinate dissimilarity within the master horizons and layers. In this typical system of differentiation, horizon nomenclature is defined in relatively more qualitative expressions. This system is known as the ABC system. This system is beneficial in making soil explanations and is deliberated as a type of "**shorthand**" which permits rapid soil science statements about the soil morphology, genesis, and, to some extent, classification or grouping of a soil without a complete pedon explanation.

7. Master and Transitional Horizons

O, A, E, B, C, and R master horizons are recognized. A transitional horizon has characteristics of two different master horizons or layers, so it needs to be recognized in the horizon symbol. Symbols for 2 master horizons are given in the symbol for the master horizon that the transitional horizon is most like is given first, and the symbol for the subsidiary horizon second. Different master and transitional horizons or layers that may take place in any soil profile are described shortly in the form of a diagram (Figures 5.13 and 5.14). No soil will contain all of the different horizons or layers that are given here.

7.1 O Horizon (Organic)

The O horizon consists of organic horizons or layers that are produced above the mineral soil surface. These horizons are formed from the litter resulting from deceased vegetation and animals. These horizons are commonly found in woodland regions, which are mostly lacking in grassland areas (Table 5.1). Some specific O horizons are given below:

Table 5.1: Abbreviations for Horizons and Their Description

Sr. No.	Abbreviations for Horizons	Description of Abbreviations
1	Oi	Organic horizons of plants and animal remains, which remain somewhat decayed.
2	Oe	Organic horizons of plants and animal residues, which are intermediate in decomposition.
3	Oa	Organic horizons of plants and animal residues are highly decomposed.

7.2 A Horizon (Above)

These horizons or layers are made up of mineral soil substances. These are intensely dark in color because of the existence of humified or partially decomposed organic matter, which is very well mixed with mineral portions of soil. The A horizon displays dark color from the lower horizon (Table 5.2).

7.3 E Horizon (Below)

The E horizon is a mineral horizon below the surface after which silicate clays, iron, aluminum, or some combinations of these minerals have been leached or eluviated. This leaching of minerals gives a light colored horizon in which sand and/or silt-sized quartz or other resistant minerals have been accumulated. A typical E horizon is generally lighter in color than the A horizon, which is formed under the A horizon (Table 5.2).

7.4 B Horizon (Further Below)

These horizons are formed below A, E, or O and indicate illuviation of ingredients which are occurred on or after overhead and even from underneath. In humid areas, these horizons are layers having the highest amounts of ingredients such as iron and aluminum oxides and silicate clays (Table 5.2). On the other hand, in dry areas (semi-arid and arid) $CaCO_3$, $CaSO_4$ and



Figure 5.13

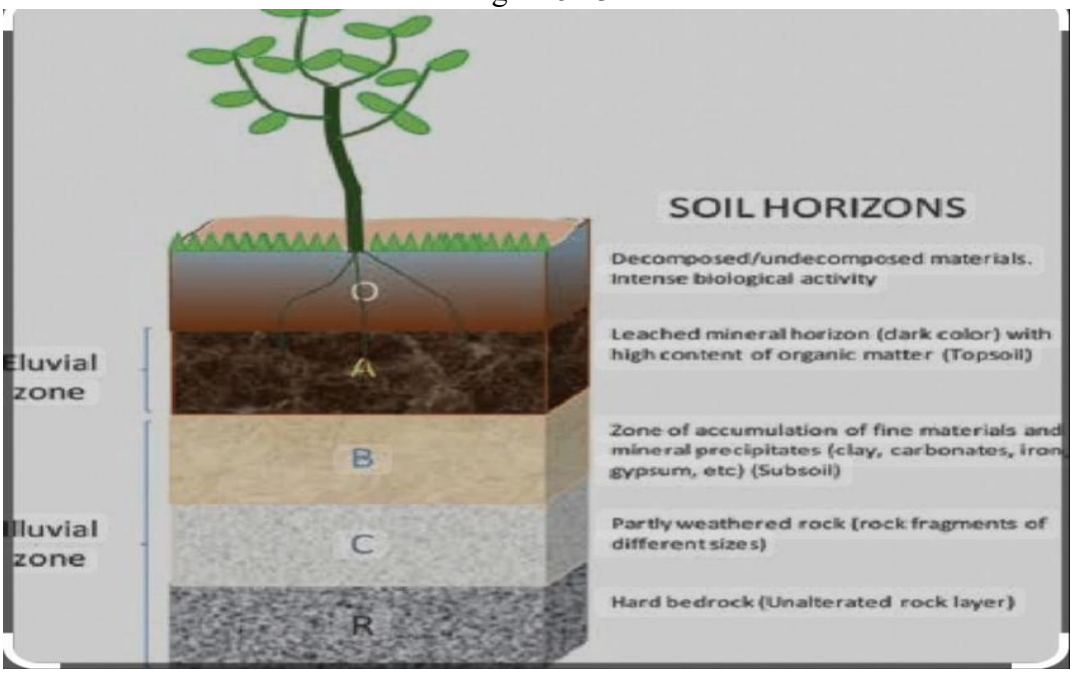


Figure 5.14

similar other salts can concentrate in the B horizon. In this regard, some important points to learn are given below:

Table 5.2: Abbreviations for Horizons and Their Description

Sr. No.	Abbreviations for Horizons	Description of Abbreviations
1	AB	Transitional horizon between A and B, however much alike A than B
2	EB	Transitional horizon between E and B, but more like E than B
3	A/B	Transitional horizon, which will come across desires instead of the A horizon, except for additions of less than 50% by volume of material that will be eligible for the B horizon.
4	E/B	The transitional horizon will meet the requirements for the E horizon except for additions of less than 50% by volume of material that will be eligible for the B horizon.
5	BA	Transitional horizon in the middle of A and B, but much alike B than A
6	BE	Transitional horizon between E and B, but more like B than E
7	B/A	The transitional horizon will see necessities for the B horizon, except for additions of less than 50% by volume of material that will be eligible for the A horizon.
8	B/E	The transitional horizon, which will see the necessities for B horizon except for additions of less than 50% by volume of material that will be eligible for the E horizon.
9	BC	Transitional horizon between B and C, but much alike B than C
10	CB	Transitional horizon between B and C, but much alike C than B

7.5 C Horizon

The C horizons are mineral layers (not bedrock) that are relatively unaffected by pedogenic processes. These layers lack the typical characteristics of horizons A, O, E, or B. These can remain similar or otherwise dissimilar to the parent material of somewhat covering/overlying solum in similar soil (Table 5.2).

7.6 R Layers

These are horizons that consist of solid bedrock. These are not essentially diggable with a garden spade. Hence, these indicate a small indication of weathering.

8. Horizons

Soil horizons are generally considered to be more or less parallel/equivalent to the surface of the earth. Nonetheless, more or less of these horizons are irregular or asymmetrical in form. Hence, it is a matter that has pedological association. Soil material is having equally identical texture that mantles or covers the landscape and most frequently has a collection of different horizons formed in it as determined by position/location in the landscape.

9. Subscripts to Show Subordinate Distinctions with Master Horizons/Soil Layers

In this case, lower or small letters show specific types of master horizons or layers. Most of these are employed only with one type of master horizon. Some of these are not to be utilized in grouping, but some of these can take preference over others (Table 5.3).

Table 5.3: Abbreviations for Horizons and Their Description

Sr. No.	Abbreviations for Horizons	Description of Abbreviations
1	a	Very rotten organic matter. Associated with O
2	b	Buried genetic horizon
3	c	Noteworthy buildup of concretions or has mono concretionary swellings cemented by oxides of Fe, Al, Mn, or Ti
4	e	Organic material of intermediate (hemic) decomposition. Used with O
5	f	Frozen soil containing permanent ice
6	g	Strongly gleyed
7	h	Illuvial buildup of organic matter. Used merely with B
8	i	Somewhat rotten (fibrous) organic matter. Typically associated with the O horizon
9	k	Buildup of secondary (alluvial) minerals. Generally $CaCO_3$ minerals
10	m	a) More than 90% cemented with carbonates (km), silica (qm), iron (sm), and gypsum (ym) b) By both carbonates and silica (kqm) or c) Salts more than gypsum (zm)
11	n	Buildup of exchangeable Na in the natric horizon
12	o	Residual buildup of sesquioxides (Fe & Al oxides)
13	p	Mixed through ploughing or extra similar (e.g., qm)
14	q	Accumulation of secondary silica as in duripans (gm)
15	s	Alluvial buildup of sesquioxides and organic matter
16	t	Accumulation of silicate clays usually occurs through illuviation
17	v	Plinthite (high iron, red material)
18	w	Typical color and structure formed with less or no illuvial buildup of elements
19	x	Fragipan character
20	y	Buildup of gypsum ($CaSO_4.2H_2O$)
21	z	Buildup of salts, extra solvable than gypsum

Pedogenesis and Pedogenic Process

10. Pedogenesis

Pedogenesis is composed of two words;
Pedo which leads to pedon and
genesis, which means mode of formation

Hence, pedogenesis can be defined as a subdivision of soil science that deals with the method of development of a pedon. i.e., "a soil."

Pedon

Pedon is a three-dimensional soil body with lateral dimensions that are sufficient to allow the study of the shape and relationships of its horizons.

11. Pedogenic Process

Pedogenic processes are inner soil construction methods. Grouping or categorization of events for the reorganization of materials, which personally disturbs soil development, in which it functions to provide a specific form of morphology, is called a pedogenic practice.

12. Fundamental Pedogenic Processes

Some relatively specified fundamental pedogenic processes are discussed below:

12.1 Calcification

It is the process through which the buildup of $CaCO_3$ occurs in the Cca horizon of any soil profile. With the passage of time, this Cca layer/horizon is changed to a cliché having equal to or greater than 15% $CaCO_3$. Under a dry climate (having less than 50 cm of rainfall), this process takes place if the parent material is of a calcareous type (Figure 5.15). In this situation, with more rainfall, lime is transferred from surface layers to subsurface but remains within the soil profile; rather than going out of profile. In the B horizon, there is no illuviation of clay. Natural flora of the region can assist in boosting the process of calcification. General chemical reaction involved is as under:

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

Calcification takes place only when either CO_2 or H_2O is removed from the soil and reaction's direction is in right way.

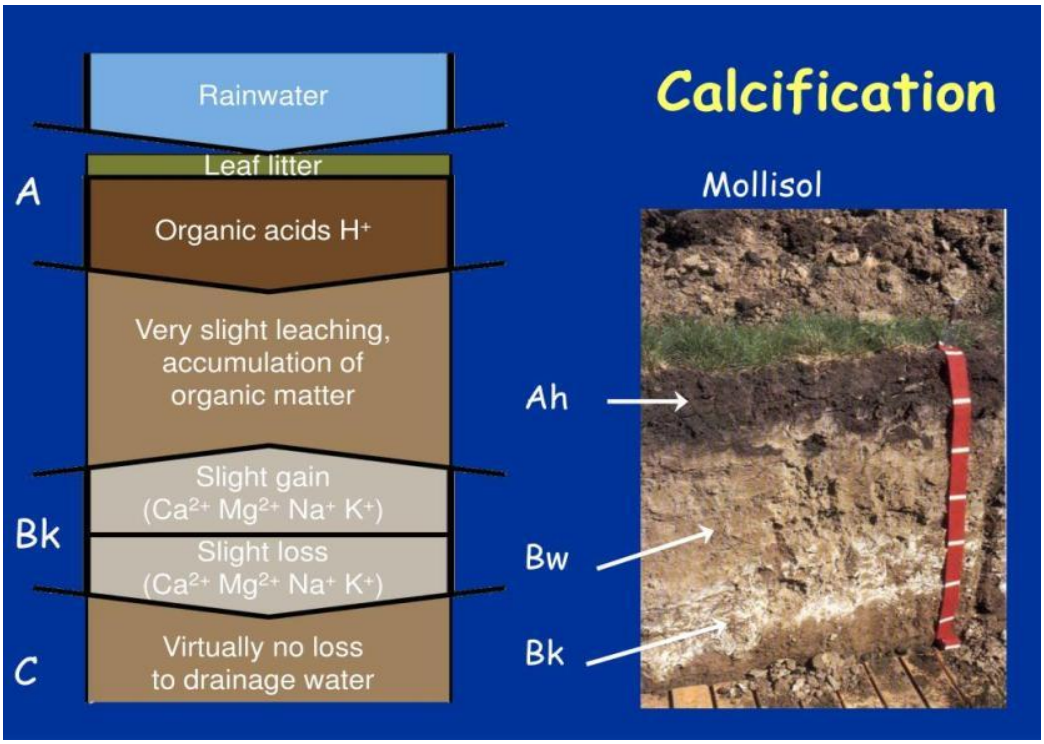


Figure 5.15

Decalcification

It is the process that deals with chemical reactions that are linked with the exclusion of $CaCO_3$ from one or more soil layers or horizons. Hence, decalcification is the eluviation of carbonates from the soil. This practice can go for thorough elimination of CO_3 from the whole soil profile, and the same is commonly observed in much humid regions. This method occurs in the existence of H_2O plus CO_2. As a result of this reaction, the formation of soluble bicarbonates is noted.

12.2 Podzolization or Silication

It is the removal or biochemical movement of aluminum and iron coupled with organic matter (OM), with the resultant buildup of silica (silication) in the layer or horizon eluviated. It is the development of the E horizon. Podzolization can be defined as a method through which sesquioxides are translocated in the soil profile. Soluble Fe^{+2} is formed in the place of eluviation, and unsolvable Fe^{+3} forms at points of illuviation. Lower temperature, much rainfall, forest vegetation and acidic soil conditions are conductive to silication process (Figure 5.16).

Podzolization or Sili cation

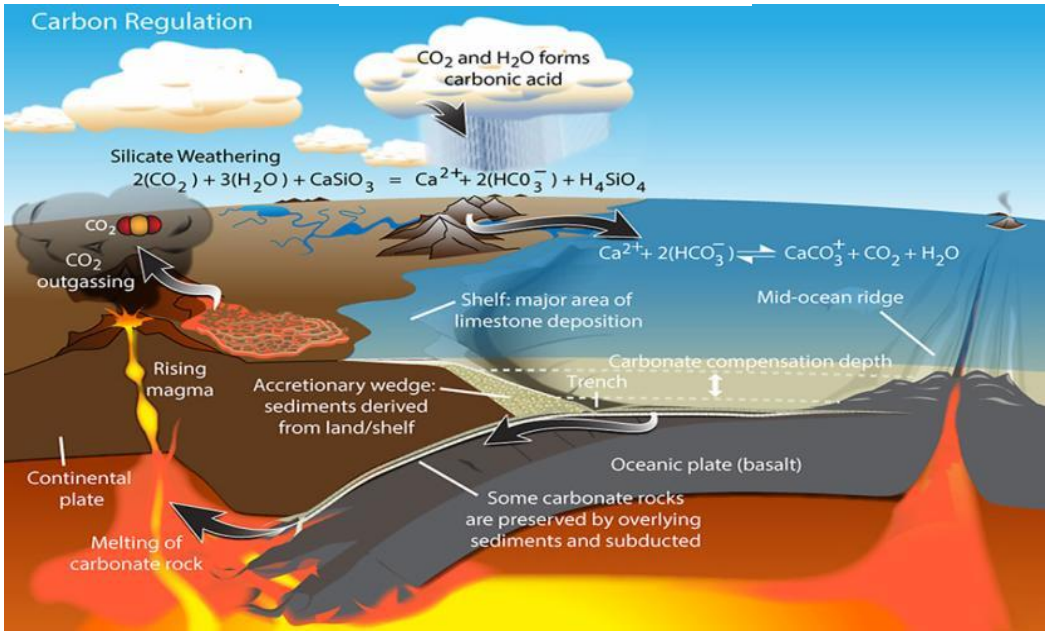


Figure 5.16

12.3 Desalination or Laterization

It is the removal or biochemical movement of silica from the soil solum. As a result of desalication, buildup of sesquioxides can take place in soil solum (gibbsite and geothite) by means of the presence of ironstone (laterite; hardened Plinthite, iron-rich, humus-poor mixtures of clay with quartz) besides concretions. Process of desalication or removal of silica is favored by high temperature, greater rainfall, and extreme leaching. As a result of these chemical alterations, a higher concentration of iron in the form of ferric oxide is produced under oxidizing soil conditions.

12.4 Gleization or Glyzation

It is the reduction of Fe in anaerobic waterlogged soil environments through the manufacture of a bluish to greenish gray color matrix, without otherwise with yellowish brown, brown, and black mottles and ferric and manganiferous concretions (Figure 5.17).

Gleization or Glyzation

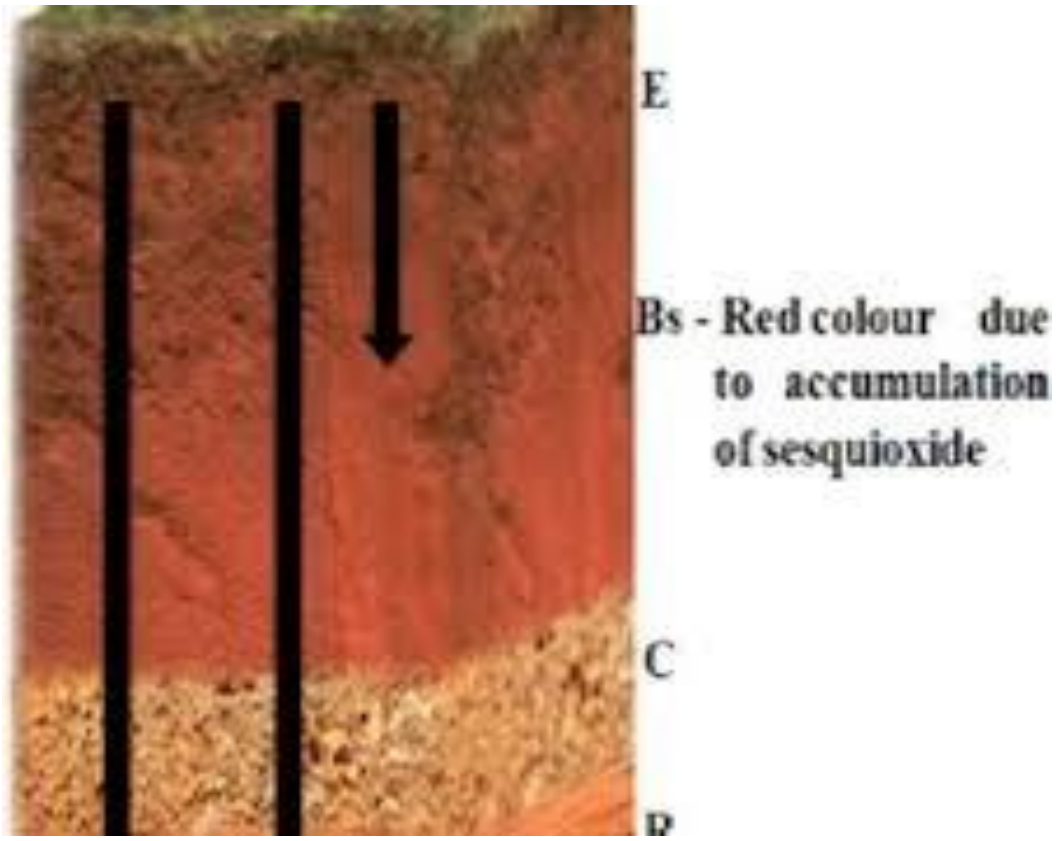


Figure 5.17

12.5 Salination

It is the buildup of soluble salts like sulfates plus chlorides of Ca, Mg, Na, and K, with the ultimate formation of a salty or salic horizon. Salination is the characteristic of soils lying in arid, semi-arid, and sub-humid regions. Salt concentration is greater in soil depressions, which are enriched in clay content and poor in permeability, with less leaching. Dominant salts in this case are sulphates and chlorides (Figure 5.18). Borates and nitrates may also rarely found.

Salination



Figure 5.18

12.6 Desalination

Elimination of soluble salts commencing salic or salty soil horizon is known as desalination. Desalination is the exclusion of soluble salts through soil layers or the complete soil profile through the process of leaching. The presence of soluble salts in sufficient amounts always a hurts plant growth. Hence, this process may be operational only when the soil has ample quantities of soluble salts.

12.7 Sodication

Sodication includes the buildup or accumulation of Na ions at exchange sites of any soil, particularly clay. All types of cations found in the soil solution are involved in a reversible reaction on the exchange sites of clay and particles of organic matter. In the first step of this process, precipitation of calcium and magnesium with carbonates occurs. In the second step, sodium ions are attracted much towards the exchange site (Figure 5.19). Consequently, dispersion of soil colloids takes place in enough amounts.

Sodi cation



Figure 5.19

12.8 Desodication

Elimination and leaching of Na ions and salts from the natric horizon of the soil profile is called desodication. It takes into account the depletion of sodium from the exchange sites through the accumulation of Ca and/or Mg salts. When Ca and/or Mg are applied to the soil solution, the system permits leaching of Na as Ca and Mg salts are capable of occupying their place on exchange sites of clay and organic matter through repelling Na out of the system. As a result of the desodication process, the dispersion condition is removed, and the soil becomes flocculated.

SELF ASSESSMENT QUESTIONS

Question No. 1: Define soil formation. Also, explain various processes of soil formation.

Question No. 2: Differentiate between the addition and loss processes of soil formation.

Question No. 3: Differentiate between the transformation and translocation processes of soil formation.

Question No. 4: Explain various factors of soil formation.

Question No. 5:	Elaborate on the importance of parent materials in soil formation.
Question No. 6:	Explain the possible roles of climate in processes of soil formation.
Question No. 7:	Write and explain possible roles of topography, time, and living organisms in processes of soil formation.
Question No. 8:	Define and explain soil morphology.
Question No. 9:	Define soil profile and write the description of a typical soil profile.
Question No. 10:	Write a comprehensive note on master and transitional horizons.
Question No. 11:	Differentiate between the B horizon and R layers.
Question No. 12:	Differentiate between the A horizon, E horizon, and C horizon.
Question No. 13:	Differentiate between pedogenesis and pedogenic process.
Question No. 14:	Write a comprehensive note on fundamental pedogenic processes.
Question No. 15:	Differentiate between calcification and decalcification processes.
Question No. 16:	Differentiate between sodication and desodication processes.
Question No. 17:	Differentiate between podzolization (silication) and laterization (desalication) processes.
Question No. 18:	Differentiate between salination and desalination processes.

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Unit:6

PHYSICAL PROPERTIES OF SOIL

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INTRODUCTION

Soil properties are largely determined by its parent material and weathering during its formation. Plant growth is influenced by the properties of the soil. The amount of water, air, and nutrients available for plant growth is affected by the soil's physical properties and other management practices. The aim of this course is basically to develop understanding among the students about the physical properties of soils and apply their knowledge to solve physical degradation problems. This course will help in understanding the behavior of soil physical properties in supporting crop growth and engineering uses. After the course, the students will be able to understand the importance of physical properties of soil in crop growth and its use for engineering purposes, the role of different tillage practices in crop growth and in management of water and soil, identify important problems about different physical properties and the management practices regarding physical degradation of soil.

OBJECTIVES

Physical properties of soil and their role in water and nutrient holding, and soil conditions in relation to plant growth, will be covered. The aim of this course is basically to develop understanding of the students about physical properties of soils and apply their knowledge to solve physical degradation problems. This course will also help in understanding the behavior of soil physical properties in supporting crop growth and engineering uses.

LEARNING OUTCOMES

The students should be able to measure and interpret the soil physical properties and their significance in crop growth. After the course, the students will be able to understand the importance of physical properties of soil in crop growth and its use for engineering purposes, the role of different tillage practices in crop growth and in management of water and soil, identify important problems regarding different soil physical properties, and identify the management practices regarding physical degradation of soil.

1. Physical Properties of Soils

Physical properties are the soil properties that are determined mainly through extent, form, organization, and inorganic composition of the soil units. All soil properties (physical, chemical, and biological) and environmental factors affect the growth and development of plants. Various characteristics of soil indicate diverse special effects on growing plants. Physical characteristics impact the development and appearance of fresh saplings and root sprouting, and root development in the soil.

In addition to the direct impact of soil characteristics on plant growth, soil physical properties affect:

1. Water movement in soil
2. Soil air composition
3. Accessibility of nutrients to growing plants

Therefore, soil physical characteristics need to be advantageous to crop growing, which means that surface soil conditions must be adequate for the successful emergence of crop seedlings. Subsurface soil conditions must permit adequate root growth. Important physical properties include:

1. Texture
2. Structure
3. Particle and bulk density
4. Porosity
5. Air and moisture content
6. Consistency
7. Colour
8. Temperature

2. Soil Texture

Natural soils are intimate mixtures of soil separates such as sand, silt, and clay. Hence, texture is a very important physical property of soil, which may be defined as "the relative quantity of different soil separates (sand, silt, and clay) in any soil". The size of particles in mineral soil is not easily changed. So the number of individual size groups in a soil cannot be altered simply. Therefore, texture is a fundamental soil characteristic.

2.1 Soil Separates

Based on size, different mineral particles present in any soil are separated from each other and placed in various groups. These groups are called soil separates. Thus, soil separates may be defined as "single size groups of mineral soil particles/units having a diameter of 2 mm or less than this" (Table 6.1). Soil separates are known as fine earth.

Table 6.1: Classification of soil separates

Sr. No.	Soil Separates Name	Diameter in millimeters
1	Clay	Less than 0.002
2	Silt	0.02 to 0.002
3	Fine Sand	0.2 to 0.02
4	Coarse Sand	2.0 to 0.2

2.2 Textural Classes of Soil

Textural class of any soil is a group of soil textural units/components that is based on the relative percentage of sand, silt, and clay (Figure 6.1). It refers to a well-defined group characterized by particle size distribution, exhibiting similar properties, and requiring similar management practices. The textural triangle is consulted to decide the soil textural class after the proportion of sand, silt, and clay is known. There are three soil textural classes:

i) Sandy Soils: In this textural class, sand is at least 70 % and clay is ≤ 15 % by weight. Low water holding capacity, low cation exchange capacity (CEC), high drainage, and aeration are characteristics of these soils.

ii) Loamy Soils: A combination of sand, silt, and clay separates in equivalent extents. It indicates good drainage, medium water holding capacity, medium CEC, nutrient supply power, and retention power is medium. Loamy soils are called **"ideal soils for crop production".**

iii) Clayey soil: Must have at least 35 % clay. These are called fine-textured soils. This class is characterized by very high CEC, high capacity for water retention, and plant available water content. Internal drainage is very poor.

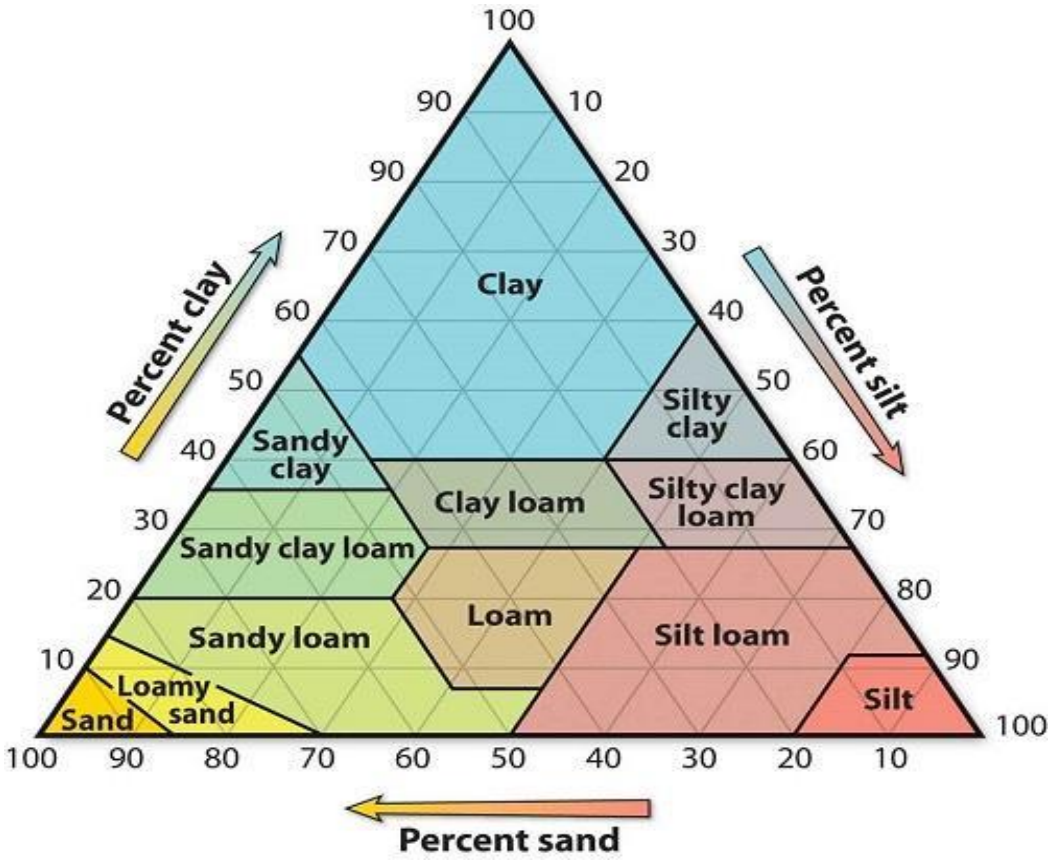


Figure 6.1

2.3 Importance of soil texture

Knowledge of texture is important in determining the suitability of soils:

1) For the production of different crops
2) Foundation of buildings
3) Construction of roads
4) Retention and transmission of water, as well as soil aeration
5) Determining nutrient nutrient-supplying ability of soils

3. Soil Structure

The word structure narrates the combination or organization of primary/basic soil particles (sand, silt, and clay) into derived/secondary particles or units, which are called peds. Peds are also known as aggregates. These aggregates are detached from each other through surfaces of weakness (Figure 6.2).

Ped: A distinct normal soil aggregate is called ped. e.g., platy ped, blocky ped, and prismatic ped, etc.



Figure 6.2

3.1 Types of structure

Soil structure is classified based on shape, size, and arrangement of peds in any specific soil. Principal types of soil structure are platy-like, block-like, prism-like like and sphere-like structures (Figure 6.2).

a) Plate-like structure

In this case, aggregates are organized in comparatively thin flat dishes, brochures, or lenses. When the horizontal axis is longer than the vertical axis, giving a dish/plate-like look to the ped, the structure is called plate-like.

b) Prism-like structure

When the vertical axis is longer as compared to horizontal axis, showing prism-like look of ped, the structure is called prism-like. These are considered by perpendicularly shaped aggregates or pillars that are longer than wide (prism).

c) Block-like structure

In this case, aggregates are reduced to blocks, irregular six-faced with their three dimensions more or less equal. When horizontal and vertical axes are similar in length, giving a round or block-like appearance of ped, structure is called block like.

d) Sphere like structure

Soils with mostly spherical or rounded aggregates are placed in this category. This type of structure is the best for crop production.

3.2 Importance of soil structure

- Soils with good physical condition are important to good yield.
- The rate of water infiltration, water holding capacity, heat transfer, aeration, porosity, and root development are greatly influenced by soil structure.
- Aggregated soil is highly desired form for plant growing, mainly in early stages of germination and seedling establishment.
- Erodibility of soils decreases as aggregates stability increases.

4. Soil Bulk Density

Bulk density of soil may be defined as the mass of dry soil solids per unit bulk volume. Bulk volume is the volume of soil particles, including pore spaces. So density for a volume of soil as it exists naturally is called bulk density (Figure 6.3). The bulk density of soil ranges from 1.0 to 1.8 Mg/m^3. The ideal bulk density of a soil is 1.33 Mg/m^3. The value is stated/written in Mg/m^3 or g/cm^3 or kg/m^3.

$$\text{Bulk density} = \frac{\text{Mass of oven dry soil}}{\text{Total volume of soil including pore spaces}}$$

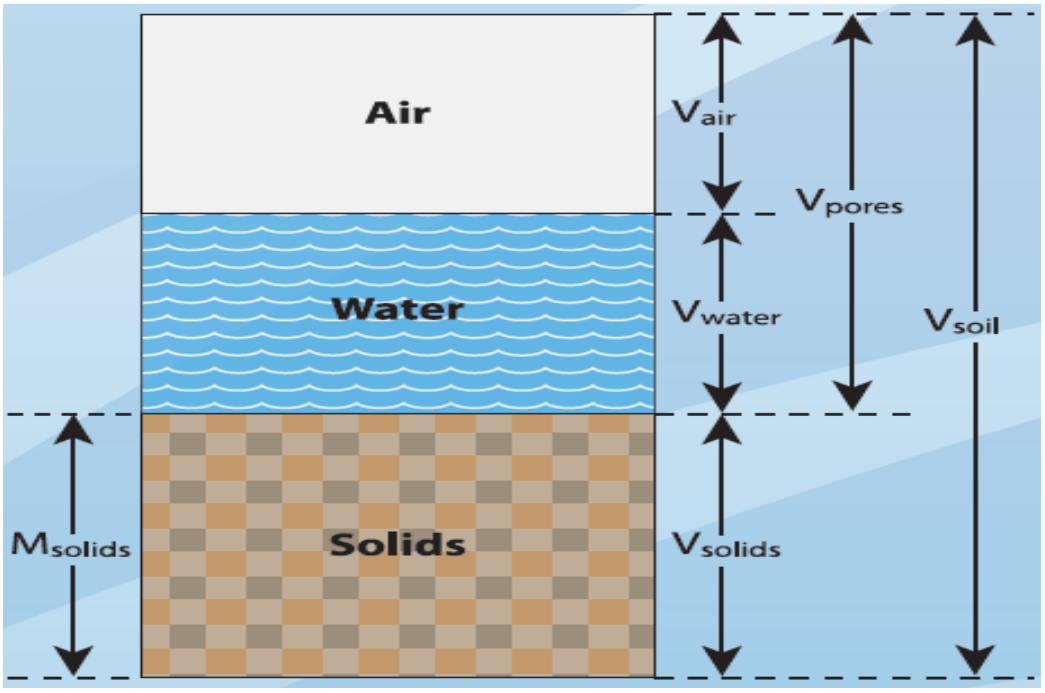


Figure 6.3

4.1 Importance of Bulk Density

- It is used to estimate the mass of volume of soil (average weight of soil for a hectare or acre = soil volume × bulk density)
- It is utilized to change water proportion by weight to quantity by volume.
- Soil porosity is computed based on bulk density values.
- It can indicate differences in compaction of a given soil resulting from heavy tillage equipment.
- Plant roots are hindered by soils high in bulk density.

5. Soil Particle Density

Particle density of any soil may be defined as the mass of dry soil per unit volume of soil solid excluding pore spaces (Figure 6.4). Particle density of mineral soils with a lesser proportion of organic matter is about 2.65 Mg/m^3. The value is written in Mg/m^3 or g/cm^3 or kg/m^3

$$\text{Particle density} = \frac{\text{Mass of oven dry soil}}{\text{Total volume of soil excluding pore spaces}}$$

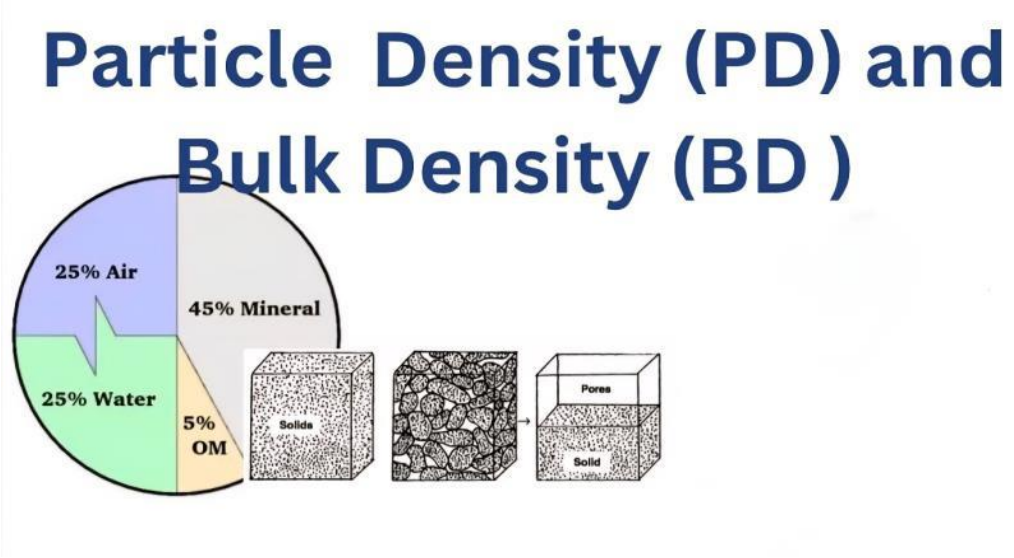


Figure 6.4

6. Soil Consistency

Consistency of any soil is the expression used to define the resistance of the soil's coherent mass to breaking/crushing (rupture). It is the ability of clay soil to be molded or altered. Hence, consistency indicates the degree of unity/cohesion or adhesion of the soil mass at several wetness stages (Figure 6.5). Soil consistency is designated at 3 moistness stages: wet, moist, and dry.

6.1 Importance: Soil consistency is important for the practical use of soils, especially for tillage operations and the resistance encountered by farm machinery. It is also useful in estimating the soil's flow or support strength under applied force (building weight, vibration of road traffic).

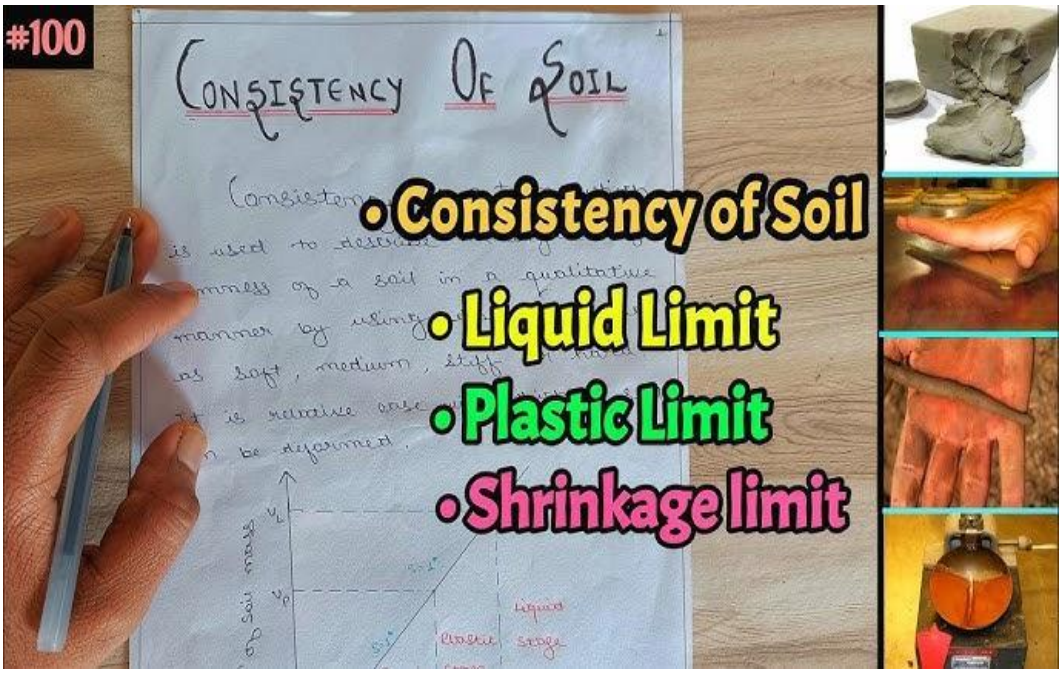


Figure 6.5

7. Soil Colour

Soil colour is a unique, important, valuable, and essential characteristic used for the identification of soils. It may vary from place to place and from horizon to horizon within the soil profile. Soil is described by its colour, such as black, yellow, and red soils. Soil colour may be inherited from parent material, but often, it is the result of different soil-forming processes. Soil colour is composed of three variables called hue, value, and chroma (Figure 6.6). Soil colour is determined by comparing it with Munsell's colour chart (Figure 6.7).

Hue: It is the main spectral or rainbow colour that is linked with the principal wavelength of light.

Value: It is the measurement of the degree of whiteness or darkness of the colour and is related to the overall extent of light reflected/returned.

Chroma: Chroma is the measurement of comparative purity or intensity of spectral colour. It increases as the amount of greyness decreases.



Figure 6.6

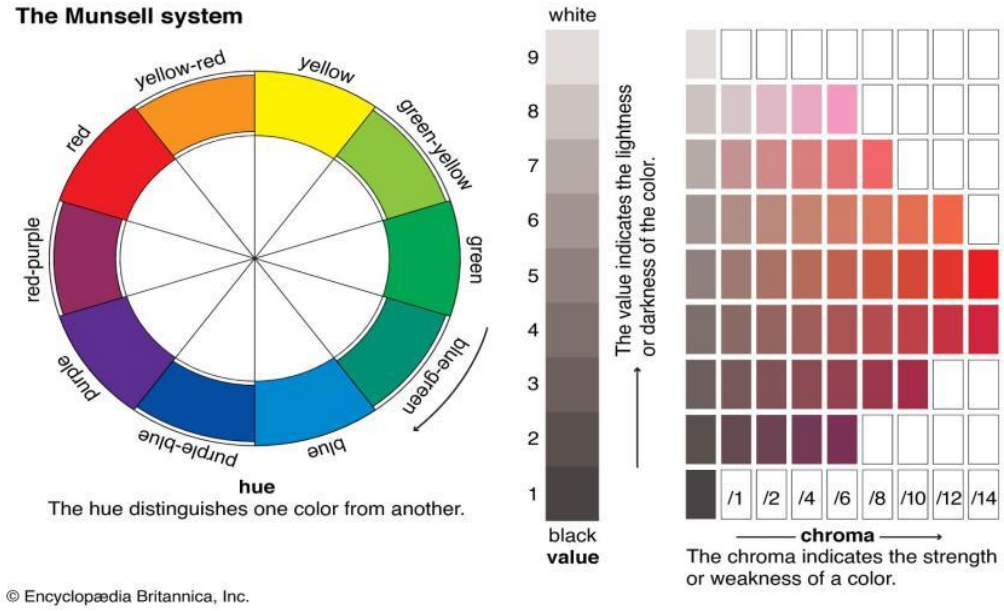


Figure 6.7

7.1 Importance of soil colour

1. Identification and classification of soils can be done based on soil colour.
2. Various horizons found in a particular soil profile become distinct and prominent based on their colour.
3. The colour of any particular soil is a gauge that shows its moisture level. e.g., when a dry soil becomes moist, its colour becomes darker.
4. Productivity of s soil can be judged from its colour. Generally, darker soils tend to be more productive, while lighter-colored soils usually indicate lower productivity.

8. Soil Temperature

Temperature is the degree of warmth or coolness of a body. Intensity of heat in the soil is called soil temperature, and it is expressed in °C, °F or °K. The soil surface is heated by the absorption of solar radiation, and the absorbed heat is conducted down through the soil profile. At any time, the temperature within the soil varies from layer to layer (Figure 6.8). Variation in soil temperature is the maximum in the uppermost soil layer, and it decreases with depth.



Figure 6.8

8.1 Factors affecting soil temperature: Important factors affecting soil temperature are as follows:

1. **Mineral composition of soil**: If a soil is sandy, it will be a good conductor of heat. Thus, sandy soils will have higher temperature than clayey soils.
2. **Water content**: If the soil is high in water content, it will resist heat penetration and hence the temperature of wet soil will be less than compared of dry soil.
3. **Soil colour**: Dark colour soils usually absorb more heat than light colour soils.
4. **Organic matter content**: Soils rich in organic matter are dark in colour. These soils absorb more heat and become relatively hotter than soils that are poor in organic matter content.
5. **Surface roughness**: A soil with a rough surface will absorb more solar radiation and usually be warmer than a soil with a smooth surface.

8.2 Importance of soil temperature: Soil temperature is very important for plant growth due to:

1. Soil temperature controls the intensity of all processes (biological, chemical, and physical) happening in soil.
2. It determines both the rate and direction of physical processes.
3. Decomposition of the soil organic matter is totally dependent on temperature.
4. All microbial activities in the soil are controlled by temperature and are very much restricted below 10 °C.
5. Seed germination is highly affected by soil temperature, and these effects vary with crops.
6. Soil temperature also affects the root growth and activity, and ultimately plays its role in determining the crop yield.
7. Soil weathering is also dependent on temperature.

9. Soil Porosity

Pore space or porosity of soil is the percentage of the overall soil capacity that is not occupied by compact units/particles. On the other hand, this is engaged by means of air or water (Figure 6.9). Usually, this is stated in proportion or percentage (%). It can also be expressed as the pore volume per unit volume of soil (cm^3/cm^3).

9.1 Types of Pores: Three types of soil pores are present based on size (Figure 6.10).

i. Macropores
ii. Mesopores
iii. Micropores

9.2 Importance of porosity

- Micropores are typically filled with water in wet soil, and they allow only slow movement of air and water into or out of the soil.
- Macro pores allow rapid movement of both water and air through the soil. Thus, movement of water and air is rapid in sandy soils due to more macro pores, even though total porosity is relatively lower.

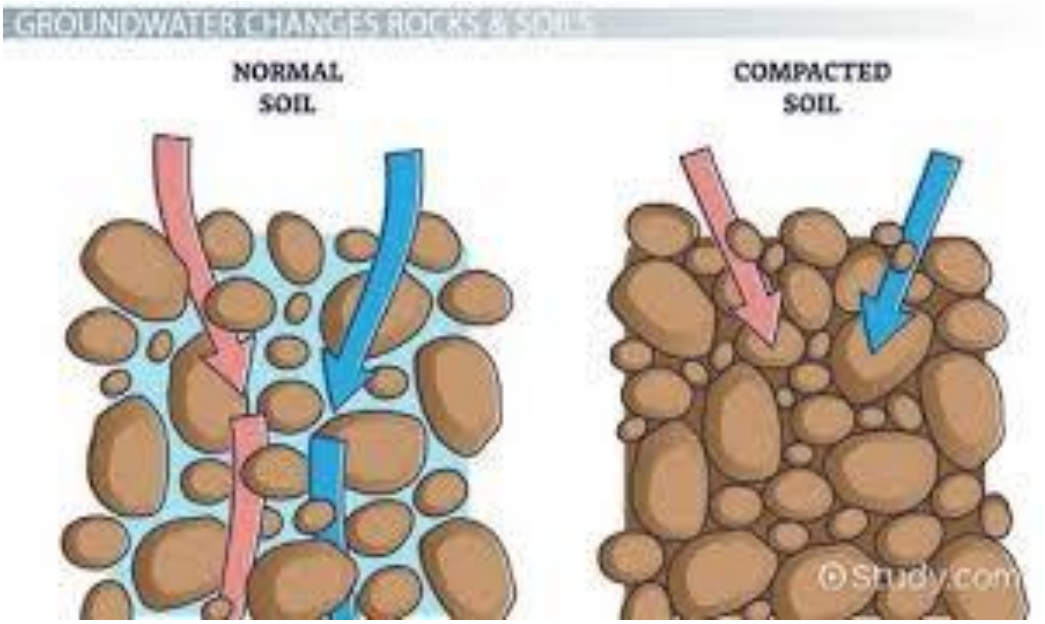


Figure 6.9

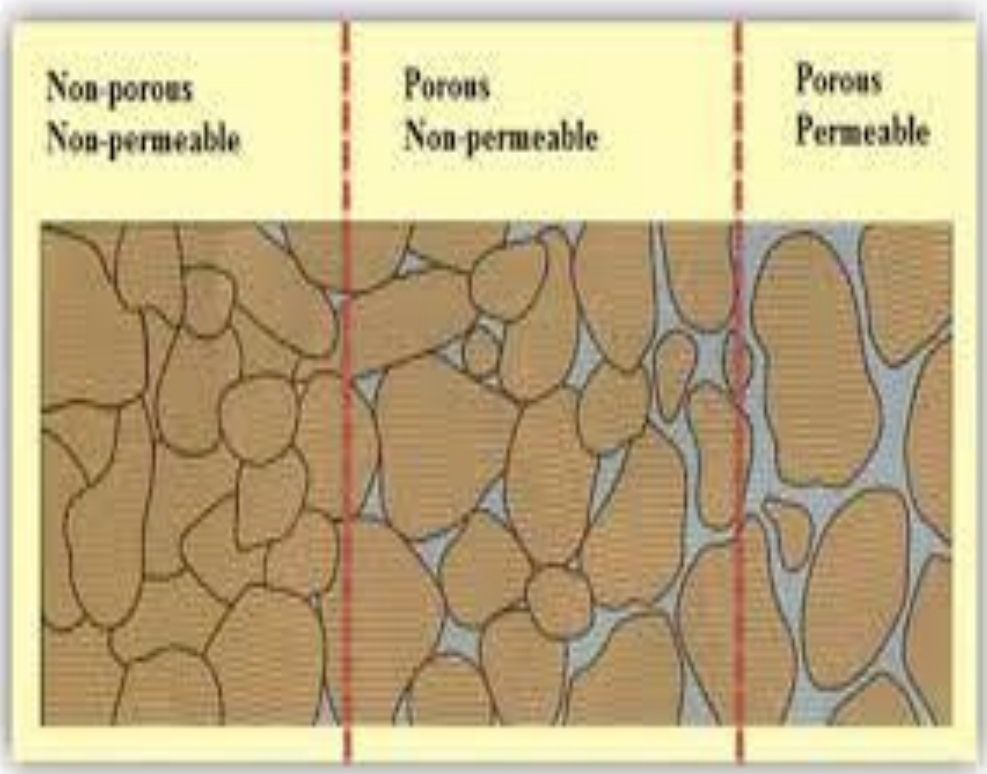


Figure 6.10

10. Soil Aeration

Soil air is the air of any constitution and any composition present in the soil. While soil aeration is the exchange of gases (CO_2 and O_2) between the soil and the atmosphere. Hence, soil aeration is the process by which air in the soil is replaced with the air from the atmosphere, and this occurs due to variation in the composition of soil air with that of atmospheric air (Figure 6.11). The composition of soil air at any time is the result of 2 processes.

a) Rate of production of CO_2 and consumption of O_2.
b) Rate at which CO_2 is released from the soil and is replaced by O_2.

In nature, soil aeration takes place by:

i. Diffusion occurs due to differences in the partial pressures of individual gases, even if the total pressure remains the same in both the soil and the atmosphere. Soil aeration by diffusion is believed to account for 90% or even more of total gaseous exchange.

ii. Mass flow due to the difference of total pressure between soil air and atmospheric air.

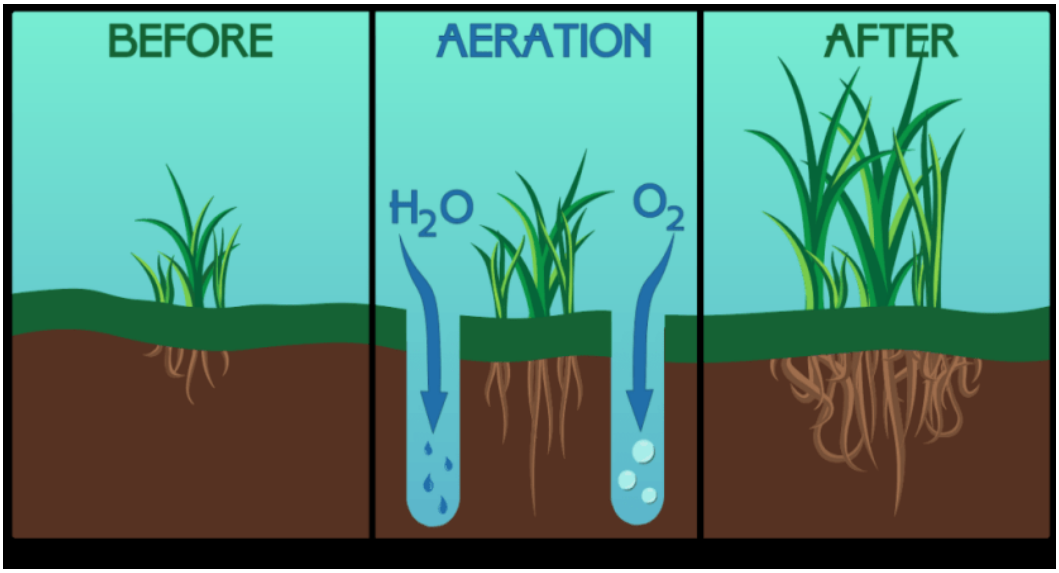


Figure 6.11

10.1 Factors Affecting Soil Aeration

Important factors affecting soil aeration are as follows:

1. Soil Water Content
2. Macro Porosity of Soil
3. Heterogeneous Nature of Soil
4. Soil Drainage
5. Soil Tillage

10.2 Importance of Soil Aeration

Soil aeration is a very important parameter of plant growth. Different plants prefer to grow at different levels of soil aeration. e.g., Hydrophytes grow well under continuous flooding conditions, but on the other hand, mesophytes and xerophytes normally grow better in well-aerated soil conditions (Figure 6.12). The effect of soil aeration on the growth of higher plants is divided into 2 categories.

I. Effect on soil constituents
II. Direct effect on the physiological condition of plants



Figure 6.12

11. Soil Water

Chemically, soil water is a compound of hydrogen and oxygen with the formula of H_2O. Arrangement of these atoms of hydrogen and oxygen is not symmetrical and linear like H-O-H. But these 2 hydrogen atoms are linked with oxygen atom at an angle of 103° to 106° with an average of 105°. This configuration of hydrogen and oxygen atoms is shown in the following diagram (Figure 6.13).

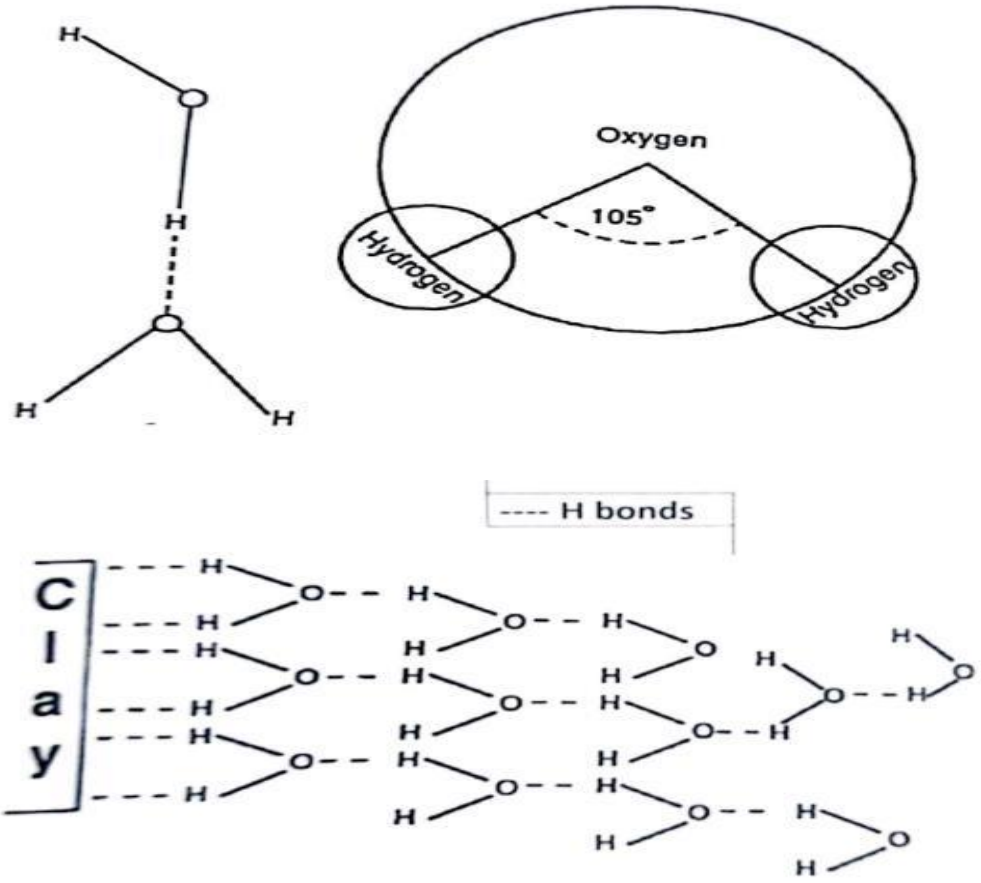


Figure 6.13

11.1 Importance of Soil Water in Agriculture

Soil water is of much importance and plays a significant role in many ways. The importance of soil water is given below:

1) It controls soil temperature and keeps the soil safe from getting too hot and too cold.
2) It controls soil air. As soil water controls air and gas exchange in the soil, it affects the activities of soil microorganisms, oxidation-reduction potential, and finally root respiration.
3) Weathering process of rocks is affected by soil water content.
4) It is accountable for soil erosion.
5) Soil water affects the process of soil formation. Differentiation of various horizons of a profile is also governed by soil water.

6) It affects numerous physical properties of soil. e.g., compaction, consistency, strength, plasticity, stickiness, swelling, and shrinkage of clay, etc.
7) Soil water is mandatory for growing plants due to the following reasons:
    a) A major part of plants is composed of water
    b) Photosynthesis occurs only when water is available
    c) Plants maintain their turgidity in the presence of water
    d) Water is a universal solvent, and all types of nutrients are dissolved in it for plant uptake

11.2 Properties of Water

Water has the following important properties:

- ✓ Viscosity
- ✓ Density
- ✓ Heat capacity
- ✓ Surface tension
- ✓ Freezing and thawing of water
- ✓ Vapour pressure
- ✓ Vaporization and condensation of water
- ✓ Capillarity/capillary rise
- ✓ Attraction of water to solid and other inorganic ions
- ✓ Water as a universal solvent

11.3 Classification of Soil Water

Soil water is classified in 2 ways:

A. Physical classification of water

Water is divided into 3 different types, which are described below and shown in Figure 6.14.

i. **Gravitational water:** It is the amount of soil water that quickly drains away under the effect of the force of gravity. This water is of limited use for plants as it is present for a short time in the soil. Removal of this water from the soil is required for optimum plant growth.

ii. **Capillary water:** It is the amount of water that is held by surface tension forces around soil particles and in capillary spaces. Only some part of this water is used by plants for their growth.

iii. **Hygroscopic water:** It is the amount of water adsorbed strongly on the surface of soil particles from an atmosphere of water vapors. Higher plants cannot use this water for their growth. However, some microorganisms remain active in soils having only hygroscopic water (Figure 6.15).

B. Biological classification of water

Water is divided into 3 different types, which are described below:

i. **Super available water or drainage water:** It is the portion of soil water held between saturated conditions and to field capacity level. This water is mostly present in macro pores and is also called drainage water. This water can be used by plants to a very small extent. If this water remains present in soil for a long time can prove harmful for plants due to a lack of soil air.

ii. **Available water:** It is the amount of water held in soil between the level of field capacity and the wilting coefficient. This water is said to be usable for plants and hence, is known as available water. It is mainly held in capillary sized pores.

iii. **Unavailable water:** It is the amount of water held in soil above the level of wilting coefficient. This type of water is not available to plants and hence, is called as unavailable water.

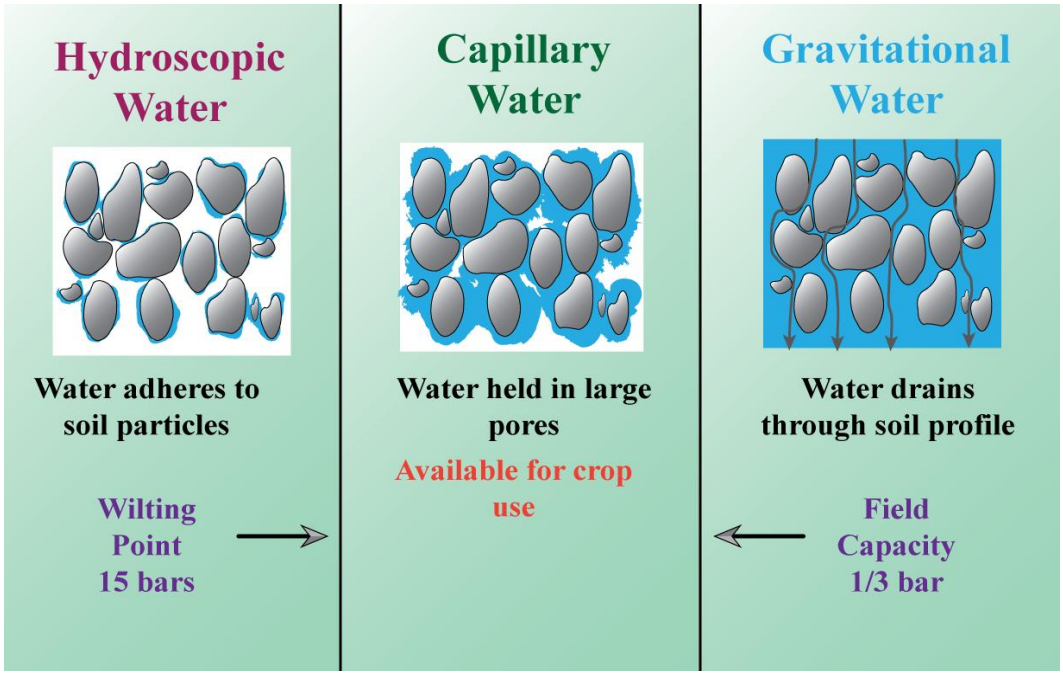


Figure 6.14

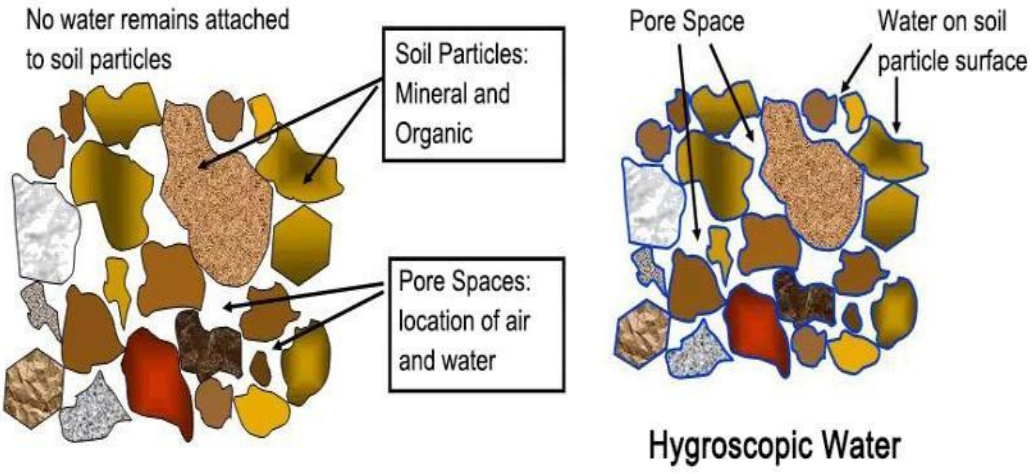


Figure 6.15

SELF ASSESSMENT QUESTIONS

Question No. 1: Define physical properties of soil. Write important impacts of physical properties on plant growth.

Question No. 2: Define soil texture and explain the significance soil texture.

Question No. 3: Define soil separates and write the classification of soil separates.

Question No. 4: Explain different soil textural classes.

Question No. 5: Define soil structure and describe the importance of soil structure.

Question No. 6: Elaborate on various types of soil structure.

Question No. 7: Differentiate between soil texture and structure.

Question No. 8: Differentiate between soil bulk density and particle density.

Question No. 9: Define soil bulk density and describe the importance of soil bulk density.

Question No. 10: Define soil particle density and soil consistency.

Question No. 11: Define soil colour and describe its three variables.

Question No. 12: What is Munsell's colour chart? Write the importance of soil colour.

Question No. 13: What is soil temperature? Write the importance of soil temperature.

Question No. 14: Explain various factors affecting soil temperature.

Question No. 15: Define soil porosity. Write down different types of soil pores.

Question No. 16: Write a comprehensive note on soil aeration and its importance in the soil body.
Question No. 17: What is soil water? Explain the importance of soil water.
Question No. 18: Enlist various properties of soil water.
Question No. 19: Differentiate between the biological and physical classification of soil water.
Question No. 20: Differentiate between gravitational hygroscopic soil water.

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Unit:7

INTRODUCTION TO SOIL CLASSIFICATION

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Prof. Dr. Sher Muhammad
Reviewed by: Dr. Sabir Hussain Shah

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INTRODUCTION

Soil classification deals with the systematic categorization of soils based on distinguishing characteristics as well as criteria that dictate choices in use. Soil classification systems are established to help people predict soil behavior and to provide a common language for soil scientists. The course is aimed at developing relations among different soil categories and their importance for particular use. The students will be able to classify soils and devise strategic and efficient land use. The students will be able to understand and describe morphological features and taxonomic relations of different soils, soil genesis, with special reference to the soil-forming factors responsible for the development of the solum, or true soil, time, parent material, topography, climate, and organisms. The students will know how the properties of soils affect their uses, and be able to evaluate alternative treatments, amendments, and/or location of different uses of soil/substrate.

OBJECTIVES

The course is aimed at developing relations among different soil categories and their importance for particular use. The students should be able to classify soils and devise strategic and efficient land use. The students will be able to understand and describe morphological features and taxonomic relations of different soils. Soil genesis, with special reference to the soil-forming factors responsible for development of the solum, or true soil, time, parent material, topography, climate, and organisms.

LEARNING OUTCOMES

The students will know how the properties of soils affect their uses, and be able to evaluate alternative treatments, amendments, and/or location of different uses of soil/substrate. Students will be able to effectively sample and describe soils. Students will appreciate the importance of soils to human civilization and survival.

1. Soil Classification

In nature, grouping is mandatory to study any heterogeneous commodity or material. It is specifically right for soils because these vary from place to place and site to site. Hence, soil classification is the grouping of soils into various categories/classes on the basis of main physical, chemical, and morphological features of each soil in a systematic manner. According to the Soil Survey Staff, the main and basic system of soil classification into various groups or classes is called soil taxonomy. Morphological features of any soil include colour, structure, texture, depth, and nature of different horizons and other similar characteristics, which are altered accordingly.

1.1 Pedon

Morphological features of any soil and changes within the soil are studied considering some criteria or minimum volume/area known as a unit. Such a minimum area/volume or unit of soil is called pedon. Hence, pedon can be defined as a three-dimensional soil body with dimensions large enough to allow its morphology. Area or volume of a pedon ranges from 1-10 square meter depending upon variation in soil (Figure 7.1). Depth of a pedon is generally up to the point where the roots of common crops can grow.

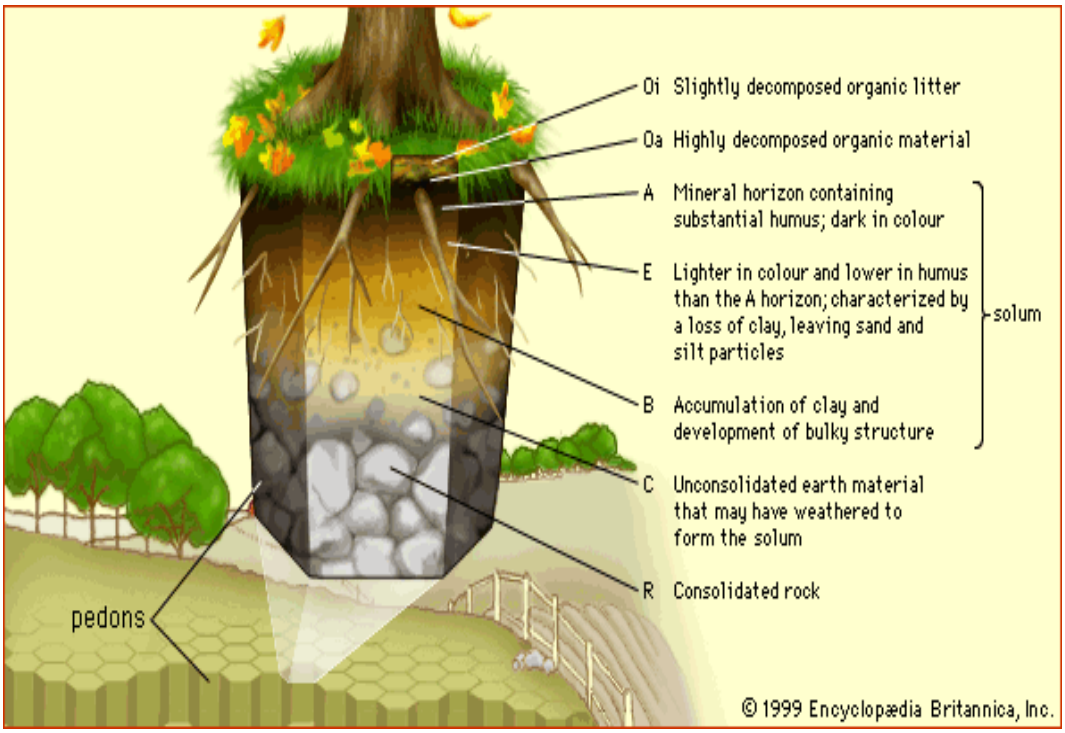


Figure 7.1

1.2 Polypedon

A soil comprises adjoining similar pedons which are surrounded on all borders/edges by "not-soil" or by the pedons of different properties. Such an assembly or cluster of adjoining similar pedons is known as a polypedon (Figure 7.2). It is also called a soil mapping unit, which is one basic unit of soil classification.

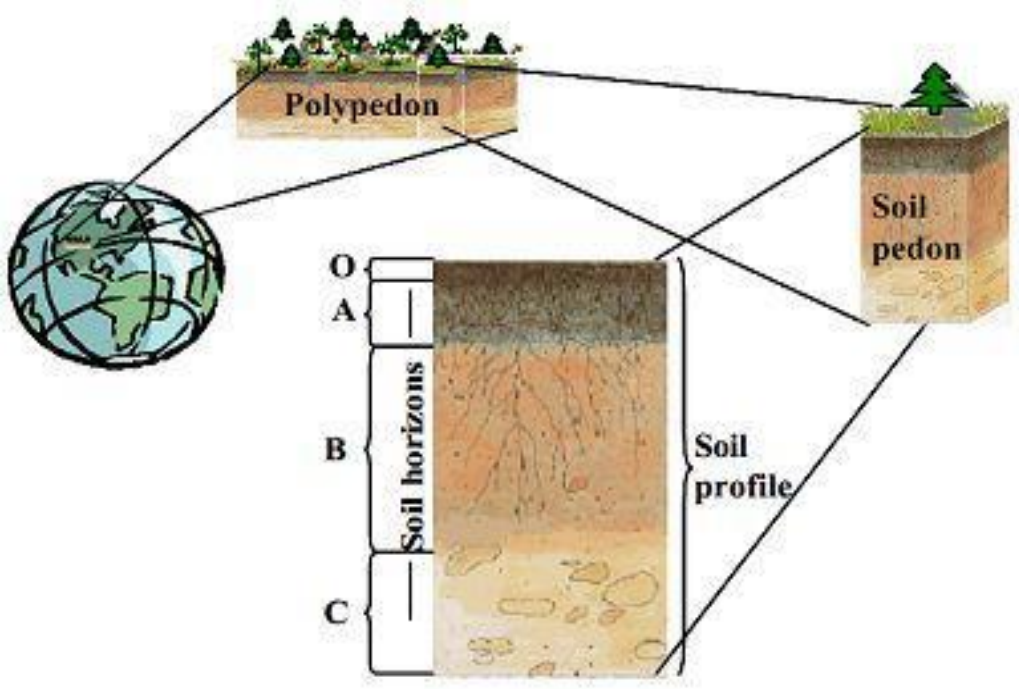


Figure 7.2

2. Soil Taxonomy

Soil taxonomy is the basic and fundamental classification system of soils for creating and inferring soil surveys. It is the grouping and arrangement of soils on the basis of individual soil's morphological features, like appearance and form. These features or characteristics are defined in the field in terms of their genetic makeup, which are appraised in terms of diagnostic horizons and features (Figure 7.3). Data regarding soil moisture and temperature regimes are also desired for taxonomic soil classification.

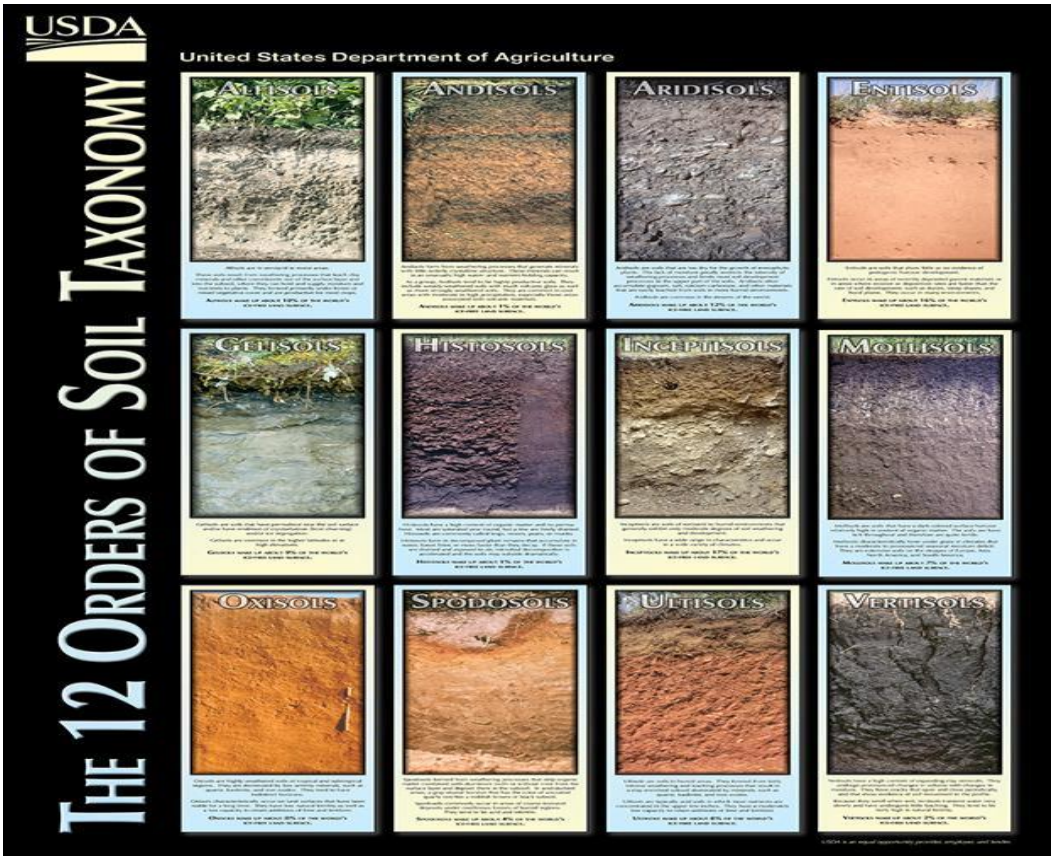


Figure 7.3

3. Classification of Categories in Soil Taxonomy

There is an increasing degree of specificity in soil properties from higher to lower categories. This system of classification is based on the characteristics of soils that are present nowadays in the field. One of the most important objectives of this system is to group soils that have formed through similar genetic developments (Figure 7.4). Hence, these categories are made on the basis of soil properties. There are 6 categories of soils. Brief details of each soil category are given below:

3.1 Order

Soil order is the most generalized category. All soils are found in one of the 11 orders. Out of the total 11 soil orders, 7 are distinguished by the existence or absence of diagnostic horizons or of diagnostic features. These horizons and features indicate the type and amount of main soil-forming processes that are generally affected by different climates and other related features of soil formation/development or genesis. These 7 orders are as follows:

1) **Inceptisols** comprising weakly developed or formed soils.
2) **Aridisols** comprising arid region soils that have characteristics with less humidity.
3) **Mollisols** comprising grasslands which are naturally fertile soils and are considered among the most productive agricultural areas worldwide.
4) **Alfisols** are well-developed soils with a high base status.
5) **Ultisols** comprising low base status soils of warm humid regions.
6) **Oxisols** comprising highly weathered tropical soils.
7) **Spodosols** comprising sandy acidic soils that are formed in cold and humid climates. Remaining 4 soil orders are as follows:

1) **Entisols** comprising no distinctive diagnostic horizons.
2) **Andisols** comprising predominantly volcanic materials.
3) **Vertisols** comprising cracking dark clay soils.
4) **Histosols** comprising organic soils.

Among these 11 total soil orders, the following 6 are found in Pakistan.

1) **Aridisols**
2) **Entisols**
3) **Inceptisols**
4) **Alfisols**
5) **Mollisols**
6) **Vertisols**

3.2 Suborder

Suborders within a soil order are distinguished based on further soil characteristics and horizons that reflect a realistic degree of genetic uniformity, soil moisture regimes, and features related to wetness or water content. The suborders are distinct from one another and are not exchangeable.

3.3 Great group

Further subdivision of suborders is called a great group. Great groups are identified mainly on the basis of distinction of soil diagnostic horizons and their respective diagnostic features. In this case, the differentiating horizons are those that have accumulated clay, iron, aluminum, and/or humus, or those that are hardened or cemented by certain binding agents. Remaining characteristics are self-mixing features of clay, soil temperature regimes, and main variances in amounts of calcium, magnesium, sodium, gypsum, and other salt buildup.

3.4 Subgroup

Every great group is further separated into 3 types of subgroups:

✓ **One** that represents the principal concept of the soil great group is called **Typic**.

- ✓ **Second** indicates features that have a tendency in the direction of other orders, suborders, or other great groups are known as **intergrades** and
- ✓ **Third** shows characteristics that inhibit its grouping as typic or as integrated into another category.

3.5 Family

Soil families are separated from each other within a subgroup on the basis of soil characteristics, which are essential for plant growth or for the use of soils in engineering purposes.

3.6 Series

Soil series have a narrower range of properties than soil families. The names of soil series have no pedogenetic importance but are derived from a prominent geographic name, such as a nearby town or region where the series was first documented and described. Soil series are distinguished and separated on the basis of morphological and some chemical features noted in the field, as well as map able features.

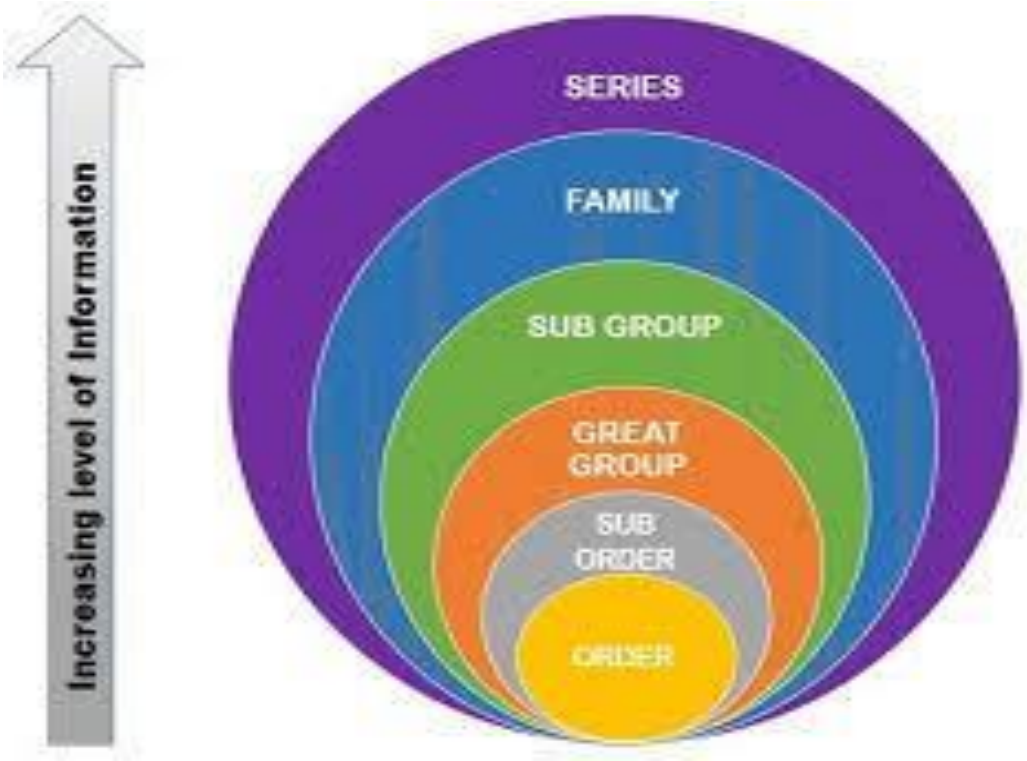


Figure 7.4

4. Diagnostic Horizons

Diagnostic horizons are quantitatively well-defined soil characteristics that can overlap one another. However, genetic horizons do not overlap each other. A typical diagnostic horizon can consist of part or completely one genetic horizons. Enclosure of more than one genetic horizon is also possible. These horizons are utilized to distinguish taxa among soil orders, suborders, great groups, and subgroups (Figure 7.5). When diagnostic horizons are formed at the soil surface, these are known as **epipedons**. But if these are formed below the soil surface are termed as **endopedons**. Endopedons are sometimes also called subsurface horizons. But some scientists define subsurface horizons separately. A short description of these horizons is given below:

4.1 Epipedons

There are 7 types of epipedons found in soils (Figure 7.5). A brief description of each is given below:

1. Mollic epipedons

It is thick (>25 cm), darker in color, rich in humus (>1% organic matter), and friable horizon having P_2O_5, which is less than 250 mg kg^{-1} of soil.

2. Anthropic epipedons

It is surface horizon formed by soil utilization by man for considerable long time for producing of irrigated crops or as home sites. This horizon has all characteristics of mollic epipedons except P_2O_5 which is equal or greater than 250 mg kg^{-1} of soil.

3. Umbric epipedons

It is thick and dark colored surface horizon. Its requirements are approximately similar to those of mollic epipedons with the exception of base saturation, that is less than 50% by NH_4OAC.

4. Melanic epipedons

It is a thick and intense black horizon that is present at or near the surface found in volcanic material. e.g., Al-Humus complexes

5. Plaggen epipedons

It is an artificial, man-made surface layer of more than 50 cm, which is formed due to consistent utilization and addition of manure from animal sheds.

6. Histic epipedons

This layer is enriched with organic matter and consists of more than 20-30% organic matter, depending on the clay contents and types.

7. Ochric epipedons

It is a light colored thin surface layer that does not meet the requirements for any other epipedons. This epipedons is most widespread in Pakistani soils.

4.2 Endopedons

Endopedons are produced below the surface of the soil. These might be exposed to the surface if the surface horizon has been eroded. These horizons reflect alterations caused by the genesis and/or weathering of parent materials. There are 8 types of endopedons found in soils (Figure 7.5). A brief description of each is given below:

1. **Argric horizon**
   It is a subsurface horizon made under the plough layer by the movement and deposition of clay + silt, and humus into the holes made by worms, the shrinking and swelling of cracks, and other similar pores.
2. **Argillic horizon**
   It is a subsurface horizon into which clay has moved. The presence of clay films on the surface of peds and within pores is evidence of clay migration and deposition. Argillic horizon has about 3-8% more clay than the overlaying horizon, depending on clay contents.
3. **Cambic horizon**
   It is a subsurface horizon that is colored or a weakly developed structural B horizon, which has textures finer than those of loamy fine sand. In this horizon, soil material is changed or transformed in situ.
4. **Kandic horizon**
   It is a subsurface horizon that has kaolinite-like clays.
5. **Natric horizon**
   It is a special type of argillic horizon having 15% or more exchangeable sodium. The sodium adsorption ratio (SAR) of the saturation extract is equal to or greater than 13. A prismatic structure is typically found in this horizon.
6. **Oxic horizon**
   It is a highly weathered B horizon which has kaolinite clay and oxides/hydrated oxides of Fe and Al, quartz, and other unweather able primary minerals.
7. **Sombric horizon**
   It is found in well-drained soils having illuvial (leach down) humus.
8. **Spodic horizon**
   It is a coarse-textured subsurface horizon in which organic matter and compounds of Al and Fe have been deposited.



Figure 7.5

5. Subsurface Horizons

These are formed due to the accumulation of solubilized substances. There are 3 types of subsurface horizons found in soils. A brief description of each is given below:

5.1 Gypsic Horizon

It is a horizon having gypsum accumulation and is a weakly cemented or non-cemented horizon. It has high contents of $CaSO_4.2H_2O$. Its thickness in cm × gypsum %age >150 cm percent (Figure 7.6).

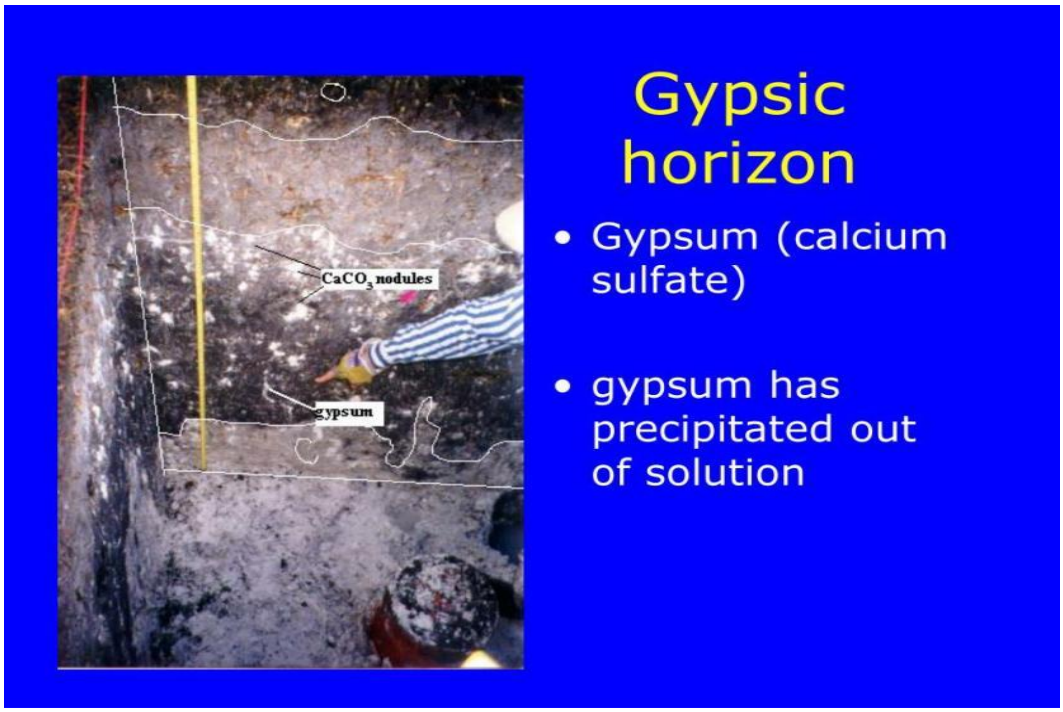


Figure 7.6

5.2 Salic Horizon

It is a horizon having soluble salts other than gypsum accumulation. A saline horizon is usually below the surface, at least 15 cm thick, and has equal to or more than 2% salts. Salt percentage by weight is equal to or more than 60% (Figure 7.7).

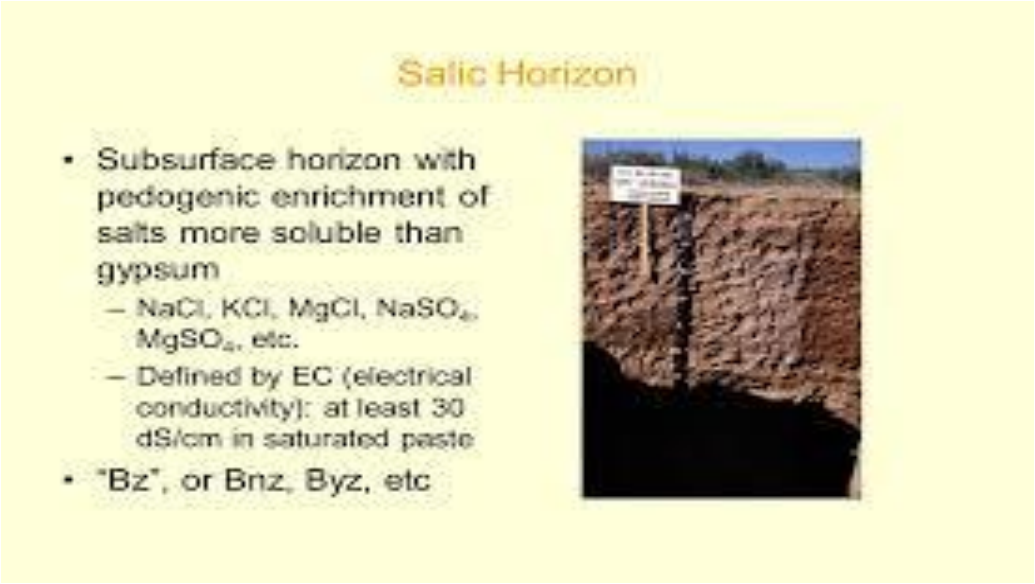


Figure 7.7

5.3 Calcic Horizon

It is a horizon with having accumulation of $CaCO_3$. There should be some evidence of secondary $CaCO_3$ concentration in it. This horizon can have $CaCO_3$ in soft powder or hard concretion forms (Figure 7.8).

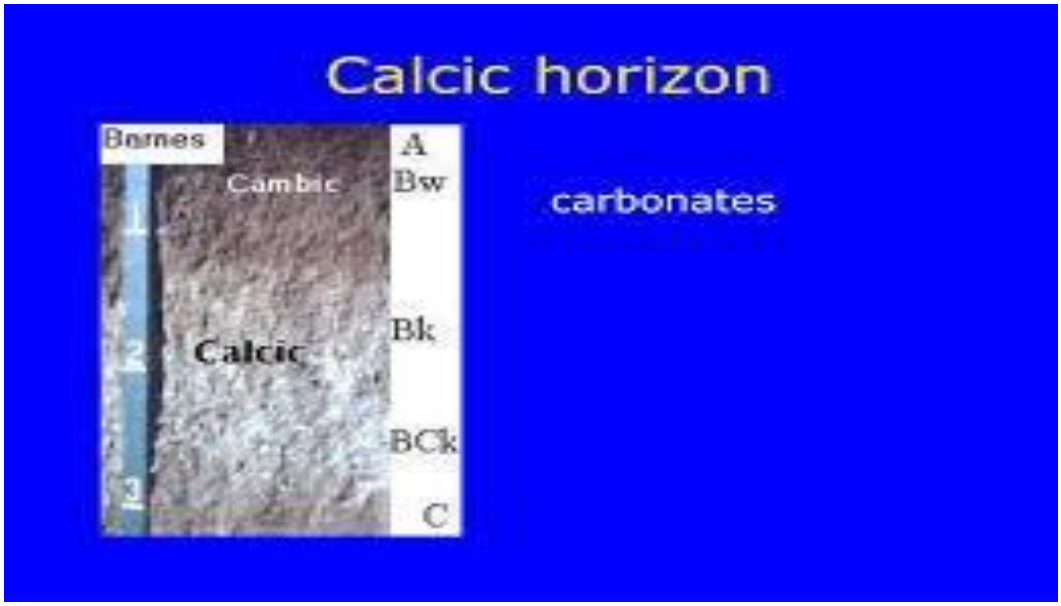


Figure 7.8

6. Land Capability Classification

Land capability classification is a system for assessing and grouping soils based on their relative suitability for common cultivated crops, grazing, or forestry. It considers general agricultural uses but does not account for specific agricultural or non-agricultural uses that may be possible when individual soils are evaluated in detail.

The differentiation or variation of classes is based on the degree of limitations imposed by a soil on its common agricultural usages (Figure 7.9). There are 8 land capability classes (Table 7.1).

Table 7.1: Land Capability Classes with Limitations

Sr. No.	Class Number	Limitations
1	I	Has none or only slight limitations for general cropping
2	II	Has minor limitations for general cropping
3	III	Has moderate limitations for general cropping
4	IV	Has severe limitations for general cropping
5	V	Has no limitations for grazing, but severe limitations for general cropping
6	VI	Has minor limitations for grazing, but no limitations for forestry
7	VII	Has severe limitations for grazing and for forestry
8	VIII	Lands of this class are unsuitable for even grazing or forestry, but may be utilized for recreational purposes

Land capability class is assessed by the degree of limitations, and land capability subclass is established based on the nature of limitations. Subclass is labelled by a small letter next to the class number, such as “II e” for erosion or “III w” for wetness, etc. Subclass descriptions are given below, permitting in order of significance. When two or more limitations exist, then one having considerably priority is shown (Table 7.2).

Table 7.2: Abbreviation of subclass with description

Sr. No.	Abbreviation of subclass	Explanation or description of the abbreviation
1	e	erosion, past erosion, or erosion hazard
2	r	irregular relief, making irrigation difficult
3	w	wetness, drainage problem, or flooded hazard
4	s	soil limitation, shallow, sandy, clayey, or stony soil
5	a	salinity and/or sodicity: saline, saline-sodic or sodic soils
6	x	river erosion or burial by river or wind deposits
7	c	unfavorable climate

Dominant limitation determines the subclass, except for climate, which is used only if there is no other limitation. If two limitations are of the same degree, the one with priority according to the above list must be considered. This system was developed by the US Salinity Conservation Service for rainfed soils. This system has been modified later to suit our prevailing conditions to make it feasible and applicable for both irrigated and rainfed regions. Class and subclass designations are preceded by "**ir**" for irrigated and "**d**" for dry-farmed soils. e.g.,

ir I – irrigated class I soil
d II – dry-farmed class II soil

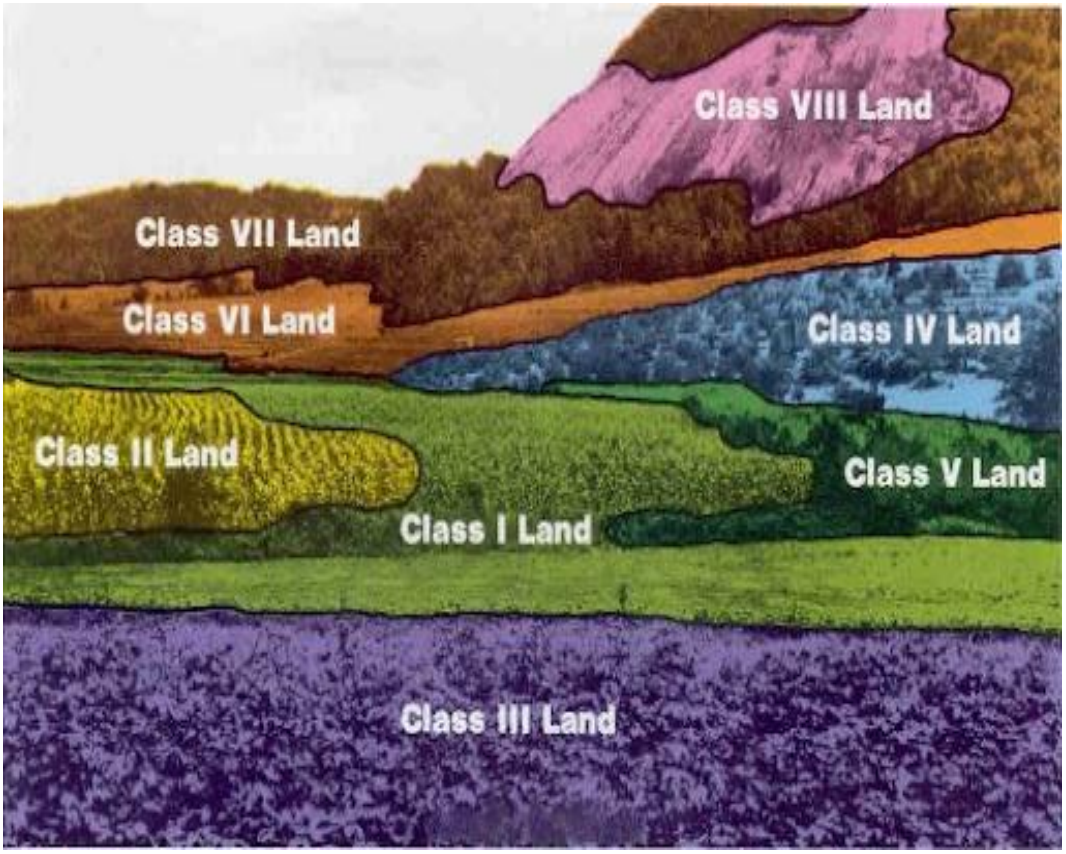

Class VIII Land
Class VII Land
Class VI Land
Class IV Land
Class II Land
Class V Land
Class I Land
Class III Land

Figure 7.9

SELF ASSESSMENT QUESTIONS

Question No. 1: Write a short note on soil classification.
Question No. 2: Differentiate between pedon and polypedon.
Question No. 3: Differentiate between soil classification and soil taxonomy.
Question No. 4: Explain the classification of different categories in soil taxonomy.
Question No. 5: Differentiate between soil order and suborder in soil taxonomy.
Question No. 6: Define soil order and explain all 11 soil orders.
Question No. 7: Differentiate between a great group and a subgroup in soil taxonomy.
Question No. 8: Differentiate between family and series in soil taxonomy.
Question No. 9: Define epipedons and explain various types of epipedons.
Question No. 10: What do you understand by diagnostic horizons?
Question No. 11: Define endopedons and explain various types of endopedons.
Question No. 12: Define subsurface horizons and explain the 3 types of subsurface horizons.
Question No. 13: Define land capability classification. Explain all 8 land capability classes with their respective limitations.
Question No. 14: Differentiate between land capability class and land capability subclass.
Question No. 15: Explain the system of identification of various land capability classes and land capability subclasses.

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Unit:8

SOIL ORGANIC MATTER

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INTRODUCTION

In agricultural sciences, the importance of this course is increasing day by day due to limited natural (water and land) resources, the need for more sustainable agricultural systems, and concern about environmental pollution. This course will introduce the students to the applied aspects of soil fertility and fertilizer use. The principles and methods of sampling and monitoring nutrients deficiency and toxicity symptoms will be covered, including soil quality criteria, and the diagnosis and monitoring of plant growth performance. It is evident that for optimum crop productivity, the soil nutrient status, i.e., the fertility of the soil, should be maintained by appropriate and efficient nutrient management. However, in order to make the best decisions about the plant nutrition, it is a basic course for soil science students. This course will improve knowledge by presenting and discussing the various management options for preventing and controlling plant nutrition problems in plants and soils.

OBJECTIVES

In the agricultural sciences, soil fertility and plant nutrition played an important role during the twentieth century in increasing crop yields. In the twenty-first century, the importance of this field is expected to increase due to limited natural resources (land and water), the need for more sustainable agricultural systems, and concern about environmental pollution.

LEARNING OUTCOMES

The students will be able to diagnose deficiency and toxicity symptoms of different nutrients in plants. It is evident that for optimum crop productivity, the soil nutrient status, i.e., the fertility of the soil, should be maintained by appropriate and efficient nutrient management. However, in order to make the best decisions on what measures and when to take one, one has to obtain actual information on soil nutrient status.

1. Soil Organic Matter

The term soil organic matter includes all materials of plant, animal, or microbial origin that are either produced within the soil or added to soil for the purpose of improving soil properties and supplying essential nutrients to plants. Farm yard manure, green manure and compost are prominent sources of soil organic matter



Figure 8.1

1.1 Composition of Soil Organic Matter

Organic matter derived from any source has the following composition (Figure 8.2).

1) Water
2) Mineral Matter
3) Organic Compounds

1) **Water**
   The quantity of water present in the organic matter of any source depends upon the type/nature of plants, different plants' organs and the age of plants. On a fresh weight basis, common organic matter has about 20-90 % water.
2) **Mineral Matter**
   The quantity of mineral matter in any type of organic matter ranges from 1-10 %. This amount is calculated on a dry weight basis. Important minerals present in any type of organic matter are nitrogen, phosphorus, calcium, potassium, magnesium, sulfur, copper, iron, zinc, and manganese etc.
3) **Organic Compounds**
   Generally, organic compounds present in any organic matter are of 3 types:
   - **i. Nitrogenous compounds**: The range of these compounds is 1-15% and these are proteins, amino acids, and nucleic acids.
   - **ii. Carbohydrates:** The range of these compounds is 1-5% and these are starch, sugar, hemicelluloses, and pectin.
   - **iii. Lignin:** It is a woody material, typically present in the range of 10-60%.

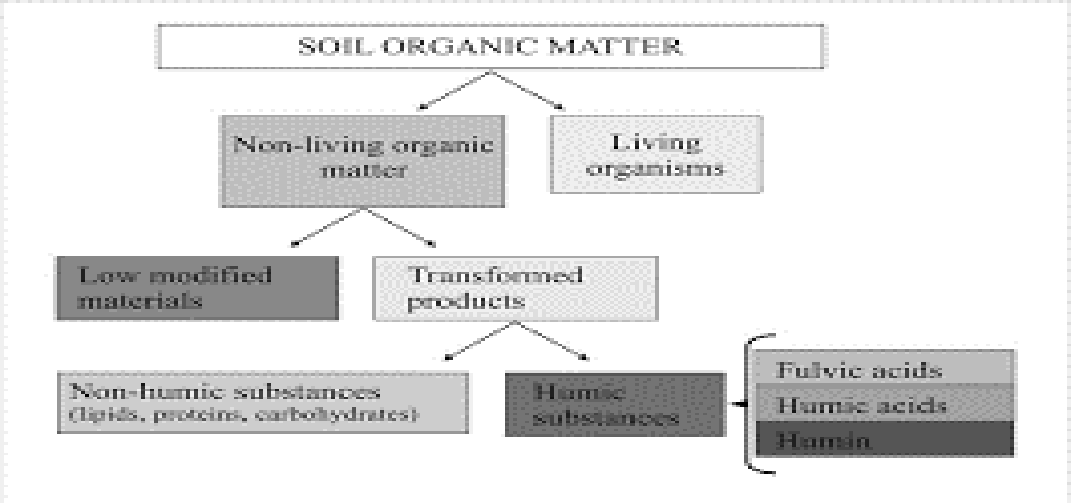


Figure 8.2

Decomposition of Plant Residues / Organic Matter:
The decomposition of plant residues to form organic matter occurs in 3 phases, which can overlap with each other.

2.1 Phase I: The decomposition process in soil starts from the breakdown of larger plant residues into smaller ones with the help of soil fauna such as termites, mice, and earthworms.

2.2 Phase II: Reduction in size makes the residues more vulnerable to attack by different soil microorganisms. Simple sugar, amino acids, proteins, and polysaccharides decompose very quickly and can be completely utilized within hours or days. Large macromolecules, which make up the bulk of plant residues, must first break down into simpler units before these can be further utilized as a source of energy. This is accomplished by the secretion of enzymes produced by microorganisms. Polysaccharides (cellulose) are first cleaved (broken down) into oligosaccharides and finally into simpler sugars, while protein is broken down into peptides and amino acids. Lignin compounds decompose very slowly. The rate of decomposition of plant residues depends upon their chemical constituents. Organic compounds can be listed below in terms of their ease of decomposition.

- Sugar starches simple protein
- Crude protein
- Hemicellulose
- Cellulose
- Fat waxes
- Lignin and phenolic compounds

2.3 Phase III: It is the final stage of decomposition of plant residues. In this phase, microbial breakdown occurs, and carbon dioxide (CO_2) is formed and resultantly energy is released.

Organic Compound + Oxygen = CO_2 + H_2O + Energy + Nutrients

$C_6H_{12}O_6 + 6H_2O = 6CO_2 + H_2O$ + Energy + Nutrients

2. Farm Yard Manure

Farmyard manure is abbreviated as FYM. It comprises various farm waste materials like excreta of various animals and feed waste materials of plant litter and microorganisms present in the soil (Figure 8.3).

Excreta: Excreta of animals is a mixture of urine and feces/dung. Excreta may be fresh or at various stages of decomposition. However, generally, excreta are partially decomposed.



Figure 8.3

3.1 Composition of Farm Yard Manure

The composition of FYM is quite different because it is a combination or mixture of feces and urine, along with other sources of farm waste. Similarly, moisture/water percentage in fresh FYM is also variable and ranges from 65-85% depending upon its source and stage. In addition to water, FYM is also an enriched source of various nutrients found in different contents. Important nutrients present in any type of FYM are nitrogen, phosphorus, calcium, potassium, magnesium, sulfur, copper, iron, zinc, and manganese, etc.

Humus

Humus is a general term used to describe decomposed organic materials formed after a series of extensive degradation processes and synthesis cycles. Generally, humus is highly acidic and varies in color from yellow to black. These decomposed substances possess compounds of higher molecular weights, like

- ✓ Humic acid
- ✓ Fulvic acid
- ✓ Hymatomelonic
- ✓ Humin

Manure

Manure may be defined as any material added to the soil to enhance growth of plants and maintaining soil health.

3. Manuring

Different methods or practices used to add manure to any soil for the purpose of increasing plant growth and maintaining soil health are called manuring.

4. Factors Affecting Quantity and Composition of Manure

In FYM, solid and liquid components are commonly present in the ratio of 3: 1. It has been noted that the solid fraction of FYM contains nitrogen up to 3.0 %, phosphorus up to 0.8 %, potassium up to 2 % and water 60-85% (Figure 8.4). Some important factors affecting the composition of any manure are as follows:

1. Age and types of animals
2. Type and quantity of feed consumed by the animals
3. Condition of animals
4. Work done or milk production by animals

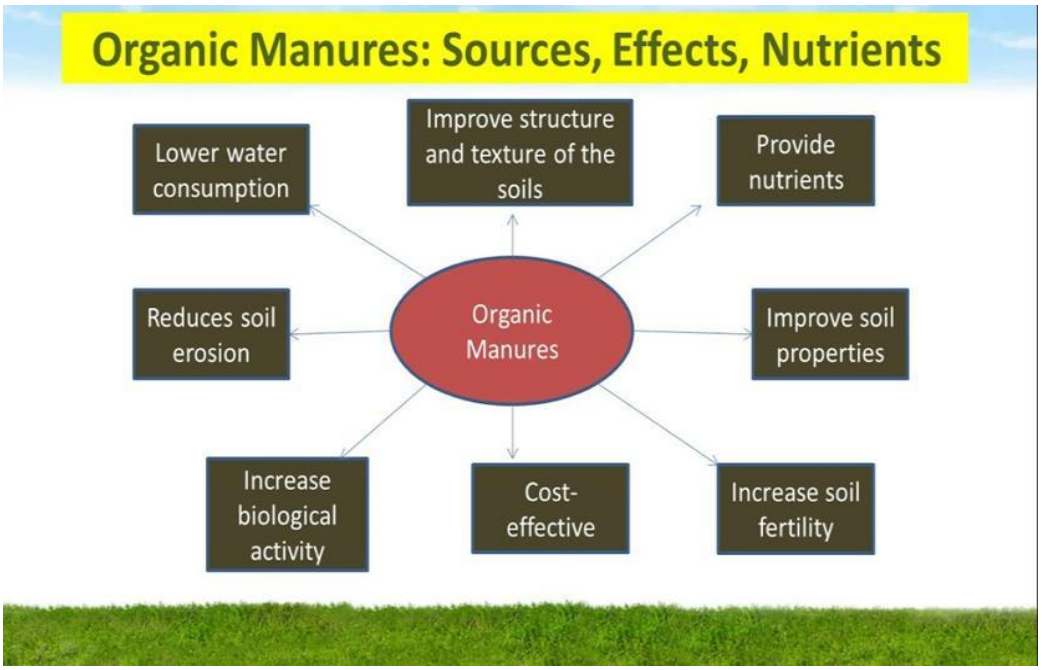


Figure 8.4\

5.1 Types of Manuring

There are two basic types of manuring

1. Manuring
2. Composting

5.2 Benefits of Manuring

Salient benefits or merits of manuring are as below:

1. It enhances soil productivity by reducing or controlling soil erosion.
2. It improves the activities of microorganisms in the soil
3. It helps with the reclamation and subsequent management of salt-affected soils.
4. It maintains and improves soil fertility, availability, as well as supply of nutrients to the plants.
5. It improves various physical (structure, aeration, porosity, and water holding capacity) and chemical (pH, EC, CEC, and buffering capacity) properties of soil.

6. Compost

Compost is a mixture of various decomposed organic materials. It is a good source of nutrients for plants and is used to maintain soil health (Figure 8.5).

6.1 Composting

Composting is the microbial decomposition of organic materials into partially decomposed organic matter. It is a controlled biological process that results in partial decomposition of organic/farm waste materials. The practice of composting involves the breakdown/decomposition and self-heating followed by cooler, slower decay of the remaining organic matter (Figure 8.6). Various types of bacteria, fungi, and actinomycetes play their active role in the process of composting. The end product of composting is called compost.



Figure 8.5

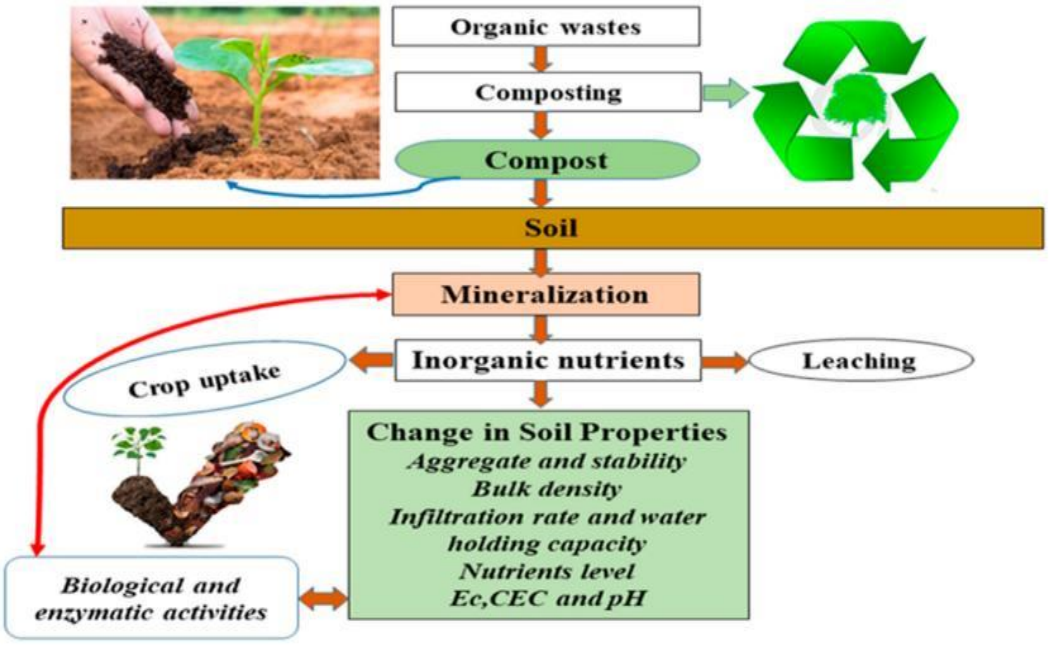


Figure 8.6

6.2 Advantages of Composting

1. Composting decreases the volume of waste materials, making it easier to transport them to the field for soil amendment (Figure 8.7).
2. It enhances soil quality, crop development, and soil fertility level.
3. Soil physical and chemical characteristics are improved by composting practice.
4. It is a very noble process and know-how to change organic waste materials to beneficial and nutrient-enriched soil conditioner and amendment.
5. Composting proves an economical method when compared with other practices employed for the same purposes.

6.3 Optimum Conditions for Composting

1. Presence of organic matter in huge amounts from any source.
2. Proper arrangement for air circulation through the composting heap.
3. Sufficient supply of water to keep composting materials moist or wet.
4. Availability of some nitrogenous materials to be used as a starter dose for composting.
5. Temperature in the warm range to achieve optimum decomposition of organic matter.

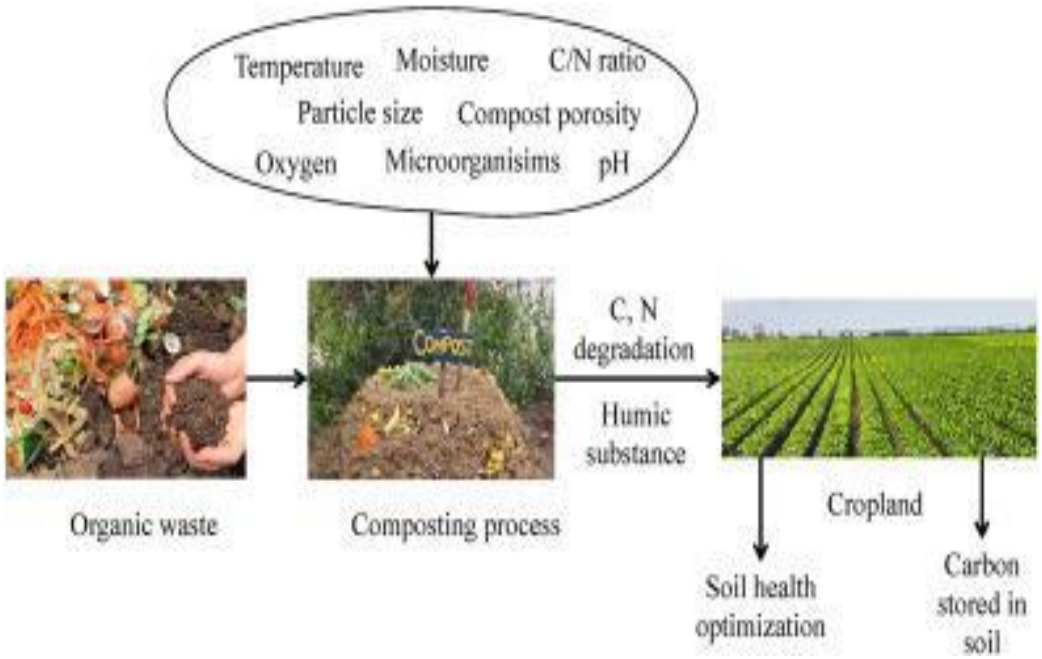


Figure 8.7

7. Green Manuring

When a crop is grown, ploughed, and mixed in the soil to enrich it with organic matter and subsequently improve soil health, it is called green manuring (Figure 8.8). Cop used for this purpose is called green manure crop, and this practice is called green manuring. Generally, a rotavator or any other deep plough is used for this purpose. A narrow Carbon-Nitrogen (C: N ratio) is required to enhance decomposition of green manure crops. To achieve this objective, any source of N fertilizer is used as a starter dose.

7.1 Characteristics of Green Manure Crops

Suitability of any crop to be utilized as green manure depends upon the following characteristics.

1. Growth of crops should be rapid and quick.
2. Crops should produce a large quantity of biomass within a short period of time.
3. Plant materials used for this purpose need to have a narrow C: N ratio.
4. Crops should have a wide climate and soil adaptation.
5. Leguminous crops should be preferred for this purpose because they are rich in nitrogen.
6. Crops should have the capability to grow on poor soil. e.g., legume crops
7. Crops should have the property to cover the maximum ground surface after their growth establishment.

Mostly guara, sesbania/jantar, berseem, soya bean, red clover (shaftal), and alfalfa are used as green manure crops.



Figure 8.8

8. Essential Plant Nutrients

Plants have a special capability to produce organic tissues openly from inorganic materials. Plants survive, develop, and reproduce by absorbing water and mineral elements from soil, CO_2 from the atmosphere, and energy from the sun to form plant tissues of various types.

8.1 Nutrient

Nutrients can be defined as any type of chemical compound that is required by living organisms for their growth and survival.

8.2 Nutrition

Supply and adsorption of different chemical compounds required by living organisms for their growth, maintenance, and metabolism may be defined as nutrition. Nutrition is the process of supplying nutrients to living organisms.

8.3 Metabolic Process

All living organisms require different nutrients to maintain their life and growth. After absorption, these nutrients are converted to cellular materials, which are used for different energetic processes taking place in the living cells of these organisms. This process is called the metabolic process or metabolism (Figure 8.9).

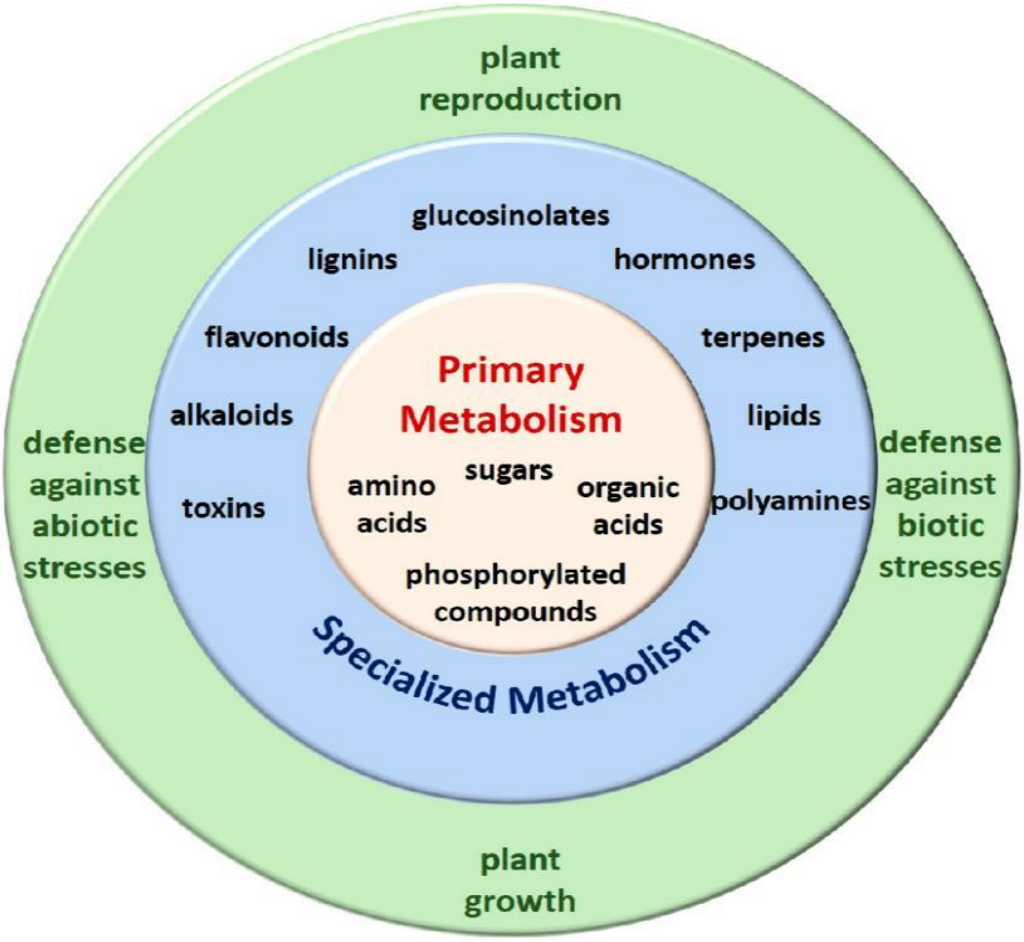


Figure 8.9

9. Essential Elements

When a plant is unable to complete its life cycle without any element, it is called an essential element. Essential elements have a specific role in the physiology of plants. If a deficiency of any essential element occurs in plants, only the supply of that element will prove a remedy for this deficiency.

9.1 Criteria for an Element to be Essential

Basic criteria for an element to be considered essential are as under:

1. Deficiency symptoms of an element in the plant body can be removed or improved merely by the supply of that precise element.
2. Deficiency of an element renders it unable for the plant to complete the vegetative or reproductive phase of its lifecycle.

3. An element is directly involved in the nutrition of plants, apart from its possible role in improving microbiological or chemical conditions in the soil.
4. There are 22 elements considered essential for plants required to complete their lifecycle. Out of these 22, 9 are macronutrients and 13 are micronutrients.

Macro-Nutrients
C, H, O, N, P, K, S, Ca, Mg
Micro-Nutrients
Fe, Cu, Mn, Zn, Mo, B, Cl, Ni, Na, Si, Co, Ci, Se

10. Pool of Nutrients in Soil

There are 4 pools of nutrients in the soil:

10.1 Water-Soluble Nutrients
10.2 Exchangeable Nutrients
10.3 Slowly Available Nutrients
10.4 Reserved Nutrients

A short description of these 4 pools is given below:

10.1 Water-Soluble Nutrients

These nutrients are present in the soil solution. These are found in ionic form and have much movement than exchangeable or unavailable nutrients. Hence, these nutrients are surely available for plant uptake. Soluble salts like chlorides, sulfates, and bicarbonates of sodium, potassium, calcium, and magnesium are mostly found in soil in sufficient amounts.

10.2 Exchangeable Nutrients

Exchangeable nutrients are present in the form of absorbed ions on the surface of minerals and organic compounds. These nutrients are also available to plants. These exchangeable nutrients have much importance from a plant nutrition point of view.

10.3 Slowly Available Nutrients

Slowly available nutrients are not easily available to plants, but have the least availability. These become available on the decomposition and breakdown of organic matter or the weathering of clay minerals.

10.4 Reserved Nutrients

This type of nutrient is inaccessible to plants. These are present as a combined, constituent, or integral part of organic or inorganic compounds which are not accessible to a plant's uptake. These nutrients only become available when they are decomposed.

11. Role of Macro-Nutrients (N-P-K) in Plant Growth

The role of macro nutrients like nitrogen, phosphorus, and potassium in the growth and development of plants is discussed briefly below:

11.1 Nitrogen (N)

Functions

1. Growth and development of all living tissues are increased by nitrogen (Figure 8.10).
2. The quality of all leafy vegetables and fodder is improved by nitrogen.
3. It improves the protein content of food grains.
4. Nitrogen is an essential component of chlorophyll, protein, protoplast, and nucleic acid.

Deficiency Symptoms of Nitrogen

1. Growth is stunted.
2. Less protein content.
3. Flowering is decreased significantly in acute deficiency of nitrogen.
4. Colour of older leaves becomes light green or pale yellow starting from the tip (Figure 8.11). It is followed by death or dropping of old leaves, depending on the degree of deficiency.

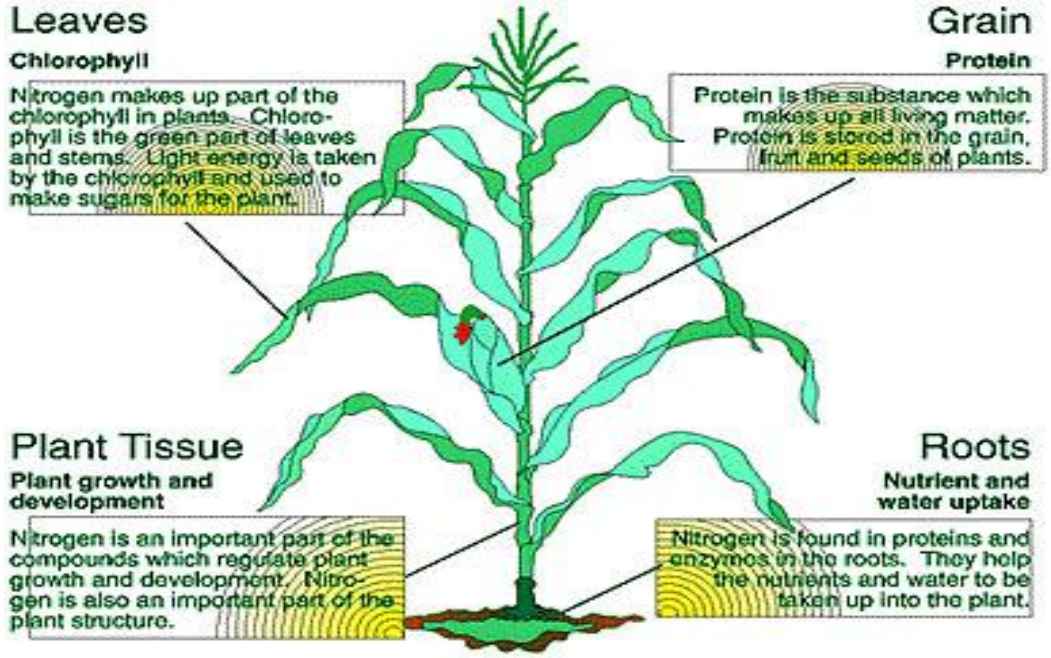


Figure 8.10



Figure 8.11

11.2 Phosphorus (P)

Functions

1. Phosphorus stimulates cell division and is a constituent of chromosomes (Figure 8.12).
2. It is essential for seed and fruit development and also stimulates flowering.
3. It is an integral component of nucleic acid, phospholipids, AMP, ADP, and ATP.

Deficiency Symptoms

1. Lack of seed development.
2. Maturity is delayed.
3. Overall growth is stunted.
4. Leaves and stem show purple colour in case of acute deficiency (Figure 8.13).

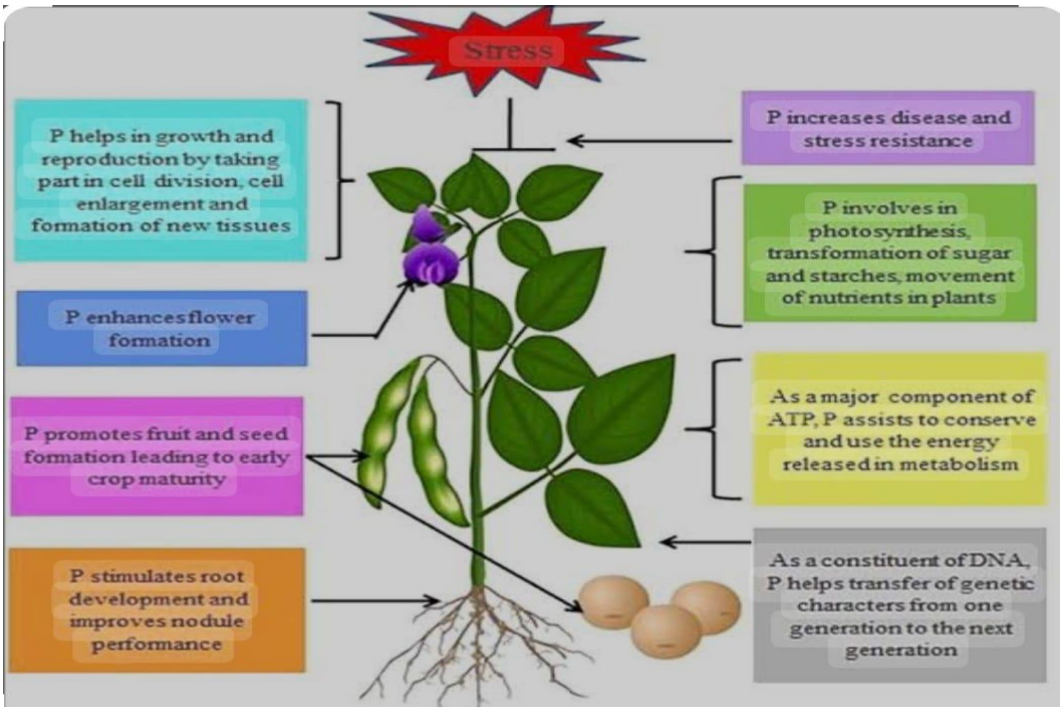


Figure 8.12



Figure 8.13

11.3 Potassium (K)

Functions

1. Potassium increases a plant’s ability to resist diseases.
2. It increases the plant's ability to resist cool conditions.
3. It facilitates the synthesis of carbohydrates and proteins by regulating stomata.
4. Potassium increases grain and seed sizes.
5. It improves the quality of fruits and vegetables.
6. It activates many enzymes which are involved in photosynthesis as well as protein and carbohydrate metabolism (Figure 8.13).

Deficiency Symptoms

1. Slow and stunted growth of plants.
2. Weak stalks and plants can lodge easily.
3. Shriveled seeds and fruits.
4. Deficiency of potassium causes chlorosis on leaves (Figure 8.14).

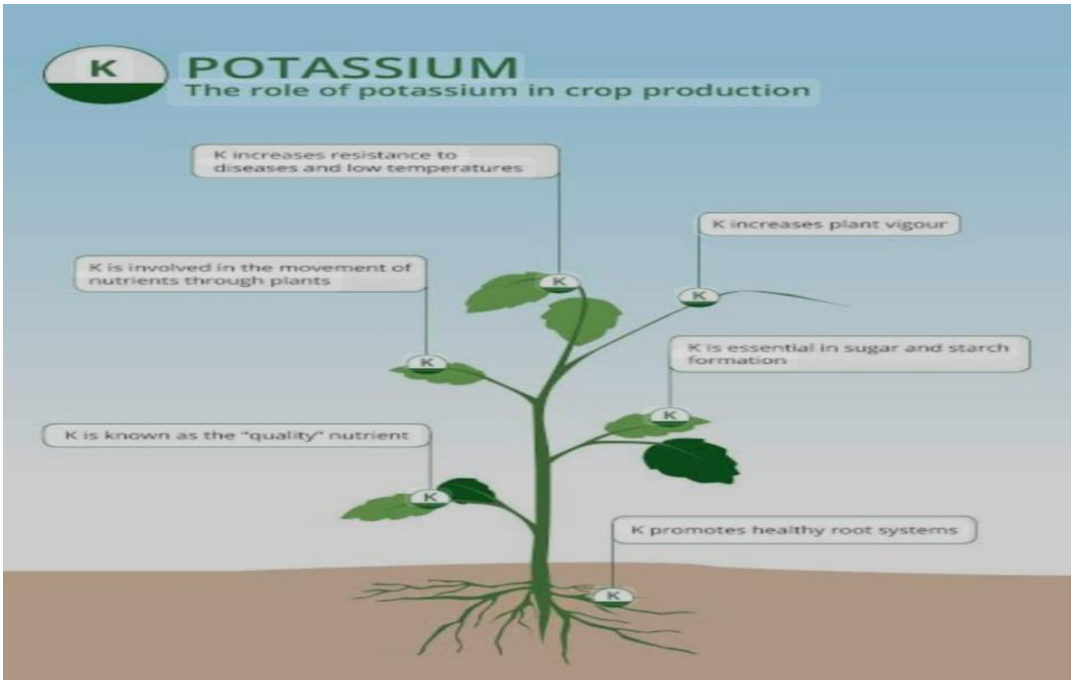


Figure 8.13



Figure 8.14

SELF ASSESSMENT QUESTIONS

Question No. 1: What is soil organic matter? Explain in detail the composition of soil organic matter.

Question No. 2: Explain the different decomposition phases of soil organic matter.

Question No. 3: What is farmyard manure? Explain in detail the composition of farmyard manure.

Question No. 4: Differentiate between humus, manure, and manuring.

Question No. 5: Write different factors affecting the quantity and composition of manure.

Question No. 6: Define manuring. Also, explain the types and benefits of manuring.

Question No. 7: Differentiate between compost and composting.

Question No. 8: Explain various advantages of composting. Also, write optimum conditions for composting.

Question No. 9: Define green manuring and explain the characteristics of green manure crops.

Question No. 10: Differentiate between nutrient and nutrition.

Question No. 11: What do you understand by essential plant nutrients?

Question No. 12: Differentiate between essential plant nutrients and essential elements.

Question No. 13: Explain the basic criteria for an element to be considered an essential element.

Question No. 14: Explain various pools of nutrients in soil.

Question No. 15: Enlist macro and micro nutrients for plants.

Question No. 16: Write various functions and deficiency symptoms of nitrogen in plants.

Question No. 17: Write various functions and deficiency symptoms of phosphorus in plants.

Question No. 18: Write various functions and deficiency symptoms of potassium in plants.

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Unit:9

SALT-AFFECTED AND WATERLOGGED SOILS

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INTRODUCTION

This course is designed to give students a good grasp of the theoretical and practical aspects of the problems, reclamation, and management of salt-affected soils. The course will start with a general overview describing the nature and extent of salinity, and the basic concepts underlying the diagnosis and the selection of salinity management options. This course aims at understanding the problems of irrigation waters and strategic treatment/management options for the sustainable and safe use of such low-quality waters in agriculture. In addition, the students will be equipped with the pre-requisite knowledge and skills necessary to become good researchers. At the completion of the course, the students will be able to understand issues related to salt-affected soils and low-quality waters, mathematical relationships to calculate SAR of soil solution from analysis of irrigation water, calculate average root zone salinity and salt balance, and strategies for the reclamation and management of salt-affected soils.

OBJECTIVES

Understanding and development of the classroom teaching (formal education) and learning activity play a pivotal role in the education system. This course will create awareness among the students about the problems, reclamation, and management of salt-affected soils. This course also aims at understanding the problems of irrigation waters and strategic treatment/management options for the sustainable and safe use of such low-quality waters in agriculture. In addition, the students will be equipped with the prerequisite knowledge and skills necessary to become a good researcher. This will in turn help develop research aptitude among the graduates, which will go a long way in their practical career.

LEARNING OUTCOMES

After the course, the students will be able to understand issues related to salt-affected soils and low-quality waters, mathematical relationships to calculate SAR of soil solution from SAR of irrigation water, calculate average root zone salinity and salt balance, and strategies for the reclamation and management of salt-affected soils.

1. Soil and Environment

Environment is a broader term that can involve many disciplines. Engineers, health professionals, biologists, geologists, and so many others are concerned with the environment in one way or the other way. There is a direct link between soil scientists and the environment, as soils play a key role in the chemical and biological cycles of many elements, including potential contaminants. Several contributions utilized in farming practices, like fertilizers & pesticides, are, to pollute when not disposed of appropriately. Soils in non-agricultural usage may be contaminated through inappropriate removal of litter and its derivatives. Eventually, everybody relies on soil not only for supplying food but also for fresh air.

The use of mineral fertilizers and pesticides, along with soil additives, is are effective method that can positively impact food production. Simultaneously, these practices impose serious dangers to both human beings and the environment. Hence, the effort of soil scientists is not restricted to farming since he is anxious by equally rural and urban problems.

Various human activities can pollute soil, leading to environmental contamination, for example, coal mining, the production and use of petroleum products, and nuclear waste. Soil protection and education are essential components of environmental awareness. The concept of soil value assessment is being developed by experts to help understand the overall impact of soil management on soil health.

2. Major Environmental Issues of Soil

Soil quality may be well-defined as the ability of a specific soil type to function within normal or managed environment limits to support plant and animal production, preserve or improve water value, and protect human health as well as habitation.

Most of the environmental issues of soil science fall into these categories.

I. **Reduction in soil quality due to improper contaminants.**
II. **Reduction is soil functions**.
III. **Soil as Contaminants**.

3. Soils and Chemical Pollution

Different aspects of soil and chemical pollution can be visualized in the following ways:

I. Soil is a primary recipient of waste products and chemicals used in daily life. It has always been convenient to throw things away that ultimately reach the soil.
II. Every year, numerous substances from various origins, like industrial, domestic, and agricultural activities, enter the soil. As soon as these

constituents enter the soil, they become part of life cycles that disturb entire systems of the lifecycle. One of the challenges is to understand how wastes affect these cycles and in turn all plants and animal's lives.

III. Tons of organic residues and animal manures are broken down by soil microbes every year, and large amounts of inorganic chemicals are fixed by soil minerals. But soil has a limited capacity to accommodate these chemicals, and hence, the quality of the soil environment suffers when these chemicals exceed this limit.

IV. Accumulation and release of these waste products are affected by soil processes. e.g., production of greenhouse gases such as N_2O, CH_4, and CO_2 is very much affected by soil processes (Figure 9.1). Other nitrogen and sulfur-containing gases coming from different industrial and domestic sources acidify the atmosphere and come to the earth in the form of acid rains.

V. Similarly, mismanaged irrigation results in the accumulation and buildup of salts, especially in arid region soils, causing formation of salt affected soils.

VI. Fertilizers and manures application leave excessive amount of nutrition in soil resulting pollution of ground and surface waters. Eutrophication of ponds, lakes and even slow moving rivers is evidence of such nutrient buildups.

VII. Industrial facilities handling animal products generate significant amounts of organic waste, which can be converted into valuable compost. However, proper management is crucial to prevent environmental pollution, pathogen transmission to humans and animals and unpleasant odors and aesthetics (Figure 9.2).

VIII. Effective waste management strategies include implementing sanitary practices, utilizing proper waste treatment and disposal methods, and converting waste into nutrient-rich compost. This approach promotes sustainability, reduces health risks, and supports environmentally friendly practices.



Figure 9.1



Figure 9.2

3.1 Eutrophication

It is the nutrient fortification of ponds, pools, and other similar rainwaters that encourages the growing of marine creatures that cause a shortage of oxygen in water (Figure 9.3 and 9.4).

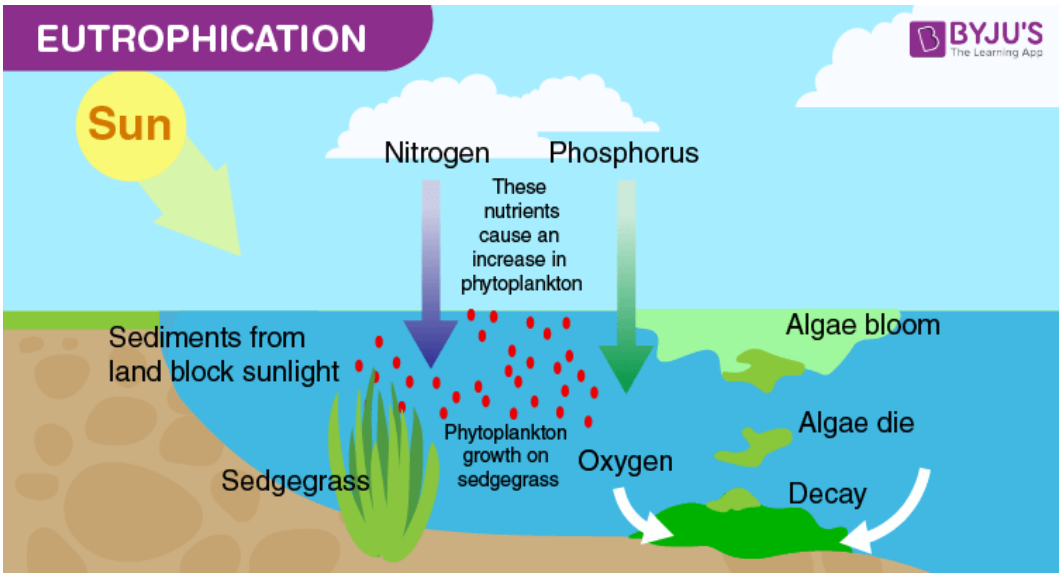


Figure 9.3

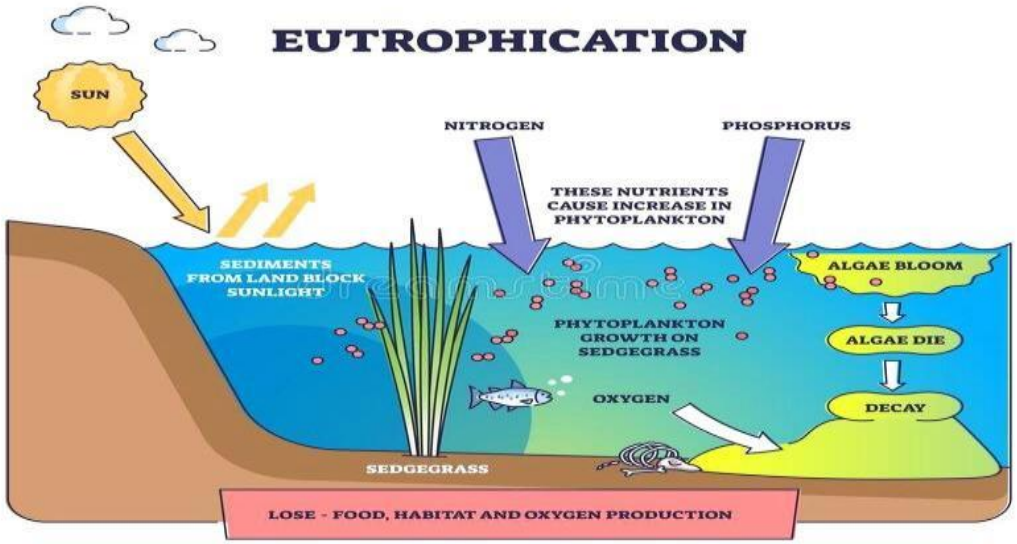


Figure 9.4

4. Major Kinds of Soil Pollutants

There are numerous kinds of soil pollutants (Figures 9.5 and 9.6) which are discussed below:

4.1 Pesticides

Numerous insects, unwanted plant types, plant infections, and nematodes are injurious to humans, animals, and plants. Chemicals have been used to control these pests. Pesticides have provided many benefits to society. These help to regulate mosquitoes and further vectors of human diseases such as yellow fever and malaria. Without biochemical weed control, minimal tillage methods will be inefficient. These also lessen the wastage of food by killing insects. By means of their movement on soil, some have become troublesome. Some chemicals persist in the soil for a long time. Some are harmful to beneficial insects and soil microorganisms.

Pesticide's Types

These are generally categorized as rendering to target pest organisms, e.g., insecticides, fungicides, herbicides/weedicides, and nematocides. Practically, all of these find their way into the soil. Since the initial 3 are utilized in huge quantities and hence, they further pollute soils and, resultantly need more attention.

Fate of Pesticides in Soils

These are used in the form of foliar spray, surface application, or combined with soil (Figures 9.7 and 9.8). In all cases, a significant proportion of these substances ultimately travels to the soil. In soils, these substances or pesticides may travel in six major directions, which are as under:

i. These might evaporate into the air without any biochemical alteration.
ii. These might remain adsorbed on humus and clay.
iii. These can travel down the soil through leaching.
iv. These may go through biochemical changes inside or on the soil surface.
v. These may be fragmented by soil microbes.
vi. They may be absorbed by plants and subsequently broken down within the plant tissues.



Figure 9.5

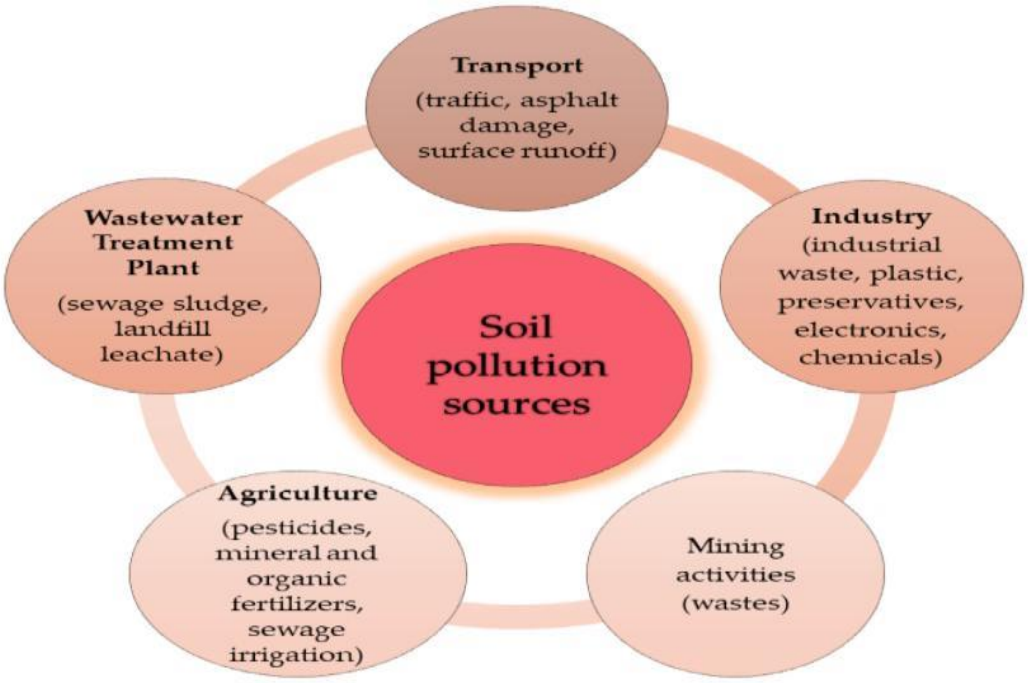


Figure 9.6



Figure 9.7



Figure 9.8

4.2 Inorganic Pollutants

Numerous inorganic substances pollute the soils, and these compounds are also toxic to animals and humans. Out of these inorganic elements, Cd, Cr, and Hg are tremendously fatal. While Pb, Ni, Mo, and F are reasonably but, B, Cu, Mn, and Zn are comparatively little in poisonousness (Figure 9.9). There are many causes of these chemicals that may accumulate in soils. The burning of fossil fuels and various processing methods release many of these substances into the atmosphere, which are then deposited into the soil.

Pb, Ni, and B are fuel essences that go to the atmosphere and then move to the soil by rainfall and snow. Borax is utilized as a fertilizer that ultimately reaches the soil. Use of products containing these chemicals has increased in recent years, and hence, chances of soil contamination have also increased. These chemicals exist in the atmosphere in large quantities, which are consumed by the public from air, food, and water.

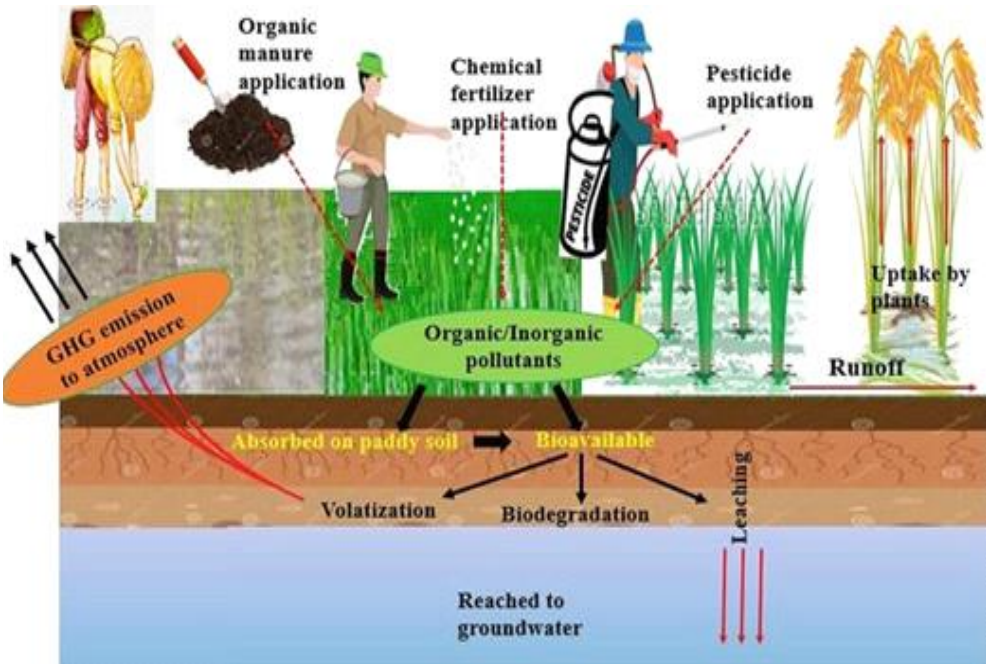


Figure 9.9

4.3 Organic Wastes

Soils act as an alternative disposal sink for municipal and industrial wastes that is being used more and more widely. Numerous carbon-based materials can recover soil physical and chemical characteristics to deliver desired elements to enhance the yield of crops. Optimistic special effects have fortified constant land submission

by these litters. Nevertheless, after extra amounts are added, production may be lessened due to soil & water pollution. e.g., nitrate ions are subjected to leaching into groundwater water which may be utilized for drinking purposes by animals or humans (Figure 9.10).

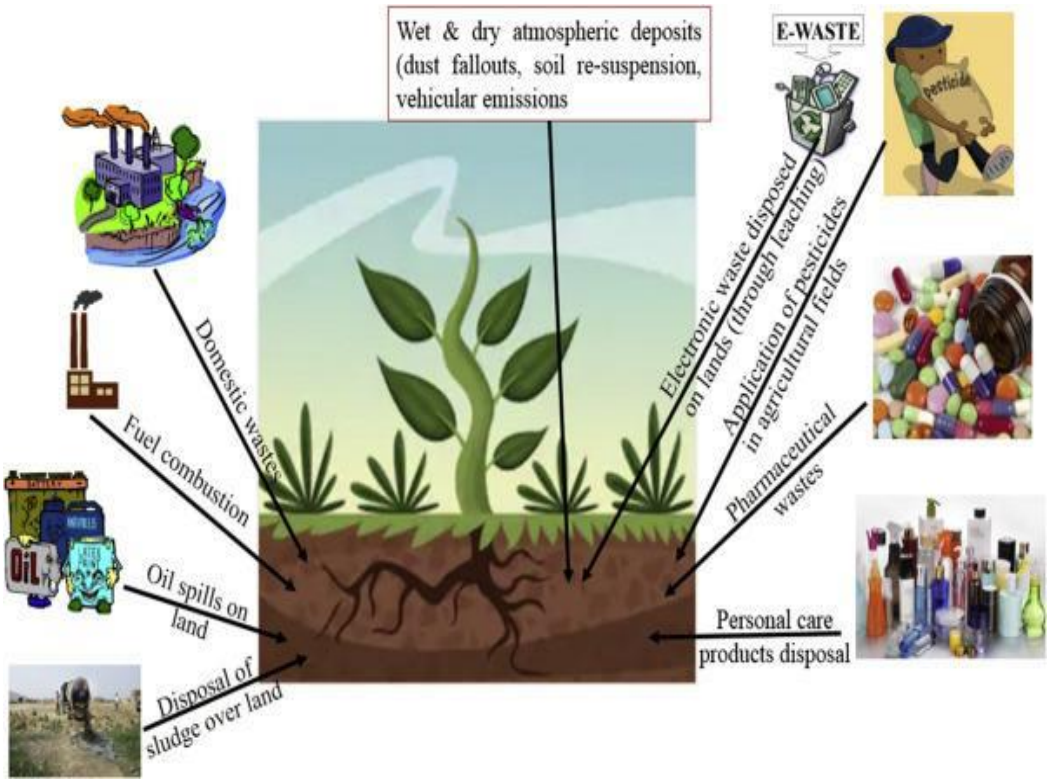


Figure 9.10

4.4 Salts

Pollution of soils through salts is also a unique method of contamination, and it is not a new problem. Salts accumulate in the soil through irrigation water (Figure 9.11). Salts come up from lower layers and become thick in the surface layers of soil. Management of salinity is determined practically and exclusively through managing brackish water (Figure 9.12). In certain regions, elimination of additional water is done by installing an appropriate drainage system. Toxic sodium ions can be eliminated through the use of gypsum.



Figure 9.11

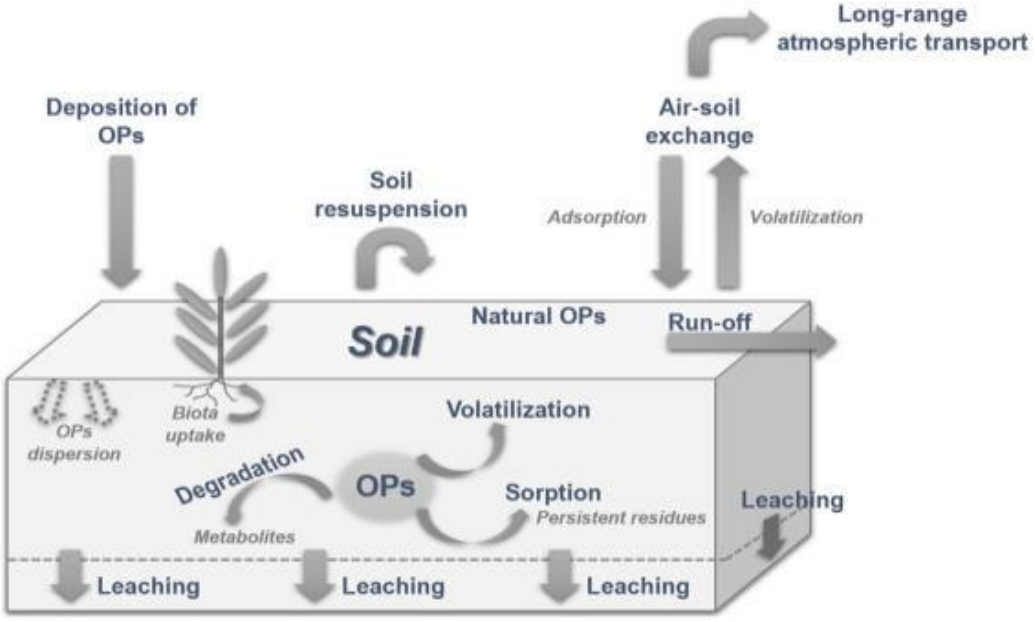


Figure 9.12

4.5 Radionuclides

Nuclear explosions related to weapons testing provide an additional source of soil pollution. Naturally, some nuclides are found in soil, and due to their presence, several nuclear substances are detected in soils (Figure 9.13). This level of nuclear substances present naturally in soils is not injurious at all. Although testing of nuclear weapons also does not prove fatal in most cases. But it is fatal when it falls directly on the growing plants from the above surface, and it proves as a source of pollution for the soil.

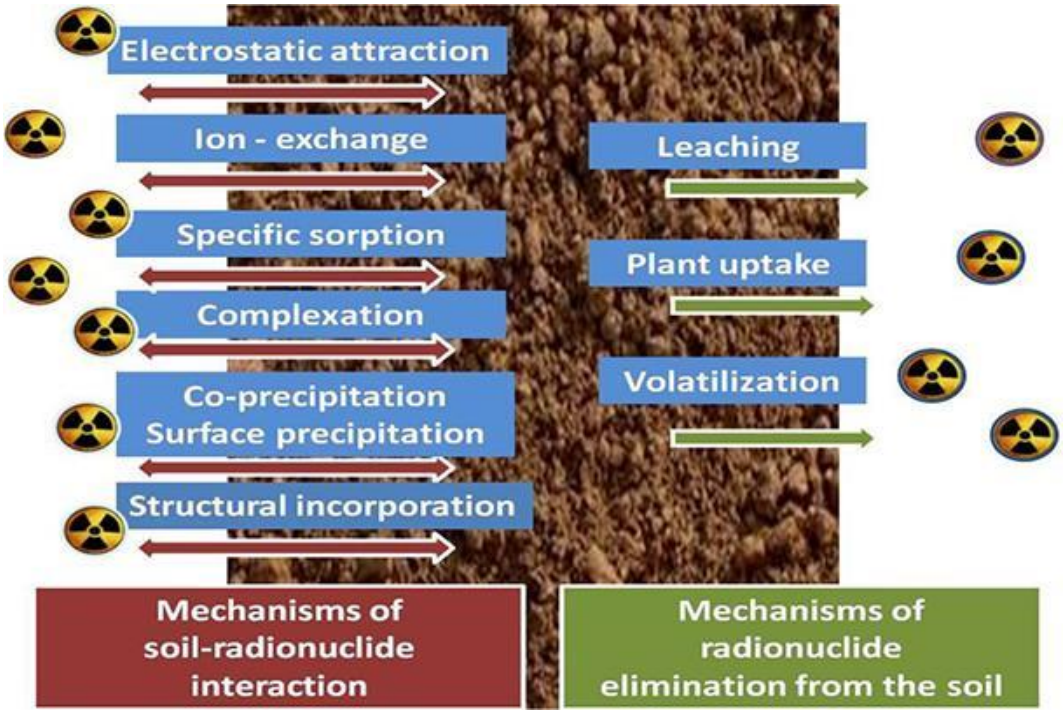


Figure 9.13

4.6 Acid Rains

In the nonexistence of polluting atmospheric fumes, rainwater shows a pH value of 5-6 due to the formation of H_2CO_3 from CO_2 found in the air (Figure 9.14). This pH value is lessened to a level of 4.0 in regions having the burning of fossil fuels or smelting of sulfide metals. In an extreme situation, this pH value is further reduced to a level of 2.0. This condition proves a severe threat for the people (Figure 9.15). Oxidation of N and S-enriched gases and their dissolution in water usually cause acid rain. Consequently, fumes of HNO_3 and H_2SO_4 fall with the rainwater, which are polluting soil (Figure 9.16).



Figure 9.14

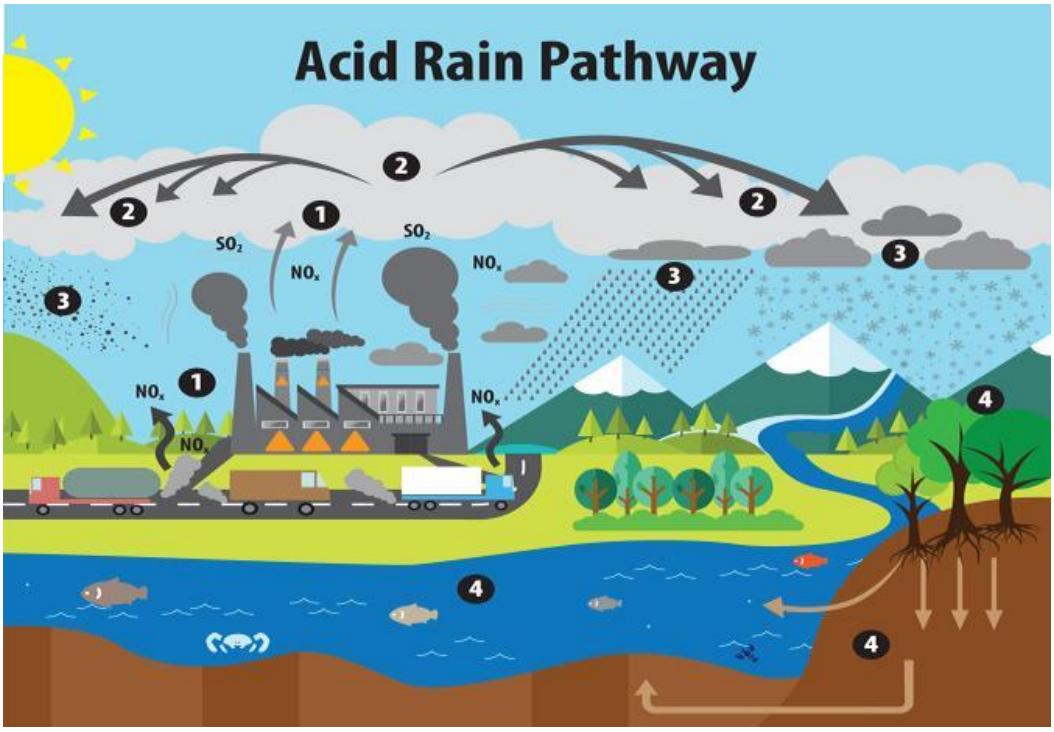


Figure 9.15



Figure 9.16

Ultimate Comments

Three main points can be drawn roughly about soils relationship with the environment.

I. Soils are valued assets and therefore, these must be secured on or after ecological pollution.
II. Due to their massiveness and extraordinary capabilities to adsorb, grip, fix, and breaking down supplementary elements, soils deliver many approaches for removal and operation of various wastes that may pollute the environment.
III. Soil pollutants and the byproducts of their decomposition may prove noxious to humans and other animals when noxious waste travels from soil to plants, soil air, and soil water.

Role of Soil Scientists

To gain a superior, thoughtful knowledge of soil usage and protection in waste management efforts, soil scientists should devote their research efforts to environmental quality problems. Furthermore, they should contribute to finding better ways to clean up environmental contamination.

5. Salt-Affected Soils

Word salt-affected soils is a collective term used for such soils which have high concentrations of any type of salt to impair plant growth. These salts may be of many kinds. e.g., soluble salts, exchangeable sodium, or a combination of both. Soluble salts are of 4 types, like NaCl, Na_2SO_4, $CaCl_2$, and $MgSO_4$. Whereas exchangeable sodium exists in the form of 2 salts, like $NaCO_3$ and $NaHCO_3$.

These soils are found across the globe and are linked with arid and semi-arid climates. The chemistry of these soils, and the physiology of plants growing from these soils, is quite different from that of the normal case. These soils need to be reclaimed for the sustainable growth of crops.

6. Importance of salt-affected soils

These soils are very important for the economy of Pakistan. The total geographical area of Pakistan is 79.61 million hectares, and out of this total area, about 6.68 million hectares soil is salt-affected. The current population of the country is 254.17 million, and it is increasing at the rate of 1.93% per annum. According to estimates, the population may approach figure of about 380.0 million in 2050. At the time of independence in 1947, the same was around 70 million for total east and west Pakistan with 33.7 million for west Pakistan.

Total cultivated area of Pakistan is about 22.04 million hectares and 6.68 million hectares is salt affected. Hence, it is dire need of time to reclaim and bring this 6.68-

million-hectare area under cultivation to feed ever increasing population of the country (Figure 9.17). There is no other option rather than rehabilitation of salt affected soils for prosperity of nation and country.



Figure 9.17

7. Classification of Salt-Affected Soils

Keeping in view the types of salts present, these soils are classified into 3 groups.

7.1 Saline Soils

These are soils that have enough quantities of soluble salts and can negatively affect plant growth. These soils do not have an excess of exchangeable sodium to impair plant development. Four types of soluble salts (NaCl, Na_2SO_4, $CaCl_2$, and $MgSO_4$) are analyzed in these soils (Figure 9.18). Soluble salts are measured in terms of electrical conductivity (EC) using a conductivity meter (Figure 9.19). Hence, saline soil may be defined as soil having values of EC greater than 4.0 dS m^{-1}, pH equal to or less than 8.5 and SAR equal to or less than 15. SAR is an abbreviation of sodium adsorption ratio. These NaCl, Na_2SO_4, $CaCl_2$ and $MgSO_4$ salts are found in an approximate ratio of 30: 40: 20: 10.

7.2 Sodic Soils

These soils have an excess of exchangeable sodium to impair plant development. These are soils that do not have enough quantities of soluble salts and can negatively affect plant growth (Figure 9.20). Exchangeable sodium is measured in

terms of the sodium adsorption ratio (SAR) using a flame photometer (Figure 9.21). Hence, sodic soil may be defined as soil having values of EC equal to or less than 4.0 dS m^{-1}, pH greater than 8.5 and SAR greater than 15. Either each of these salts ($NaCO_3$ and $NaHCO_3$) or both in combination is causing high contents of exchangeable sodium. Physical properties of sodic soils are impaired due to an excess of exchangeable sodium.

7.3 Saline Sodic Soils

These soils have both soluble salts and an excess of exchangeable sodium to impair plant development. Hence, saline sodic soil may be defined as soil having values of EC greater than 4.0 dS m^{-1}, pH greater than 8.5 and SAR greater than 15 (Figure 9.22). A combination of pH and EC meter or separate ones are used for the measurement of pH and EC of these soils (Figure 9.23).



Figure 9.18

Conductivity Meter



Figure 9.19

Sodic Soil



Figure 9.20

pH Meter



Figure 9.21

Saline Sodic Soil



Figure 9.22

Combined EC & pH Meter



Figure 9.23

8. Genesis/Formation of Salt-Affected Soils

Genesis means formation or development of salt affected soils. Some basic causes or factors responsible for the formation of salt-affected soils are listed below:

1. Parent Material
2. Uneven Distribution of Rainfall
3. Arid Climate
4. Surface Roughness
5. Irrigation with Salty Water

9. Reclamation of Salt-Affected Soils

9.1 Objectives of Reclamation

Objectives of reclamation are as under:

1. To enhance yield per unit area and thus overall production of all crops.
2. To increase water use efficiency through reclaiming patchy salt-affected soils occurring in association with good soils and thus increasing crop production per unit of irrigation water applied.
3. To improve farmers' living standard and lifestyle through increased yield from a given
   i. Area of land
   ii. Quantity of irrigation water
   iii. Amount of fertilizers and other inputs.

9.2 Pre-Requisites of Reclamation

a) Crust removal
b) Leveling of land
c) Deep ploughing
d) Strong boundaries of fields
e) Soil sampling and analysis
f) Good subsurface drainage
g) Arrangement of a sufficient amount of good-quality water

10. Various Methods of Reclamation/Approaches of Reclamation

10.1 Physical or mechanical reclamation

Use of machinery i.e., deep ploughing, sub-soiling, profile inversion, vibro drainer, rotavation, sanding, chiseling, and crust removal.

10.2 Biological Reclamation

Addition of organic material and growing of salt-tolerant grasses, crops, and bushes/trees.

10.3 Hydrological or hydro technical reclamation

a. Installation of drainage system (Tile drain and open drain).
b. Boring of tube wells.
c. Leaching of salts through excessive irrigations.

10.4 Chemical reclamation

Addition of chemical amendments, mixing, and subsequent leaching.

10.5 Integrated Approach

A combination of two or more of the above approaches.

10.6 Soil Amendments

a. The most feasible and economical chemical used for this purpose is gypsum ($CaSO_4.2H_2O$). It is called the superlative amendment in Pakistan. Once it is used on sodic soil, the following chemical reaction occurs and soil is reclaimed.

$$2\,Na\,X + CaSO_4.\,2H_2O \rightleftharpoons Ca\,X2 + Na_2\,SO_4 + 2H_2O$$

b. In case of dense sodic calcareous soil, sulfuric acid (H_2SO_4) is also used in combination with gypsum. In this case, the chemical reaction will be as under:

$$H_2SO_4 + CaCO_3 \rightleftharpoons CaSO_4 + CO_2 + H2O$$

$$Na\,X + CaSO_4 \rightleftharpoons Ca\,X_2 + Na_2SO_4$$

Precaution: Sulphuric acid should be added to water.

10.7 Comparison of Amendments Equivalent Quantity

Quantity of H_2SO_4 eq to Gypsum	=	0.57
Quantity of H_2SO_3 eq to Gypsum	=	0.47
Quantity of HCl eq to Gypsum	=	1.71

10.8 Post-Reclamation Strategies

1) First crop should preferably be Rice.
2) Selection of a high delta salt-tolerant crop sequence.
3) Inclusion of green manuring crops in crop rotation.
4) Addition of organic material.

5) Frequent soil testing.
6) Fallowing should be completely avoided.

11. Waterlogged Soils

The meaning of the word waterlogged is saturation or nearly saturation of anything with water. Therefore, saturation of soils with water for an adequately prolonged period is called waterlogged soils (Figure 9.24). This saturation is the result of a high water table and has a negative effect on the majority of crops. Sometimes, soils are saturated with water on a temporary basis for a short duration, but in other cases, soils are permanently saturated with water due to the water table near the soil surface. Both of these types are known as waterlogged soils. Hence, when excessive water is present in the root zone of soils or on the surface, it will definitely cause waterlogging. Its reason may be natural or artificially induced by humans. Due to waterlogging, oxygen becomes deficient for plants in arid climatic regions, and soils are exposed to salinity threats. It is said that salinity and waterlogging are coupled problems in most cases (Figure 9.25). The effects of waterlogging are very drastic in many ways and affect crop yields negatively (Figure 9.26).

Pakistan has the largest irrigation system, spreading over an area of 17×10^6 ha. Nearly 90 % of its agricultural output comes from irrigated lands. Irrigation in this area is very old. However, the construction of the present system started a century ago.

Formerly, lands nearby to watercourses were irrigated by barrage canals. Groundwater tables remained equally deep, using a few exceptions:

1. Near the confluences of rivers
2. Beneath narrow strips of grasslands alongside the canals, which are submerged annually during the monsoon period.

Seepage of water through waterways, percolation of rainfall, and irrigation water applied within a particular area were in symmetry by the release of groundwater via evapotranspiration and by the transfer to sea.

11.1 Types of Waterlogged Soils

There is no single internationally accepted categorization of waterlogged soils. In general, water table depth inside 1.5 m of the soil surface is considered a criterion for the identification of waterlogged soils in Pakistan. Some scientists categorized waterlogged soils through the relationship of salinity. In this way, the following 2 groups are formed:

a) Saline Waterlogged Soils
b) Non-saline Waterlogged Soils

Waterlogged Soils



Figure 9.24

Waterlogging and Salinity in Pakistan



Figure 9.25

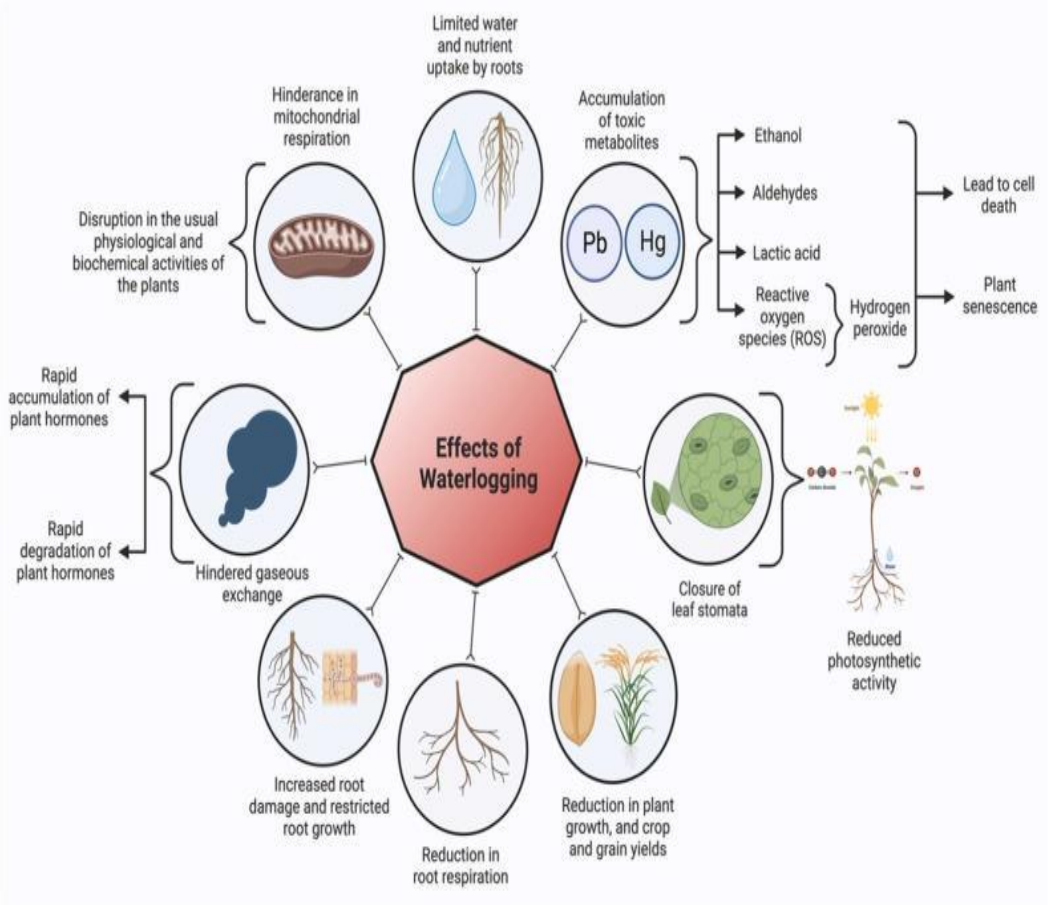

Limited water and nutrient uptake by roots
Hinderance in mitochondrial respiration
Accumulation of toxic metabolites
Ethanol
Aldehydes
Lactic acid
Reactive oxygen species (ROS)
Hydrogen peroxide
Lead to cell death
Plant senescence
Disruption in the usual physiological and biochemical activities of the plants
Pb
Hg
Rapid accumulation of plant hormones
Rapid degradation of plant hormones
Hindered gaseous exchange
Effects of Waterlogging
Closure of leaf stomata
Reduced photosynthetic activity
Increased root damage and restricted root growth
Reduction in root respiration
Reduction in plant growth, and crop and grain yields

Figure 9.26

11.2 Extent of waterlogged area

The extent of these soils in Pakistan is described by different agencies such as the Directorate of Land Reclamation (DLR), WAPDA, and the Soil Survey of Pakistan (Table 9.1). Some agencies used criteria of 3-meter depth water table to qualify a soil to be waterlogged, and others insisted on a 1.5-meter depth. Most of the waterlogged soils have patchy/surface salinity. Estimates of a seasonal survey show a greater than two-fold increase in the extent of waterlogged soils during the post-monsoon period.

Table 9.1: Extent of waterlogged area (water table within 1.5 m) in Pakistan (000 ha)

Depth of water table (meters)	Name of Province				Total
	Punjab	Sindh	KPK	Baluchistan	
	Non-Saline Waterlogged Soils				
1.0-1.5	239.2	39.4	39.7	-	318.3
0.5-1.0	78.6	189.2	20.7	4.3	292.8
< 0.5	368.0	280.0	30.3	137.8	816.1
	Saline Waterlogged Soils				
< 1.5	10.0	116.0	1.1	-	127.1
Total	695.8	624.6	91.8	142.1	1554.3

11.3 Sources/Causes of Waterlogging

The main sources of waterlogging are recharge from:

1. Canal irrigation system comprising all distributary branches
2. Irrigated fields and water courses
3. Rainwater
4. River water
5. Water Movement below the surface

Development of basic infrastructure and construction of roads, factories, and housing colonies has disturbed natural water movement. Resultantly, water remains standing at lower places and becomes a cause of waterlogging (Figure 9.27).



Figure 9.27

11.4 Control Measures/Management/Remedies of Waterlogged Soils

Important control measures are as under:

1. Lining of canals may reduce seepage by about 75 %.
2. Tree plantation along the spoil banks.
3. Construction of surface drains can lessen seepage losses and rainwater runoff.
4. Pumping of groundwater proved to be beneficial in dropping the low water table. This practice can provide water for crops after testing its quality.
5. Building of seepage interceptor drains parallel to lower side of main canals proved to be good strategy in this regard. This practice was done on both sides of the Upper Chenab Canal.

Hence, building of drainage system and driving groundwater through tubewells demonstrated to be relatively beneficial for controlling waterlogging.

12. Future Strategies for Managing Waterlogged Soils

A sustainable irrigated agriculture in the Indus Basin requires a strategy that should be based on:

1) Water conservation measures to increase availability of water at the farm gate include lining at least one of the conveyance channels and improved on-farm water management (Figure 9.28).
2) Rehabilitation and extension of the surface drainage system.
3) Implementation of high-cost sub-surface drainage where urgently required.
4) Improved management of the system, including studies on salt movement, mining of groundwater and salt build up in fresh groundwater areas, disposal and utilization of poor quality drainage effluent, and drainage studies in brackish groundwater areas (Figure 9.29).
5) Environmental impact of the drainage projects to alleviate drainage and public health problems.
6) It is proposed that some staff of the agricultural extension department must be given intensive training in soil reclamation technology so that they can handle the problem with confidence, and they can train & guide the farmers properly and accordingly.
7) There is a strong need to initiate new projects on farmers' fields in some participatory programs comprising of scientist-extension worker-farmer trio.
8) All soil reclamation facilities, such as subsidies on canal reclamation supplies, gypsum purchase, and bank loans for soil reclamation purposes, provision of relevant agricultural machinery at reduced rates etc., should be provided in kind through the trained reclamation extension workers. This is essential because soil salinization and sodification tend to persist under the arid and semi-arid climates of irrigated lands in Pakistan, necessitating strong infrastructure to address these issues.

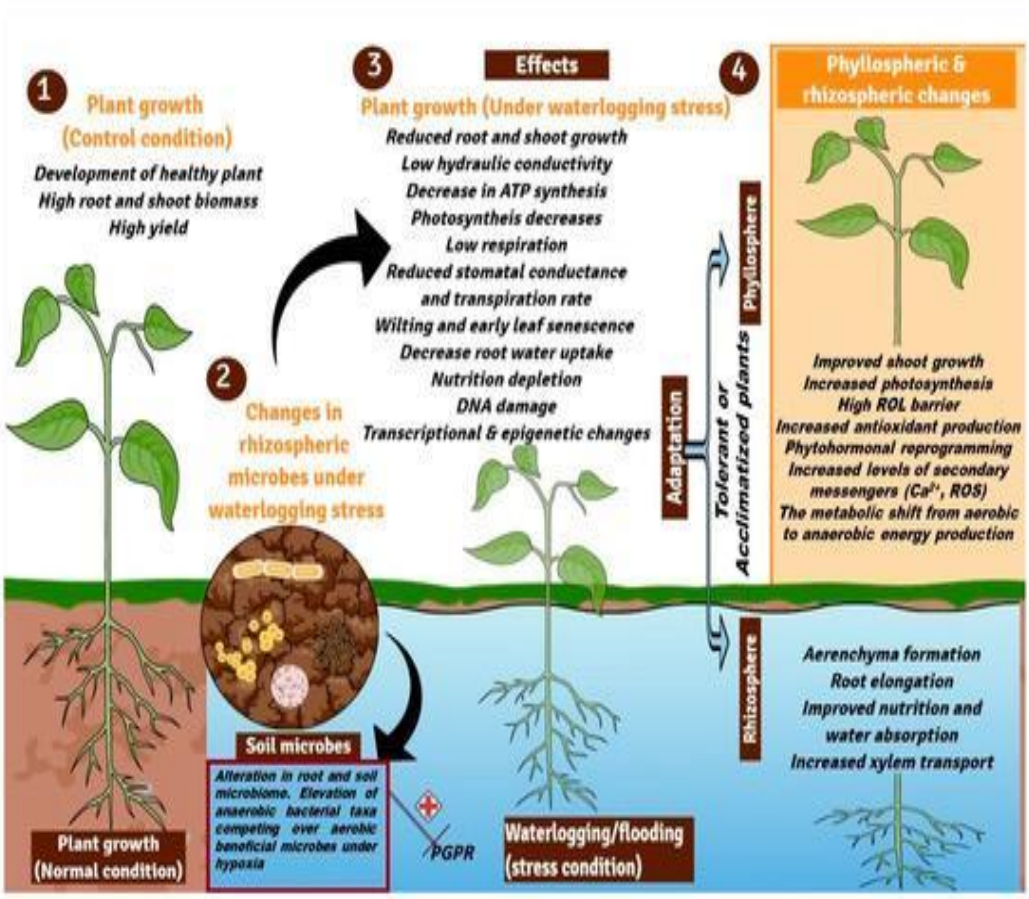

1
Plant growth
(Control condition)
Development of healthy plant
High root and shoot biomass
High yield
2
Changes in rhizospheric microbes under waterlogging stress
3
Effects
Plant growth (Under waterlogging stress)
Reduced root and shoot growth
Low hydraulic conductivity
Decrease in ATP synthesis
Photosyntheis decreases
Low respiration
Reduced stomatal conductance and transpiration rate
Wilting and early leaf senescence
Decrease root water uptake
Nutrition depletion
DNA damage
Transcriptional & epigenetic changes
4
Phyllospheric & rhizospheric changes
Improved shoot growth
Increased photosynthesis
High ROL barrier
Increased antioxidant production
Phytohormonal reprogramming
Increased levels of secondary messengers (Ca^{2+}, ROS)
The metabolic shift from aerobic to anaerobic energy production
Adaptation
Tolerant or Acclimatized plants
Phyllosphere
Rhizosphere
Aerenchyma formation
Root elongation
Improved nutrition and water absorption
Increased xylem transport
Soil microbes
Alteration in root and soil microbiome. Elevation of anaerobic bacterial taxa competing over aerobic beneficial microbes under hypoxia
PGPR
Plant growth
(Normal condition)
Waterlogging/flooding
(stress condition)

Figure 9.28

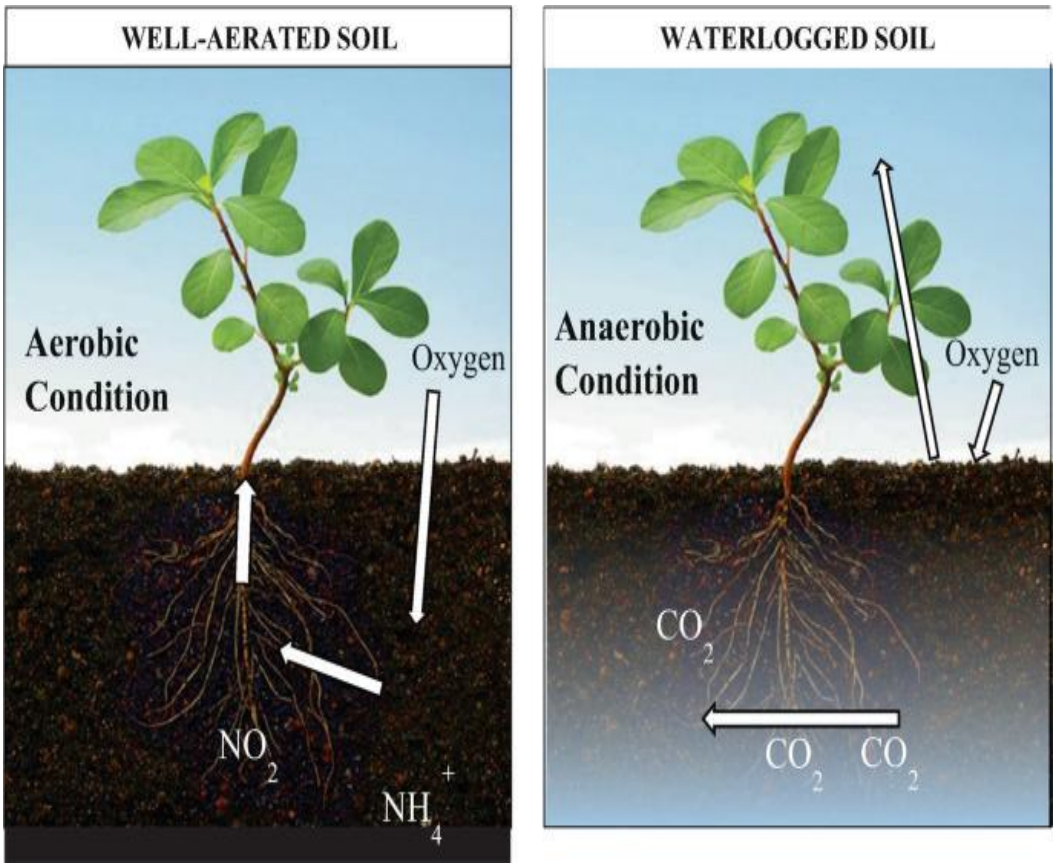


Figure 9.29

13. Introduction to SCARP (Salinity Control and Reclamation Project) Programs

In Pakistan, the irrigation system comprises 3 main reservoirs, 23 barrages, 45 canals with about 1.0 million small watercourses. This irrigation system was introduced due to a sufficiently deep groundwater table (below 33 meters). However, the construction of the canal irrigation system introduced waterlogging and salinity because of a lack of proper drainage. This situation was further intensified due to flat topography, seepage losses, poor irrigation management, and even the utilization of salty water as a source of irrigation. During the late 1950s, this problem was so serious that it was considered the number one problem for consistent agriculture in the country. The SCARPs were launched by WAPDA in the early 1960s to control this problem. In about 4 decades, WAPDA has completed 57 SCARPs, mostly in Punjab and Sindh. The SCARP mainly aims at setting up tubewells besides building external and tile drains.

Soon after its creation, WAPDA developed a program for the construction of SCARPs. In the last 35 years, WAPDA has completed 57 SCARPs total cost of Rs. 26.48 billion on an extent of 7.81 m ha. Even with these gigantic efforts, waterlogging and salinity are still serious problems in Pakistan, where 12 % of gross irrigated area has a water table at less than 1.5 m and 14 % area is affected by moderate to high salinity. Under SCARPs, about 20000 huge-sized tubewells have been set up, and tile drainage structure has been delivered on 14000 ha. Consequently, more groundwater was pumped for agricultural purposes. Therefore, waterlogging in Punjab is lessened. However, it has decreased in Sindh by the year 2002.

13.1 Effectiveness of SCARP

The effectiveness of SCARP can be visualized by the following explanation and Figure 9.30.

1. **Waterlogging:** A network of 5000 observation points was established in irrigated areas of Pakistan to monitor the water table. These points consist of open wells, observation wells, tube wells, dug wells, and automatic water table recorders. Effects of drainage measures on the water table show that waterlogging generally decreased. This decrease has been favored by the installation of tube wells in the private sector to meet the water requirements of crops, as canal flows have declined significantly due to drought for the last several years.
2. **Cropping intensity:** Data show that as a result of additional supplies made available by SCARP tube wells and associated drainage, the cropping intensities have considerably increased, ranging from 31 to 73 % in different SCARPs.
3. **Crop yield:** Before the start of SCARP, crop yields in the agricultural areas were decreased and became very low, rather uneconomical, in many areas for several years. After the implementation of projects, yields have been increased tremendously.
4. **Soil salinity:** The improvement in surface and profile salinity of some projects is evident due to various efforts. However, during the last few years, an increase in salt-affected areas has been reported because of the installation of tube wells in the private sector, pumping poor quality water. About 70-80 % of the pumped water is hazardous; as a result, significant salts from deeper depths are being brought to the soil surface.
5. **Socio-economic impacts:** The socio-economic status of the farming communities has been improved due to remedial measures for waterlogging

and salinity. Farmers are getting more returns from their lands because of the better and favorable effects of SCARPs on soil environments.

6. **Performance of public & private tube wells:** A comparative review of public and private sector tube well performance shows that SCARP tube wells have provided important benefits in terms of alleviating waterlogging and salinity, increasing agricultural production, and helping to stimulate the growth of private tube wells. However, the performance of SCARP tubewells suffered due to some factors. In contrast, the performance of private tubewells has exceeded expectations due to:
    a) Efficient management, particularly to help encounter the highest crop water supplies.
    b) Private tube wells have also provided the bulk of groundwater irrigation supplies as well as drainage where their density was adequate, resulting in a significant increase in production and financial return to farmers.
    c) Pumping of shallow groundwater, which is generally less saline/sodic than deeper groundwater, with tube wells of smaller size.



Figure 9.30

SELF ASSESSMENT QUESTIONS

Question No. 1: What are the major environmental issues of soil?

Question No. 2: What are the major ways through which chemicals can pollute soils?

Question No. 3: Explain in detail six major kinds of soil pollutants.

Question No. 4: What is the fate of different pesticides in soils?

Question No. 5: Explain different approaches/methods of soil reclamation.

Question No. 6: Write and define various classes of salt-affected soils.

Question No. 7: Write a short note on the genesis or formation of salt-affected soils.

Question No. 8: What are the objectives and prerequisites of reclamation?

Question No. 9: What do you understand by different amendments being used for soil reclamation? Also, write post-reclamation strategies.

Question No. 10: Define waterlogged soils. Also, write about different types of waterlogged soils.
Question No. 11: Write various sources/causes of waterlogging.
Question No. 12: What are the control measures for the management of waterlogged soils?
Question No. 13: Explain in detail the SCARP (Salinity Control and Reclamation Project).
Question No. 14: How do you assess the effectiveness of SCARP?
Question No. 15: Write a note on the future strategies for managing waterlogged soils.

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GLOSSARY FOR DIFFICULT TERMINOLOGIES/WORDS

Soil: It is the unconsolidated mineral and organic material on immediate surface of the earth which serves as a natural medium for plant growth. or Soil is free movable and loose matter which covers earth's surface and consists of minerals, organic fractions, water and gases.
Earth: Earth as a material is loose/free substance or stuff from which much portion of surface of ground is prepared. It provides solid foundation for the soil.
Land: Land is a commonly used word to describe the non-water portion of earth, commonly in situations to an enormous external part. In some contexts, it is similar to soil.
Lithosphere: It is the hard / compact / solid / rock type part of the earth, which is flattened at the poles owing to rotation.
Hydrosphere: Hydrosphere is the part of the Earth that contains various water sources altogether (oceans, seas, lakes, and rivers, etc.).
Atmosphere: Atmosphere is a mixture of various gases that are retained on the earth under the direct impact of gravitational force.
Biosphere: Biosphere is the part of the Earth that comprise of all living things, like microorganisms, animals, plants, and human beings.
Soil Science: It is the branch of agriculture that deals with different aspects, types, and properties of soil.
Soil Chemistry: Soil chemistry may be defined as a branch of soil science that deals with chemical properties, reactions, and various developments taking place in the soil.
Soil Survey: Soil survey is the branch of soil science that deals with investigation, grouping, explanation, and drawings/mapping of soil in an organized and orderly manner.
Soil Genesis/Formation: Soil genesis is the branch of soil science that deals with various methods and processes of soil formation.
Soil Morphology: Soil morphology is the visual observation of soil structure, shapes, and the arrangement of soil horizons in the soil profile.
Soil Classification: Soil classification is the branch of soil science that deals with the grouping of soils into various classes/categories through organized, orderly, and systematic procedures that are based on specific characteristics.
Soil Taxonomy: Soil taxonomy is the basic and fundamental classification system of soils for creating and inferring soil surveys. It is the grouping and arrangement of soils based on individual soil's morphological features, like appearance and form.
Soil Conservation: Soil conservation is a branch of soil science that deals with different management approaches designed to prevent soil erosion, salinity, acidity, or other similar types of pollution caused due to any reason.

Soil Fertility: Soil fertility is the branch of soil science that deals with the capability of any particular soil to provide all essential (macro and micro) nutrients to the growing plants, besides favorable growing environment.
Soil Microbiology: Soil microbiology is the branch of soil science which deals with the study of various microorganisms present in the soil.
Soil Mineralogy: Soil mineralogy is the branch of soil science that deals with the study of various minerals present in any particular soil.
Soil Physics: Soil physics is the branch of soil science that deals with different physical properties and processes taking place in the soil.
Soil Salinity: Soil salinity is the branch of soil science that deals with the knowledge of salt-affected soils in relation to plant growth and water stress caused due to excess salts.
Soil Biology: Soil biology is the subdivision of soil science that deals with the study of many creatures living in the soil, their relationships with each other, as well as their interaction with the environment.
Mineral: A Mineral is a naturally occurring inorganic substance with a definite chemical composition with physical characteristics that are identical or flexible within certain restrictions.
Rocks: Rocks are the most familiar objects of the earth, made up of minerals. Rock is an assembly of many mineral grains.
Igneous Rocks: Igneous rocks are made from chilling and subsequently crystallization magma/lava material.
Sedimentary Rocks: Sedimentary rocks are formed from the deposition and re-cementation of materials that originated from the weathering of other rocks.
Metamorphic Rocks: These rocks are derived from preexisting igneous or sedimentary rocks by alteration due to tremendous pressure and high temperature.
Weathering: Weathering is a method of fragmentation and breakdown of rocks and minerals to new constant formulae underneath distinctive environments.
Physical Weathering: Physical weathering is the method through which rocks and minerals are fractured, crushed, crumpled, and expanded.
Chemical Weathering: Chemical weathering comprises processes that change rocks and minerals that are stable at high temperatures and compressions at the earth surface.
Biotic/Biological Weathering: When physical and chemical weathering takes place through certain biological agents, it is called biotic or biological weathering.
Hydrolysis: Hydrolysis is an imperative practice in the chemical weathering of alumino-silicates, general rock-forming minerals.
Oxidation: From the point of view of simple weathering, the term oxidation describes the reaction of any element with oxygen to produce its oxides.

Reduction: Reduction, the gain of electrons, is the opposite of oxidation and takes place in geochemical environments where the material remains saturated with water.

Hydration: It is the relationship of water and a mineral, deprived of definite disintegration or alteration of the mineral itself.

Parent Material: Parent material is the result and product of weathering processes. It is the material from which soil is developed.

Soil Formation: It deals with the manufacture of parent material by means of weathering processes and the subsequent development of the soil profile.

Soil Profile: It is a vertical section of soil through its different horizons, which are extended into the C horizon. So, the profile is the appearance of soil from a vertical section.

Horizons: Soil horizons are generally deliberated to be more or less parallel/equivalent to the surface of Earth. Nonetheless, more or less of these horizons are irregular or asymmetrical in form.

Pedogenesis: Pedogenesis can be defined as the subdivision of soil science that deals with the method of development of a pedon. i.e., "a soil".

Pedogenic Process: Pedogenic processes are inner soil construction methods. Grouping or categorization of events for the reorganization of materials, which personally disturbs soil development, in which it functions to provide a specific form of morphology, is called a pedogenic practice.

Pedon: Pedon is a three-dimensional soil body with lateral dimensions that are sufficient to allow the study of the shape and relationships of its horizons.

Calcification: It is the process through which the buildup of $CaCO_3$ occurs in the Cca horizon of any soil profile.

Decalcification: It is the process that deals with chemical reactions that are linked with the exclusion of $CaCO_3$ from one or more soil layers or horizons.

Podzolization or Silication: It is the removal or biochemical movement of aluminum and iron coupled with organic matter (OM), with the resultant buildup of silica (silication) in the layer or horizon eluviated.

Desalication or Laterization: It is the removal or biochemical movement of silica from the soil solum.

Gleization or Glyzation: It is the reduction of Fe in anaerobic waterlogged soil environments through the manufacture of a bluish to greenish gray color matrix, without otherwise with yellowish brown, brown, and black mottles and ferric and manganiferous concretions.

Salination: It is the buildup of soluble salts like sulfates plus chlorides of Ca, Mg, Na, and K with the ultimate formation of a salty or salic horizon.

Desalination: Elimination of soluble salts commencing the salic or salty soil horizon is known as desalination. Desalination is the exclusion of soluble salts through soil layers or the complete soil profile through the process of leaching.

Sodication: Sodication includes the buildup or accumulation of Na ions at exchange sites of any soil, particularly clay.
Desodication: Elimination and leaching of Na ions and salts from the natric horizon of the soil profile is called desodication.
Physical Properties of Soils: Physical properties are the soil properties that are determined mainly through extent, form, organization, and inorganic composition of the soil units.
Soil Texture: Natural soils are intimate mixtures of soil separates such as sand, silt, and clay. Hence, texture is a very important physical property of soil, which may be defined as "the relative quantity of different soil separates (sand, silt, and clay) in any soil".
Soil Separates: Based on size, different mineral particles present in any soil are separated from each other and placed in various groups. These groups are called soil separates.
Soil Structure: The word structure refers to the combination or organization of primary/basic soil particles (sand, silt, and clay) into derived/secondary particles or units, which are called peds.
Soil Bulk Density: Bulk density of soil may be defined as the mass of dry soil solids per unit bulk volume.
Soil Particle Density: Particle density of any soil may be defined as the mass of dry soil per unit volume of soil solid excluding pore spaces.
Soil Consistency: Consistency of any soil is the expression used to define the resistance of soil's coherent mass to breaking/crushing (rupture). It is the ability of clay soil to be molded or altered.
Soil Colour: Soil colour is a unique, important, valuable, and essential characteristic used for the identification of soils. It may vary from place to place and from horizon to horizon within the soil profile.
Soil Temperature: Temperature is the degree of warmth or coolness of a body. Intensity of heat in the soil is called soil temperature, and it is expressed in °C, °F or °K.
Soil Porosity: Pore space or porosity of soil is the percentage of the overall soil capacity that is not occupied by compact units/particles.
Soil Aeration: Soil aeration is the exchange of gases (CO_2 and O_2) between the soil and atmosphere. Hence, it is a process by which air in soil is replaced with the air from the atmosphere, and this occurs due to variation in the composition of soil air with that of atmospheric air.
Land Capability Classification: Land capability classification is a system for assessing and grouping soils based on their relative suitability for common cultivated crops, grazing, or forestry. It considers general agricultural uses but does not account for specific agricultural or non-agricultural uses that may be possible when individual soils are evaluated in detail.

Soil Organic Matter: The term soil organic matter includes all materials of plants, animals, or microbial origin that are either produced within the soil or added to soil for the purpose of improving soil properties and supplying essential nutrients to plants. Farmyard manure, green manure, and compost are prominent sources of soil organic matter.

Farm Yard Manure: Farm yard manure is abbreviated as FYM. It comprises various farm waste materials like excreta of various animals and feed waste materials of plant litter and microorganisms present in the soil.

Humus: Humus is a general term used to describe decomposed organic materials formed after a series of extensive degradation processes and synthesis cycles. Generally, humus is highly acidic and varies in color from yellow to black.

Manure: Manure may be defined as any material added to the soil to enhance growth of plants and maintaining soil health.

Manuring: Different methods or practices used to add manure to any soil for the purpose of increasing plant growth and maintaining soil health are called manuring.

Compost: Compost is a mixture of various decomposed organic materials. It is a good source of nutrients for plants and is used to maintain soil health.

Composting: Composting is the microbial decomposition of organic materials into partially decomposed organic matter. It is a controlled biological process that results in partial decomposition of organic/farm waste materials.

Green Manuring: When a crop is grown, ploughed, and mixed in the soil to enrich it with organic matter and subsequently improve soil health, it is called green manuring. Plants have a special capability to produce organic tissues openly from inorganic materials. Plants survive, develop, and reproduce by absorbing water and mineral elements from soil, CO_2 from the atmosphere, and energy from the sun to form plant tissues of various types.

Nutrient: A Nutrient can be defined as any type of chemical compound that is required by living organisms for their growth and survival.

Nutrition: Supply and adsorption of different chemical compounds required by living organisms for their growth, maintenance, and metabolism may be defined as nutrition. Nutrition is the process of supplying nutrients to living organisms.

Essential Plant Nutrients: Plants have a special capability to produce organic tissues openly from inorganic materials. Plants survive, develop, and reproduce by absorbing water and mineral elements from soil, CO_2 from the atmosphere and energy from the sun to form plant tissues of various types.

Essential Elements: When plant is unable to complete its life cycle without any element, it is called an essential element. Essential elements have specific role in the physiology of plants. If deficiency of any essential element occurs in plants, only supply of that element will prove remedy for this deficiency.

Eutrophication: It is the nutrient fortification of ponds, pools, and other similar water bodies which encourages the growth of marine creatures that cause a shortage of oxygen in the water.

Salt-Affected Soils: The Word salt-affected soils is a collective term used for such soils that have high concentrations of any type of salt to impair plant growth. These salts may be of many kinds. e.g. soluble salts, exchangeable sodium, or combination of both. Soluble salts are of 4 types like NaCl, Na_2SO_4, $CaCl_2$, and $MgSO_4$. Whereas exchangeable sodium exists in the form of 2 salts, like $NaCO_3$ and $NaHCO_3$.

Saline Soils: These are soils that have enough quantities of soluble salts and can negatively affect plant growth. These soils do not have an excess of exchangeable sodium to impair plant development. Four types of soluble salts (NaCl, Na_2SO_4, $CaCl_2$, and $MgSO_4$) are analyzed in these soils.

Sodic Soils: These soils have an excess of exchangeable sodium to impair plant development. These are soils that do not have enough quantities of soluble salts and can negatively affect plant growth.

Saline Sodic Soils: These soils have both soluble salts and an excess of exchangeable sodium to impair plant development. Hence, saline sodic soil may be defined as soil having values of EC greater than 4.0 dS m^{-1}, pH greater than 8.5 and SAR greater than 15.

Waterlogged Soils: The meaning of the word waterlogged is saturation or nearly saturation of anything with water. Therefore, saturation of soils with water for an adequately prolonged period is called waterlogged. This saturation is the result of a high water table and has a negative effect on the majority of crops.

Soil pH: It is an abbreviation for soil reaction.

EC: It is an abbreviation for electrical conductivity.

SAR: It is an abbreviation for sodium adsorption ratio.

CEC: It is an abbreviation for cation exchange capacity.

SCARP: It is an abbreviation for Salinity Control and Reclamation Project.