



ZAMBIAN OPEN UNIVERSITY

SCHOOL OF AGRICULTURAL SCIENCES

DEPARTMENT OF AGRICULTURAL ECONOMICS

ABM 211/ AGE 222

INTRODUCTION TO SOIL SCIENCE

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Aim

This course aims to provide an understanding of the nature, behaviour and uses of soil in natural and disturbed conditions. The course gives you an in-depth knowledge on the inherent soil characteristics, fundamental soil properties, basic soil plant relationships and the available soil-management technologies and practices.

Objectives

To achieve the aims set out, the course has a set of objectives. Each unit has specific objectives which are usually included at the beginning of a unit. You should read these objectives before you study the unit. You may wish to refer to them during your study of the unit to check on your progress. You should always look at the unit objectives after completing a unit. By doing so you would be able to locate your bearing and level of attainment of the objectives of the unit.

Below are the comprehensive objectives of the course as a whole. By meeting these objectives, you should have achieved the aims of the course as a whole. After going through this course, you should be able to:

- Explain the properties of parent rocks from which soils are formed, the soil forming factors and processes of soil formation
- Appreciate physical composition of soils such as texture, structure, soil water and soil air
- Explain soil moisture retention curve and measurements of dynamic soil physical properties
- Explain the composition and structure of alumino-silicate clays and organic colloids
- Explain ion exchange reactions in soil, soil colloids and cation exchange capacity.
- Appreciate the importance of soil acidity and alkalinity, as well as exchange and reserve acidity
- Explain the principles of liming in soil management

Course Outline

Unit 1	Origin and Development of Soil: Different Factors and Processes of Soil Formation
Topic	
1	Importance of the Knowledge of Soil Origin and Development
2	Types of Rocks
3	Factors of Soil Formation
4	Processes of Soil Formation
5	Essential Characteristics of Soil
Unit 2	Soil Minerals (Structure and Characteristics)
Topic	
1	General Properties
2	Silicate Minerals of Sand and Silt
3	Minerals of the Clay Fraction
4	Charges in Minerals
Unit 3	Physical Characteristics of Soils
Topic	
1	Soil Texture and Textural Composition
2	Soil Textural Classes
3	Soil Structure and Aggregates
4	Soil Consistence
5	Soil Compaction
6	Porosity and Pore Spaces
7	Soil Density and Permeability
8	Soil Tilth
9	Soil Colour
UNIT 4	Water Dynamics in the Soil - Movements (Retention and Loss), Measurement and Management
Topic	
1	Importance and Uses of Water to Plants
2	Availability of Water to the Soil-Plant System
3	Measuring Soil Water
Unit 5	Soil Air and Temperature
Topic	
1	Soil Air
2	Oxidation – Reduction (Redox) Potentials (Eh
3	Conditions that Affect Soil Air Composition
4	Soil Aeration on Biological Activities and Plant Growth
5	Temperature and Plant Growth

Unit 6	Soil Organic Matter and Colloids
Topic	
1	Soil Organic Matter and Organic Materials
2	Roles Microorganisms in Organic Matter Transformation
3	Factors Affecting the Decomposition of Organic Matter in Soil
4	General Importance of Soil Organic Matter
Unit 7	Soil Reaction: Acidity and Liming
Topic	
1	Topic 1: Meaning of Soil Reaction
2	Topic 2: How Soil Becomes Acidic
3	Topic 3: Importance of Soil Acidity
4	Topic 4: Measurement of Soil Acidity
5	Topic 5: Liming Practice
UNIT 8	Soil Salinity and Alkalinity
Topic	
1	Sources of Salt-Affected Soils
2	General Feature of Saline and Alkaline Soils (Halomorphic Soils)
3	Reclamation and Management of Alkaline and Saline Soils
UNIT 9	Soil Microorganisms: Bacteria
Topic	
1	General Description of Soil Micro-organisms
2	Description and Classification of Soil Bacteria
3	Economic Importance of Bacteria
4	Conditions that Affect the Growth and Activities of Soil Bacteria
Unit 10	Soil Actinomycetes, Fungi And Algae
Topic	
1	Description of Soil Actinomycetes
2	Activities and Functions of Actinomycetes
3	Description of Fungi
4	Activities and Functions of Fungi
5	Mycorrhiza
6	Algae, Protozoa and Nematodes
Unit 11	Nitrogen Transformations In Soil
Topic	
1	Nitrogen Cycling
2	Nitrification and De-nitrification
3	Nitrogen Fixation
4	Ways of Promoting Soil Organisms
5	Ways of Controlling Harmful Organisms
Unit 12	General Principles of Soils and Water Conservation and Management
Topic	
1	Importance of Soil and Water Conservation
2	Types of Water Erosion
3	The Universal Soil Loss Equation

4	Factors in Wind Erosion
5	Agronomic Techniques for the Control of Soil Erosion (Water and Wind)
Unit 13	A look at Zambian Soils

Assessment: This module will be assessed on 50% continuous assessment of two assignments and another 50% of a written examination at the end of the semester

Recommended Readings

1. More recent editions of these books are recommended for further reading.
2. Brandy, N.C. and Weil, R.R. (1999). *The Nature and Properties of Soils*. (12th ed). New Jersey: Prentice-Hall. Donahue, R.L.; Miller, R.W. and Chickluna, J.C. (1990). *Soils: An Introduction to Soils and Plant Growth*. (5th ed). New Delhi: Prentice-Hall.
3. Russell, E.W. (1980). *Soil Conditions and Plant Growth*. (10th ed). London: Longman.

Prescribed Readings

1. Tisdale, S.L. and Nelson, W.L. (1976). *Soil Fertility and Fertilizers*. New York: Macmillan.
2. Webster, C.C. and Wilson, P.N. (1980). *Agriculture in the Tropics*. (2nd ed). Longman.
3. Millar, C.E. and Turk, L.M. (2002). *Fundamentals of Soil Science*. New Delhi: Biotech Books.

Introduction to the Module

Welcome to module AGE 224/ABM 202 ***Introduction to Soil Science*** which aims to provide you with a basic understanding of the principles of soil science. Soils are not only beautiful to look at, fascinating to study, and challenging to understand, they are also critically important to all living things, ourselves included. Everyday our life is made possible by the functions that soils perform in our environment. This fact is just as true today, as ever, but is less clearly perceived by the majority of people who no longer work directly with the land. I hope this course will be an enjoyable and stimulating experience that opens up a part of your world to which, perhaps, you have previously given little thought.

Many non plant science students think that soil science has no place in the study of agriculture and agricultural science. This course will should give you sufficient details and explanations on the major areas of soil science, such that it could serve as a text for students interested in the study of the soil. Going through this course will increase your understanding of the significance of basic soil properties, relationships between soil properties and plant needs and offer the student thorough knowledge of the principles underlining the use of proved soil-management practices. .

The soil is a complex system; every aspect of it is connected to every other. As you progress into this module, these connections should become increasingly clear. You should I focus on understanding the fundamental physical, biological and chemical principles that explain how soils work. You should avoid memorization as much as possible, but some terminology will have to be learned in order for you to communicate. You should study the soil as a natural system and consider applications of soils concepts in many locations and professions from farming to engineering. As with so much in life, you will be likely to benefit from this course in proportion to what you put into it. I do hope you will fully and enjoy! This course generally deals with how soil is formed from primary rocks and minerals, the transformation factors and processes that give rise to different soils on the earth surface, the dynamic chemical entity and several external factors that react together to make the soil an indispensable national resource to plants, animals and humans. I would like to acknowledge Prof. O. O. Agbede, Sam I. Ogunrinde, and Dr. Jari Sanusi for use of material contained in their module CSP 312

UNIT 1

ORIGIN AND DEVELOPMENT OF SOIL: DIFFERENT FACTORS AND PROCESSES OF SOIL FORMATION

Introduction

A soil develops from all kinds of rocks, deposits in lakes, rivers and glacials, wind-blown silt or sand which are all referred to as **Parent materials**. The interactions of the soil forming factors, namely, parent material, climate, topography, organisms and time control the physical and chemical processes that change the parent materials into soil.

The main purpose of this unit is to acquaint the student that soil is formed from different types of rocks by certain pedogenetic processes through some factors of soil formation.

The formation of soil from parent material is a slow but continuous process. The variabilities in the characteristics of soils such as texture, colour, structure, porosity, chemical and microbiological properties, usually result from the actions of soil forming processes.

Objectives

At the end of this unit, you should be able to:

- Explain the origin and characteristics of rocks as parent materials
- Enumerate the benefits derivable from the knowledge of soil origin
- Describe the roles of soil forming factors and their interrelationships
- Discuss the processes (physical and chemical) involved in soil formation
- Discuss the different characteristics of soil

Topic 1: Importance of the Knowledge of Soil Origin and Development

In everyday language, **Soil genesis** is the study of the history of the soil. i.e. what has been going on in the soil that gave it the properties which it possesses today.

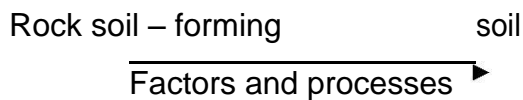
The better we understand the history of our soils and the more we learn about their properties, the better we are able to make wise decision concerning their use and

management. Bearing this in mind, the reasons behind the quest for soil genesis include:

1. To help us understand some of the properties of our soils better.
2. To help us appreciate some of the things we do not understand about the soils.
3. To be able to formulate law governing soils behavior.
4. To help us provide adequate method for management of our soils and make better interpretative usage.

Topic 2: Types of Rocks

Parent rock is the starting material of soils. A rock is defined as a consolidated mass composed of one or more minerals. A set o processes and factors act on rock to produce soil.



Rocks are residual or in-place parent material that weather into soil without first being moved by wind or water. Rocks are divided into three main groups (igneous, sedimentary and metamorphic) which are further subdivided by mineralogy, particle size, crystallinity and specific mode of formation. Table 1 below gives the summary of rock types.

Table 1: Major Rock Types, their Origin and properties

Rock type	Origin	Example	Properties
Igneous	Cooling of magma	Granite basalt	Light colour coarse grained dark colour fine grained
Sedimentary	Deposition and compaction	Shale Sandstone limestone	Any colour, fine grained Any colour, coarse grained Light coloured, shells or CaCO_3 present
Metamorphic	Change in igneous or sedimentary	Slate marble	Any colour, hardened shale Any colour, changed limestone

Source: Singer and Munns, 1999.

a. Igneous Rocks

These are formed from cooled magma (a hot mixture of elements). Magma that cools at the earth's surface forms **extrusive** igneous rocks, and magma that cools below the surface forms **intrusive** igneous rocks. It must be noted that the faster the rate of cooling the smaller the sizes of the mineral crystals. Cooling at earth surface is usually very fast giving rise to extremely small crystals.

General, basic rocks give rise to basic soils. While acid parent rocks give rise to acid soils. The amount of silica determines the acidity of a rock – the more basic the rock the less the amount of silica. Common members of igneous rocks are:

i. Granite

Which consists mainly of quartz, silica (SiO_2), feldspar, and mica (muscovite and biotitic).

ii. Gabro and Basalt

Dark coloured. Have little or no quartz. These are basic rocks that form basic soils. Main components are feldspars, hornblende and augite minerals.

b. Sedimentary Rocks

These are sediments or precipitates laid down in water or by wind, usually in the lakes oceans or lowland regions e.g limestone, skeletons clay which all consolidate into rocks over time and under pressure of overlaying material. Sedimentary rocks are further classified into five groups depending on hardness, pressure and composition.

i. Arenaceous

Mainly sandstone which originates from mostly sand sized sediments.

ii. Argillaceous

Shale, clay from mostly clay-sized sediments, bituminuous shale.

iii. Calcareous

Limestone which is rich in carbonates from the shells of lakes or ocean organisms.

iv. Carbonaceous Rocks

Peat, usually vegetation remains which varies in colour from brown to black. It is rich in nutrients, has large cation exchange capacity and water-holding capacity e.g. coal of different kinds.

v. Siliceous Rocks

Flint-compact form of silica.

c. Metamorphic Rocks

These are igneous or sedimentary rocks usually subjected to heat and pressure converted to new rocks. For example, marble from carbonate, which is re-crystallized. Gneiss originated from granite, schist-foliated rock like leaf easily split at weak foliation lines. The minerals here are quartz feldspar and mica (muscovite and biotite). Slate – formed from argillaceous sediments.

Topic 3: Factors of Soil Formation

Some soils are similar but many are different to various degrees. It is important to understand the relationship between soils and the basic factors that cause them to differ from one area to another. The processes of additions, removals, transformations and translocation in producing soils are controlled by five group of independent variables. These are referred to in many scientific texts as soil formation factors.

In the original formulation, **hydrology** was separated from **relief** while nowadays, **man** because he can substantially alter physical environment is considered as a separated factor in soil formation. However, for convenience of our study the factors of soil formation will be taken as five as originally formulated by Jenny.

These five factors are:-

- a. Climate
- b. Organisms (vegetation and Fauna)
- c. Relief (shapes of the land surface)
- d. Parent material
- e. Time

These factors set the conditions that bring about the processes which in turn bring about the properties of the soil.

Climate and Vegetation

Affect the parent material and their action is conditioned by relief over a period of time. The ability to predict soil characteristics to understand those that are observed is determined by a knowledge of these five soil formation factors.

There have been several attempts to formulate theoretical relations between forming factors and soil properties. In consideration of soil formation, the soil themselves become the dependent variable and the other factors independent and causative.

The equation of **Jenny** being the initial letter of the factor is:

Where S = The total effect of all the factors

F = any soil properties

$S = F(C), o, r, p, t.$

This states that any soil property will be a function of climate if other factors are held constant. Similarly, the equation can be applied to other factors ($o, r, p, t.$).

The equations are intended to be symbolic rather than utilitarian, and should be regarded only as a conceptual model.

Climate

It exerts its influence through this action.

- i. Rainfall (precipitation)
- ii. Temperature
- iii. Sunshine

The most important components of climate that affect the process of soil formation are rainfall and temperature, both influence the intensity and nature of rock weathering. Even after the rock has been completely weathered, rainfall and temperature influence the trend of soil development from weathered materials. Climate affects soil formation in at least 4 ways:

- 1. Weathering of parent material
- 2. Transportation of parent material
- 3. Pedogenesis
- 4. Erosion.

Rainfall affects the intensity of weathering and leaching within the soil. It is necessary for

the important processes of hydrolysis, hydration, carbonation and other associated weathering processes to take place. It determines leaching occurs in the soil. It weather affects plant growth and vegetation and hence in content localities that tremendously influence the processes of pedogenesis; for example; the alteration of wet season with dry season is important in Zambia. Wind and sunshine affect the effectiveness of rainfall and the intensity of temperature. Climate is the most important soil forming factor affecting organic matter content and associated properties (notably nitrogen), reaction and base saturation. It has a substantial influence in profile depth and texture and is one of several factors influencing the type of clay mineral synthesized.

Organisms

The factor termed **organism** covers vegetation and soil Fauna. The major role of living organisms in profile differentiation cannot be over emphasized. Profile mixing by earth-worm, cretina, nutrient, cycling and structural stability are all made possible by the presence of organisms in the soil. Also nitrogen is added to the soil system by micro-organisms alone or in association with plants. Vegetation covers the ground of soil surface, protects it from erosions and other physical traumas. It provides the very essential component of soil, the organic matter does the nutrient recycling that is so important for soil maintenance. The micro-climate provided by the vegetation is extremely important. We can differentiate between grass-land, forest and desert. The micro-climate under these different vegetation communities influences the nature of the soils developed under them. For example the organic matter content of Savannah soils is generally much lower owing to the sparse vegetation here in Zambia. Climate determines the types of vegetation and the type of soil. The soil determines the types of vegetation and the type of pedogenesis. There is a two way interaction between vegetation and soil. **Man** influences the trend of soil development in several ways. **Man** changes the type of vegetation, reclaims lands from swamps and the sea, does a lot of land leveling and soil transfer, cultivates the soil and plants various types of crops which have influence on the soil.

Relief

The spatial distribution of soil types is related to relief at all levels of scale. Relief influences soil development because of its influences in:

- a. Water relation
- b. Erosion
- c. Temperature
- d. Vegetation

Topography, or relief is commonly considered to be factor that modifies the effects of other factors of soil formation such as established before soil formation begins.

Soils formed on upper slopes are characteristically different from those of middle slopes which also differ from those of lower slopes.

Parent Materials

Soil parent materials represent the initial state of the soil system, there are essentially 2 types of original parent material.

1. Residual Parent Materials

This is weathered material which is derived from the underlying rock below the soil profile. Soil which develops from this type of parent materials is known as “Sedentary”, a term indicating that the soil has been formed in place insitu.

2. Transported Parent Materials

These are classified on the basis of the manner in which they came into existence e.g *colluvial marine, Lacustrine, Cilacical, alluvial*. The characteristics of the parent materials influence the characteristics of the soil which is formed from it. Parent material affects the type of nutrient, particularly when the soil is still young and has not been severely leached. Soil parent material also affects the texture, soil reaction and other properties of the soil. The importance of parent material tends to decline with age or degree of soil development.

Time

In this connection time strictly cannot be considered as a soil forming factor as other factors mainly because it does not exert any effect on the soil as such. However, **time** or **age** as being one of the factors of soil formation is important because the length of time during which other factors persist to have an influence on the amount of time a soil requires to develop varies widely according to the action of the other soil-forming factors. Young soils may develop in a few days from the alluvium (sediments left by flood) or from the ash from volcanic eruptions. Other soils may take hundreds, thousands or millions of years to form.

Topic 4: Processes of Soil Formation

There are two main processes that lead to the formation of soil (loosed and unconsolidated) from rocks (hard and consolidated). The first is the physical aspect which does not involve chemical change. That is, if we start with homogenous parent material, we have homogenous soil. The second is the chemical aspect which involves chemical changes. These two processes occur simultaneously.

Physical Weathering

Physical weathering ensures that rocks are broken down into smaller particle sizes. The processes in physical weathering include freezing and thawing, uneven heating, abrasion, shrinking and swelling which break large particles into smaller ones. In cold climates like Canada, water collected in crevices expands during freezing; this makes the rock to crack. Roots of plants generate some pressure and cause rocks to break into pieces. Water and wind moving some materials cause them to scour.

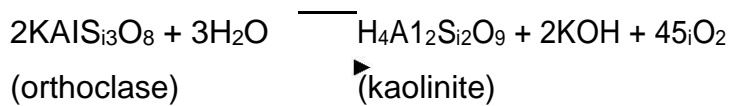
Chemical Weathering

Chemical weathering is the main process converting parent material into soil while the bulk of chemical weathering is brought about by water. Organic and inorganic acids contained in water enhances mineral weathering. Chemical weathering may take the forms stated below:

i. Hydrolysis

This is chemical alteration of a mineral and the formation of its oxide through the action of water. E.g.

Orthoclase



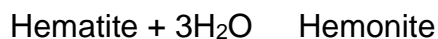
In the presence of CO_2 KCO_3 will be formed instead of KOH in the equation. That is, the process of hydrolysis usually results in the formation of compounds different from the parent material.

ii. Solution

The solvent action of water has the ability to dissolve soluble materials or rocks due to the nature of acidic property it has.

iii. Hydration

That is, water molecules are being added to a mineral's structure but the water molecule does not dissociate. Significantly, the rock swells when water weathering processes. For example, smectite hydrates and dehydrates readily when water enters and leaves its interlayer. Similarly for hematite.



These minerals give rise to the red, brown and yellow colour of soils.

iv. Oxidation Reduction

Oxidation – reduction reactions are very important in minerals that have Fe^{2+} such as biotite mica. Depending on the environment various compounds can be formed in oxidative processes. For instance the oxidation of Fe^{2+} to Fe^{3+} will strain the crystal and result in reduction of Fe and Mn in soil.

v. Carbonation

That is CO_2 may combine with dissolve marble compounds to form carbonate precipitates.

Topic 5: Essential Characteristics of Soil

Scientists can learn a lot about a soil's composition and origin by examining various features of the soil. **Colour texture, aggregation, porosity, ion content, and pH** are all important soil characteristics.

1. Colour

Soils come in a wide range of colors – shades of brown, red, orange, yellow, gray, and even blue or green. Color alone does not affect a soil, but it is often a reliable indicator of other soil properties. In the surface soil horizons, a dark color usually indicates the presence of organic matter. Soils with significant organic material content appear dark brown or black. The most common soil hues are in the red-to-yellow range, getting their colour from iron oxide minerals coating soil particles. Red iron oxides dominate highly weathered soil. Soils frequently saturated by water appear gray, blue, or green because the minerals that give them the red and yellow colours have been leached away.

2. Texture

A soil's texture depends on its content of the three main mineral components of the soil: sand, silt, and clay. Texture is the relative percentage of each particle size in a soil. Texture differences can affect many other physical and chemical properties and are therefore important in measures such as soil productivity. Soils with predominantly large particles tend to drain quickly and have lower fertility. Very fine – textured soils may be poorly drained, tend to become waterlogged, and are therefore not well-suited for

agriculture. Soils with a medium texture and a relatively even proportion of all particle sizes are most versatile. A combination of 10 to 20 percent clay, along with sand and silt in roughly equal amounts, and a good quantity of organic materials, is considered an ideal mixture for productive soil.

3. Aggregation

Individual soil particles tend to be bound together into larger units referred to as aggregates or soil peds. Aggregation occurs as a result of complex chemical forces acting on small soil components or when organisms and organic matter in soil act as glue binding particles together.

Soil aggregates form soil structure, defined by the shape, size, and strength of the aggregates. There are three main soil shapes: plate like, in which the aggregates are flat and mostly horizontal; prism like, meaning greater in vertical than in horizontal dimension; and block like, roughly equal in horizontal and vertical dimensions and either angular or rounded. Soil peds range in size from very fine-less than 1mm to very coarse-greater than 10mm. The measure of strength or grade refers to the stability of the structural unit and is ranked as weak, moderate, or strong. Very young or sandy soils may have no discernible structure.

4. Ion content

Soils also have key chemical characteristics. The surfaces of certain soil particles, particularly the clays, hold groupings of atoms known as ions. These ions carry a negative charge. Like magnets, these negative ions (called anions) attract positive ions (called cations). Cations, including those from calcium, magnesium, and potassium, then become attached to the soil particles, in a process known as cation exchange. The chemical reactions in cation exchange capacity is an important measures of its fertility.

5. pH

Another important chemical measure is soil pH, which refers to the soil's acidity or alkalinity. This property hinges on the concentration of hydrogen ions in solution. A greater concentration of hydrogen results in a lower pH, meaning greater acidity.

Scientists consider pure water, with a pH of 7, neutral. The pH of a soil will often determine whether certain plants can be grown successfully. Blueberry plants, for example, require acidic soils with a pH of roughly 4 to 4.5.

Alfalfa and many grasses, on the other hand, require a neutral or slightly alkaline soil.

Unit summary

In this unit, we have learnt that:

- Several factors of soil formation act either singly or in combinations to convert geological parent material to soil through mainly physical and chemical weathering. Soils with different characteristics result from the different combinations of factors and processes.
- The judicious use and management of our soils depend on our thorough knowledge of their origin and development.
- The three major rock types (igneous, sedimentary and metamorphic) have their peculiar origin, composition and properties.
- Five major factors and several processes interplay to break down parent materials into soils which may be similar or different in characteristics from the starting materials
- Soil physical and chemical characteristics enable us to effectively use and manage soils

Activity

1. Give examples of situations in which each of climate, parent material and topography is the dominant soil forming factor.
2. Discuss the differences between physical and chemical weathering products?

UNIT 2

SOIL MINERALS (STRUCTURE AND CHARACTERISTICS)

INTRODUCTION

Minerals make up the solid portion of the soil in addition to living and dead organic matters. The individual mineral particles are of different sizes of sand, silt and clay soil separates. The particles are held together by cementing nature of clay and organic matter to form aggregates of many sizes and shapes, and the arrangement of these aggregate is the soils structure.

The sizes and chemical, physical and mineralogical characteristic of the mineral particles contribute to the soil properties. Students should be familiar with the most important minerals in soils such as the layer silicates especially the secondary mineral clay fractions made up of sheets of silicon, aluminum and oxygen atoms.

This unit describes the basic framework and properties of both primary and secondary clay minerals of soil. Knowledge of the structure of a mineral helps in understanding how easily it can weather and what elements it is likely to release after weathering.

OBJECTIVES

At the end of this unit, you should be able to:

- Enumerate the important general properties of soil minerals
- Describe the structures and general characteristics of individual silicate minerals (sand, silt and clay)
- Define some terminologies associated with the characteristics of alumino silicates
- Discuss the various sources of fixed and variable charges in.

Topic 1: General Properties

A mineral is a naturally occurring inorganic substance which has a fairly definite chemical composition and physical properties. The mineral has a regular well-defined crystalline structure except slight variation in chemical composition as a result of the substitution of one

element for another in the crystal structure. Two groups of minerals are in existence-primary and secondary.

A Primary Mineral is formed from the solidification of molten material while a Secondary Mineral is formed by the alteration of primary mineral formed in molten material. For example, feldspar is transformed into clay by chemical alteration.

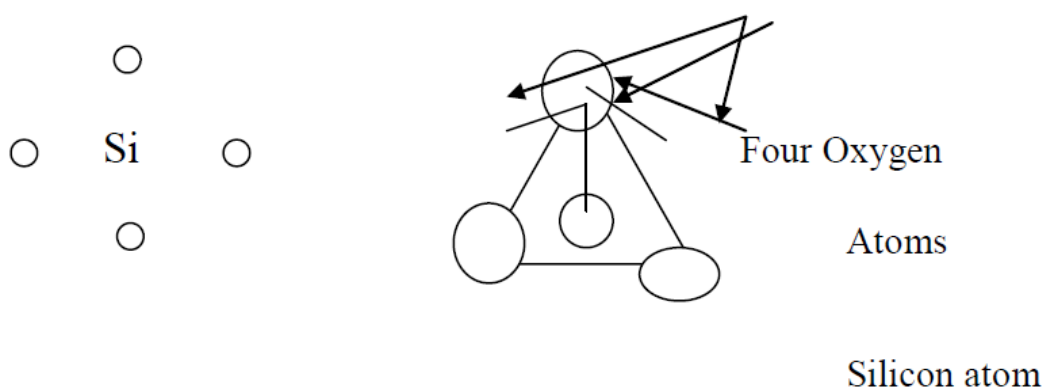
Feldspar	Clay
(Primary Mineral)	(Secondary Mineral)

Minerals are either crystalline if their atoms are in a definite order of arrangement or organized repeatedly in three dimensions. They are described as amorphous without a definite long-range atomic pattern. Crystallinity describes the organization of atoms and composition describes the kinds of atoms in the crystal. For example the only difference between diamond (crystalline) and graphite (amorphous) is the arrangement of the carbon atoms (crystallinity); the composition (kind of atoms) is the same.

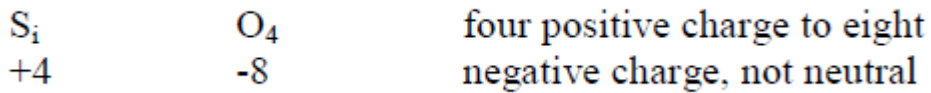
Difference in composition confers difference in properties even if arrangement is the same potassium chloride (KCL) has bitter taste while sodium chloride (NACL) tastes salty even though they have same atomic arrangement.

Topic 2: Silicate Minerals of Sand and Silt

The primary silicate minerals are the most abundant in rocks, sand and silt. About 90% of Earth surface is made up of silicates. The silicates in turn are made up of spheres of oxygen of definite arrangement. Silicates have the structure comprising of SiO_4



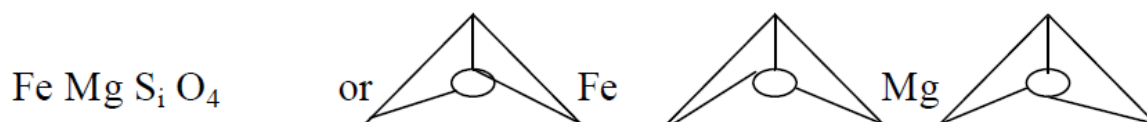
That is, there are four oxygen atoms surrounding a centrally placed silicon atom to form a SILICON-TETRAHEADRON(a four-sided unit). This unit does not exist alone in nature because it is not electrically neutral.



Therefore other elements (occasional cations) must be added to Si O_4 to make it neutral. That is, positive: negative ratio should be 1:1 for neutral molecules. Defining on the type of mineral, neutrality is achieved by sharing oxygen ions among tetrahedral units and by the incorporation of cations, mostly Fe^{3+} , Fe^{2+} , Ca^{2+} , Mg^{2+} , Na^+ and K^+ , silicate minerals are classified on the basis of the way the building silicon tetrahedral blocks have linked together,

1. Nessilicates (Olivine)

These are silicate minerals in which the silica tetrahedral remain independent of one another but are connected by Fe^{2+} and Mg^{2+} to form neutral compounds.



In weathering processes the Fe and Mg can easily be knocked out. This implies that olivine is an easily weathered mineral, and releases magnesium and iron. Olivine is usually dark in colour.

2. Inosilicates (Pyroxene and Amphiboles)

These silicate minerals have their silica tetrahedral joined together to form chains. The single-chain family is the pyroxene while the double chains are the amphiboles. The connecting cations are Ca^{2+} and Mg^{2+} . Hornblende is a typical example of these Ferromagnesia chain silicates.

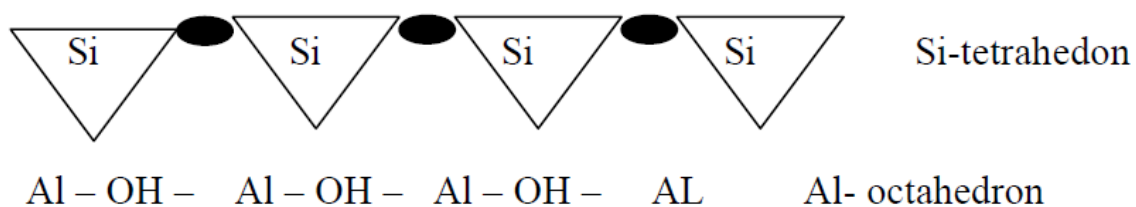


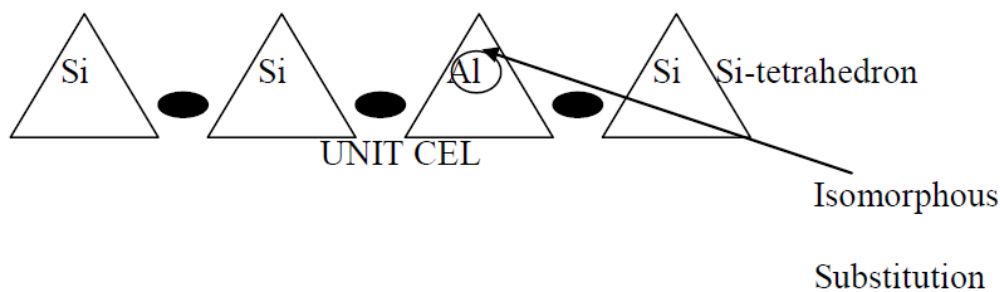
As we have more sharing of oxygen, weathering becomes harder; that is, pyroxene does not weather easily as Olivine and amphiboles are harder than pyroxene. The inosilicates are usually dark-coloured minerals that weather relatively easily releasing large amount of Ca and Mg to the soil on weathering.

3. Phyllosilicates

With more elimination and sharing of oxygen among the silica tetrahedra, flat sheets linked together by cations are formed; we then have $\text{Si O}^{-1}_{2.5}$ which is close to neutrality as in layer silicates. These include the clay silicates. The common ones are the mica minerals muscovite (white mica) and biotite (black mica). White Muscovite (white mica): $\text{KA}_{12} (\text{AlSi}_3 \text{O}_{10}) (\text{OH})_2$

In the unit cell formula, there are six oxygen atoms at the base of tetrahedral which are shared and four oxygen atom at the apex position in the tetrahedral which are free. There are three silicon atoms and one aluminium in the Si- layer, two aluminium and two hydroxyl ($-\text{OH}$) groups in the structure. Potassium is the preferred cation to give stability rather than Na.





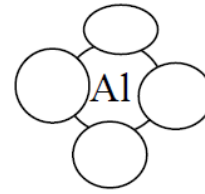
The Al introduced in the silicon – tetrahedral layer is called isomorphous substitution which could be defined as the replacement of one atom by another atom of similar size but different charge in a crystal lattice without disrupting the crystal structure of the mineral. Because the substituting atom has almost similar size with that being substituted there is no great change in the crystal lattice. In case of mica where Al^{3+} replaces Si^{4+} or Mg^{2+} replaces Al^{3+} , there is usually net negative charge from the unsatisfied oxygen left behind. For electrical neutrality, an additional cation (such as Na^+ or K^+) has to be introduced into the structure.

Biotite mica (black mica) has same structure like white mica but there is substitution of Al_2 by $(\text{Fe}, \text{Mg})_3$ in the Al-Octahedral layer: $\text{K}(\text{Mg}, \text{Fe})_3 (\text{Al Si}_3 10) (\text{OH})_2$. Here, a +2 charge substitutes +3 Charge; thus the side becomes more negative, this increases the cation exchange and rate of weathering micas and K-Feldspar are the main sources of potassium in the soil. The bond between the silicate layer and the potassium is very strong and therefore water molecules, H_2O , do not enter, and this makes them to be non-expanding layer silicates. The difference between mica and feldspar is that mica is made up of layers (sheets) of 2 silicon tetrahedral plus one Al-octahedral layers, feldspar is a group of framework structure without layering. Because of the strains in side crystals black mica weathers more easily than white mica. This extra strain in black mica is caused by additional isomorphous substitution of Al by Fe and Mg in the Al-octahedra

Si – Tetrahedron

Al – octahedron

Si – Tetrahedron



A unit cell of 8 sided Al-

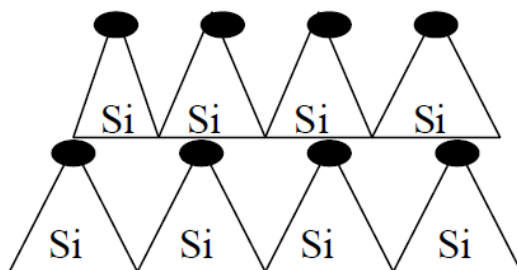
Layer silicate Octahedral unit

Aluminium has three missing electrons (Al^{3+}). The octahedron has configuration of 8 sides where six oxygen atoms surround the aluminium atom.

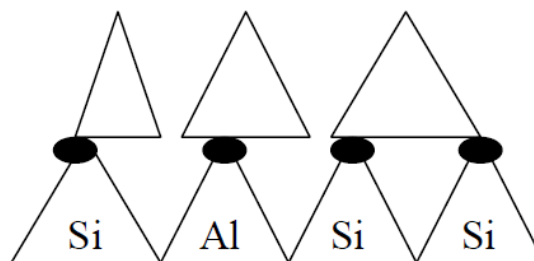
4. Tectosilicates

Here, all the oxygen atoms are shared completely among the tetrahedral forming 3 – dimensional framework silicate structures.

Quartz and feldspar (Orthoclase and plagioclase) are typical examples. However while quartz, SiO_2 , have no accessory cations, feldspars have Al^{3+} substituted in some tetrahedral, balanced by Na^+ , K^+ or Ca^{2+} as accessory cations. Quartz is extremely resistant to chemical weathering because all the bonds are Si – O with simple and regular structure.



Unit of quartz, SiO_2



Unit cell of feldspar
with isomorphous
substitution

Topic 3: Minerals of the Clay Fraction (Secondary Minerals)

Clay minerals have some distinguishing properties as stated below:

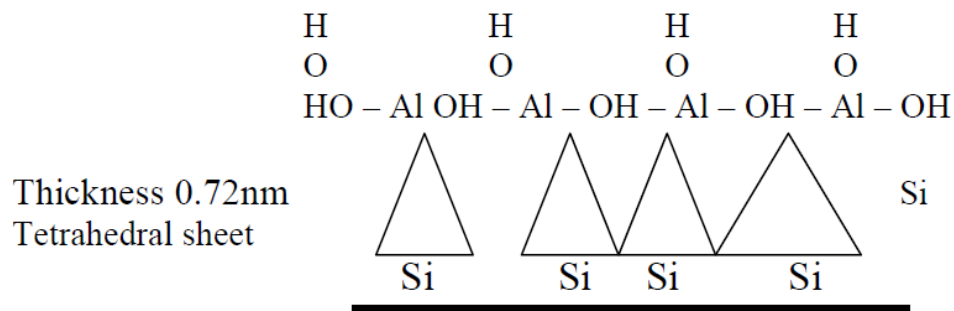
- They are colloidal ($< 2\mu\text{m}$) with large surface area. That is, they carry either positive or negative charges on their surfaces.
- Their layered crystal structure makes them to be platy or flaky, slippery and plastic when wet.
- They have built-in negative electrical charge, balanced by cations on the surface and can interchange with cations from the surrounding soil solution.
- All. Clays absorb water on their surface and into some of the expanding-lattice clays.
- Most clay minerals are aluminosilicates with oxygen, silicon, and aluminium as main elements in their structure. The tetrahedral and octahedral sheets are held together on top of each other by oxygen atoms to form the different clay minerals.

Aluminosilicate clay minerals also referred to as layer silicates are in two groups based on the number of sheets of Si-tetrahedra and Al-octahedra in their layer. There are those having 2 – to – 1, Si – to – Al sheets, two silicon sheets for every aluminium sheet such as vermiculite montmorillonite and Illite. The other group has one silicon sheet and one aluminium sheet (that is 1 to 1, Si: Al,) such as kaolinite and Halloysite

A unit cell of aluminosilicate clay minerals is the minimum unit that is repeated in orderly fashion in three dimensions to form the crystal structure. There are usually millions of unit cells linked together horizontally and vertically in one crystal of silicate clay mineral. A brief characteristic of some clay minerals are given between.

i. Kaolinite

This is called 1 – 1 clay mineral because it has one sheet of silica tetrahedral to one Aluminum Octahedral sheet in the unit cell. This is the type of clay common in the tropics including Zambia. The formula is $\text{Al}_4 (\text{Si}_4 \text{O}_{10}) (\text{OH})_8$ with about 0.72nm (nanometer, 10^{-9} m) in thickness.



There is no isomorphous substitution; therefore there is no need of having cations around the cell. The clays cells are held together by H – bonding. There is good bonding and stability resulting in very large particles, size: 0.0001 – 0.

Kaolinite has a little bit of exchange only on the edges because the side oxygen atoms do not have enough satisfaction. So also is the –OH groups on the edges would have anion exchange from unsatisfied Hydrogen atom. The H – bonding makes kaolinite to be non – swelling while the cation exchange capacity is low ranging between 3 – 15 cmol charge kg^{-1}

2. Vermiculite

This is a degraded form of biotite mica, slightly altered black mica through weathering processes.

Black mica Vermiculite

(Primary silicate (Secondary silicate

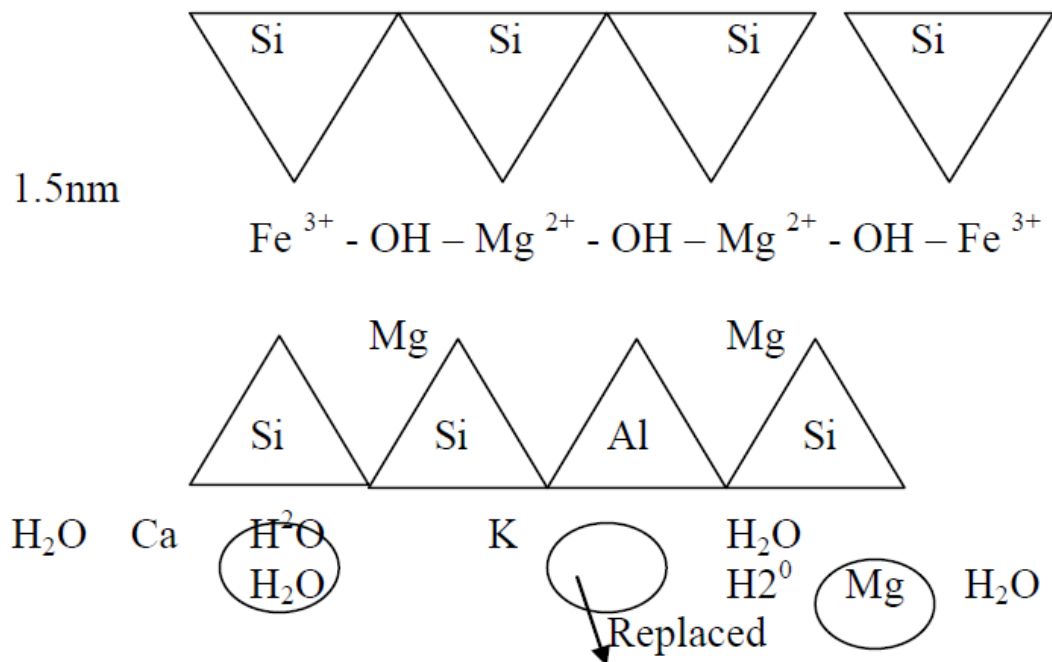
2:1 mineral) 2:1 mineral)

Formula is $x (\text{Fe}, \text{Mg}) (\text{Al} \text{Si}_3 \text{O}_{10}) (\text{OH})_4$

Vermiculite is a 2:1 expanding clay mineral. There is isomorphous substitution of Al^{3+} for Si^{4+} in the tetrahedral sheet and of Fe^{2+} , Fe^{3+} and Mg^{2+} for Al^{3+} in the octahedral

sheet. The interlayer K has been removed and replaced by Ca and Mg around which are water molecules thus increasing the interlayer spacing to between 1.0 to 1.5 nm or more. The layers of vermiculite are held together tightly due to the high negative charge resulting from high substitution in the tetrahedral Si layer.

The iron in the octahedral layer is mostly in the oxidized form and the plates are spread apart by Mg and Ca with very little swelling. Cation exchange capacity is high, between 100 – 150 cmol. Charge Kg^{-9}

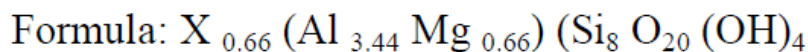
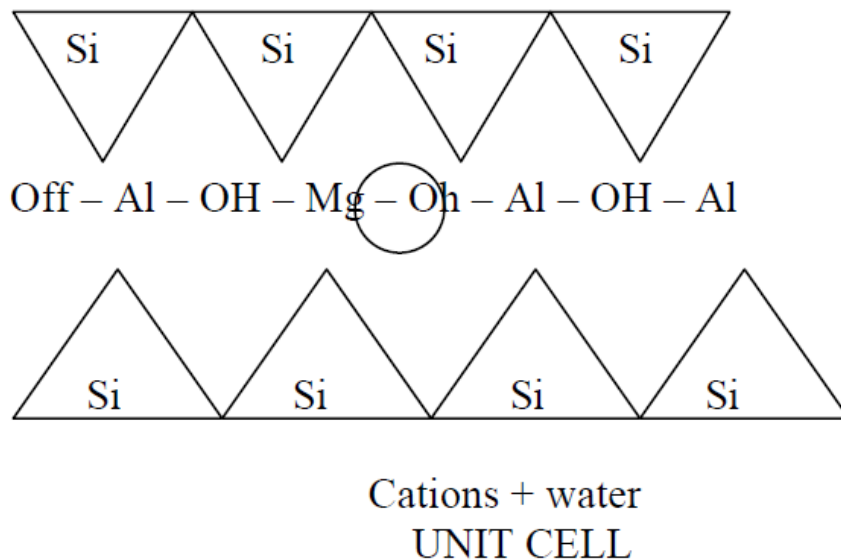


3. Montmorillonite

Montmorillonite is a 2:1 layer aluminosilicates. The aluminium sheet is sandwiched between two silicon tetrahedral sheets to make a unit layer. Aluminium often substitutes for Si in the tetrahedral sheet and Fe^{2+} , Fe^{3+} or Mg^{2+} substitutes for Al^{3+} in the octahedral sheet.

The individual three layer sheets (2:1) can separate out a little to make more space between them, and thus form an expanding lattice. The expanding lattice clays allow water to penetrate between the sheets and cause them to expand. There is no isomorphous substitution in the silica tetrahedral sheet but there is in the octahedral sheet. Therefore, there is nothing pulling the cell in a rigid position; usually, water gets into the cell to give swelling situation. Magnesium replaces about 16% of aluminium.

Negative charge which results from isomorphous substitution is balanced by cations which are loosely held. Montmorillonite is a highly swelling clay whose plates are flimsily and break easily, hence small size particles of 0.00001mm. Water could enter freely into the clay particle from the entrance surface giving the clay a large surface area. It is on the surface area that chemical activities occur, e.g exchange of gases, aeration and nutrients for the support of plants. It is not good for agriculture because of too much swelling. It has no definite shape, but ragged looking. The cation exchange capacity is considerably high: - 60 – 100 cmol charge kg⁻¹



Topic 4: Charges in Minerals

There are three sources of charge in silicate clay minerals

1. Fixed, Permanent or Lattice Charge

This is the internal charge caused by the isomorphous substitution of one cation for another in a clay mineral's structure

2. Edge Charge

The charge at the end of the crystal as a result of unsatisfied oxygen or hydrogen atom.

3. Variable Charge

This is due to the protonation and deprotonation. It is also reference to as PH-dependent charge.

Unit Summary

In this unit, we have learnt that

- Soil minerals are mainly silicates; two sheets of silicate tetrahedral and aluminium octahedral are the main building blocks of the silicate minerals. In aluminosilicate clay minerals, the sheets of tetrahedra and octahedra alternate in unit cell layers.
- The mineral portion of the soil is a framework of mineral particles of different sizes usually held together in large units called aggregates by clay, humus and iron oxides.
- Soils are made up of mineral particles of peculiar properties
- That the different minerals have silica tetrahedral and aluminium octahedral as their building blocks
- Primary minerals make up the stone, sand and silt fractions of the soil while secondary minerals make up the clay fraction
- Clays are important because they are charged and possess large surface area.

Activity

1. What is clay and why are clay minerals important to soils and man?
2. Describe the differences between kaolinite and montmorillonite.

UNIT 3

PHYSICAL CHARACTERISTICS OF SOILS

INTRODUCTION

Soil physics is a branch of Soil Science which deals with the study of soil physical conditions. It is necessary that persons dealing with soil in any way should be acquainted with the physical nature of different soils-such as moisture retention capacity, plasticity, ease of penetration by roots or compaction. The knowledge of the physical concepts will enable the user of soil to know to how to alter these properties to an advantage. That is, knowing about physical properties of soil will form a basis for much of what you learn about and do with soils.

This unit describes the key soil physical concepts and conditions in relation to plant growth and development.

OBJECTIVES

At the end of this unit, you should be able to:

- Describe the concept of soil texture and its importance
- Identify the textural class of a sample of soil
- Describe soil permeability and related properties
- Describe structure and its formation and importance
- Explain other physical properties
- Discuss soil compaction and porosity.

Topic 1: Soil Texture and Textural Composition

Soil texture could be defined as the relative proportion of particle size groupings in the soil on percentage basis. It describes the sand, silt and clay composition of the soil. The smaller the particles in a soil, the larger the internal surface area. Similarly,

the smaller the particles in a soil the more water and nutrients the soil can retain. In the field a soil is composed of a mixture of **separates** which are groups of soil particles of a given size ranges (i.e different size particles which together make up a given soil).

Physical test for these three groups reveals that **sandy soil** is generally coarse, gritty, non-sticky with low cohesion; **silt** is smooth like flour while **clay** is sticky and plastic when wet but very hard when dry. A loam texture soil usually exhibits a combination of the three properties.

A soil sample usually contains a combination of at least two separates thus there are classes of soil texture. These combinations are therefore classified into twelve different combinations called soil textural classes. Table 1 shows two schemes of classification used for defining various separates in soils.

Table 1. Size limits of soil separates in the USDA and ISSS Schemes.

USDA Scheme		ISS Scheme	
Name of separate	Diameter Range (um)	Name of separate	Diameter range (um)
Very coarse sand	2000-1000		
Coarse sand	1000-500	Coarse sand	2000-200
Medium sand	500-250		
Fine sand	250-100	Fine sand	200-20
Very fine sand	100-50		
Silt	50-2	Silt	20-2
Clay	<2	Clay	<2

Gravels	Coarse fragments
Cobbles	2000-750um (2-75mm)
Stones	75000-254000um (75-254mm)
	>254000um(>254mm)

Source: Ivara E. Esu. (1999). Fundamentals of Pedology

Topic 2: Soil Texture Classes

Apart from the modification of study textures with terms such as gravelly, coarse, very fine, fine, etc. There are twelve basic soil textural classes recognized. In order of increasing proportions of the fine separates, the classes include: sand, loamy

sand, sandy loam, loam, silt, clay and clay.

The basic soil textural class names in present use are defined in terms of particle-size distribution as determined in the laboratory by a procedure termed Particle Size Distribution Analysis or Mechanical analysis or

Granometric Analysis. The percentage of size fractions combined to determine the texture using a standard soil textural triangle is show in Fig. 1

In general, the twelve textural classes may be defined as follows:

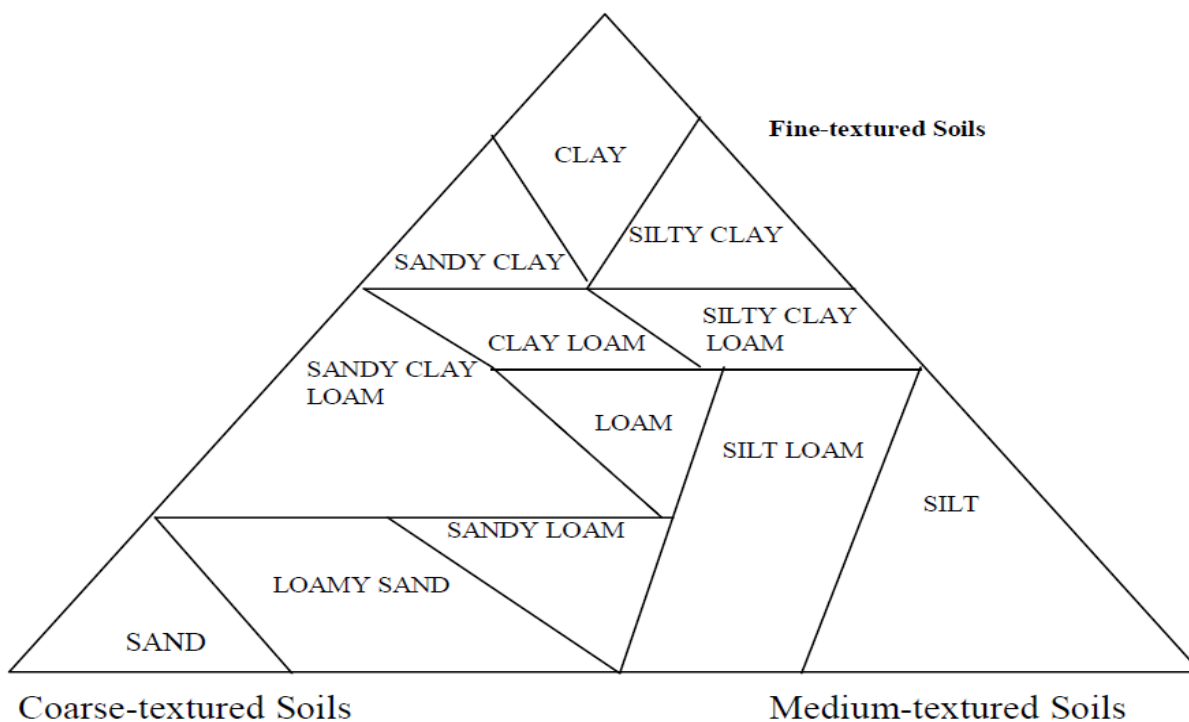
- | | | |
|-----------------------|---|--|
| Sand | - | Soil material that contain 85% or more of sand and a percentage of silt plus 1 ½ times the percentages of clay not exceeding 15. |
| Loamy Sand | - | Soil material that contains at the upper limit 85 to 90% sand, and the percentage of silt plus 1 ½ times the percentage of clay is not less than 15; at the lower limit it contains not less than 70 to 85% sand, and the percentage of silt plus twice the percentage of clay does not exceed 30. |
| Sandy Loam | - | Soil material that contains either 20% clay or less and the percentage of silt plus twice the percentage of clay exceeds 30, and 52% or more sand; or less than 7% clay, less than 50% silt, and between 43% and 52% sand. |
| Loam | - | Soil material that contains 7 to 27% clay, 28 to 50% silt, and less than 52% sand. |
| Silt Loam | - | Soil material that contains 50% or more silt and 12 to 27% clay (or) 50 to 80 percent and less than 12% clay. |
| Silt | - | Soil material that contains 80% or more silt and less than 12% clay. |
| Sand Clay Loam | - | Soil material that contains 20 to 35% clay, less than 28% silt and 45% or more sand. |
| Clay Loam | - | Soil material that contains 27 to 40% clay |

and 20 to 45% sand.

- | | | |
|------------------------|---|---|
| Silty Clay Loam | - | Soil material that contains 27 to 40% clay and less than 20% sand |
| Sandy Clay | - | Soil material that contains 35% or more clay an 45% or more sand. |
| Silty Clay | - | Soil material that contains 40% or more clay and 40% or more silt. |
| Clay | - | Soil material that contains 40% or more clay, less than 45% sand, and less than 40% silt. |

In the field however, a method known as the “Feel method” is used in assessing soil texture. In this method, a sample of the soil usually moist or wet is rubbed between the fingers and the texture assessed by the behaviour of the soil particles using acknowledge of the behaviour of the various quantities of the separates present in the soil sample. In other words, the differing sizes of the constituent particles give each soil a characteristic feel. Thus, a soil composed mainly of coarse sand particles feels light and gritty; one composed mainly main of clay feels heavy and sticky. In general, the twelve textural class names already established form a more or less graduated sequence from soils that are coarse in texture and easy to handle to the clays that are very fine and difficulty to manage, while the loams are in between the two extremes.

Figure 1.3: The soil triangle is redrawn to show fine-, medium-, and coarse-textured soils. An exception is very fine sandy loam, which is considered medium textured.



Why Study Soil Texture

Soil texture is studied so that:

- i. Rate at which water enters the soil (**infiltration**) and drains through (percolation) depends on whether it is sandy, silt or clay soil.
- ii. Rate of nutrient leaching also depends on rate of water infiltration e.g. Clay soils have the best holding ability for water and chemical nutrients.
- iii. Soil texture influences the ease at which a soil can be worked; clay soils are more difficult than sandy soils.
- iv. The knowledge of soil texture and crop requirement of soil texture and crop requirement enable the grower to select suitable soils/land for his crop.
- v. Grower would be able to know management practices suitable for the soil types especially in terms of fertilization, irrigation and organic materials incorporation.

Topic 3: Soil Structure and Aggregates

Soil structure may be defined as the organization of sand, silt, clay and humus particles into somewhat stable groupings (peds). It can also be defined as the aggregation of primary soil particles (sand, silt and clay) into compound particles termed **peds** or **aggregates**, which are separated by adjoining peds by lines of weakness.

Three groups of characteristics are used to classify different kinds of structure:

- i. Type which refers to the shape of the soil aggregate e.g granular, platy, crumb, etc.
- ii. Class refers to the size of the peds e.g. fine, medium, coarse etc.
- iii. Grade describes how distinct and strong the peds are. It expresses the differential between cohesion within aggregates and adhesion between aggregates e.g weak, moderate, strong, strong or structureless terms are used for grade. A structureless condition exists when there is no observable degree of aggregation.

Thus, the full description of the structure of a ped could be strong, coarse, prismatic structure; moderate fine granular structure; weak fine crumb structure or structureless (massive) or structureless (single – grained).

Soil structure is important in agriculture from the point of view that a well that a well aggregated soil is often well drained, has good permeability of water, air and roots. Such a soil is also easily worked or tilled and thus serves to control erosion. All these are made possible because of the numerous macropore spaces created by the existence of numerous lines of weakness between aggregates or peds.

Common agents of aggregation which are responsible for binding primary soil particles into peds include the following:

- i. Colloidal clay minerals which consist of the finer, more reactive part of clay in soils

- ii. Colloidal oxides of iron, aluminium and manganese, which are collectively, termed sesquioxides. These are especially typical of tropical soils
- iii. Microbial gums; which are gums secreted by micro-organisms in soils
- iv. Organic compounds, especially humus which are also colloidal in nature
- v. Carbonates.

Table 2.3: Diagrammatic Definition and Location of Various Types of Soil Structure

Structure type Common Horizon	Aggregate Description aggregate	Diagrammatic location
Gangwar	Relatively non-porous, small and spheroidal peds; not fitted to adjoining aggregates	A horizon
Crumb	Relatively porous, small and spheroidal peds; not fitted to adjoining aggregates	A horizon
Platy	Aggregates are platelike Plates often overlap and impair Permeability	E horizon in forest and claypan soils
Blocky	Blocklike peds bounded by other aggregates whose sharp angular faces form the cast for the ped. The aggregates often break into small blocky peds	
Subangular Blocky	Blocklike peds bounded by other aggregates whose rounded subangular Faces form the cast for the ped.	Bt horizon
Prismatic	Columnlike peds without Rounded caps. Other prismatic Aggregates form the cast for the ped. Some prismatic aggregates break into	Bt horizon

smaller blocky

Columnar	Columnlike peds with rounded caps Bounded laterally by other columnar aggregates that form the cast for the peds	Bt horizon
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Adapted from Soils Laboratory Source Book, Am. Soc. Of Agron, 1964 Source:
Ivera Esu, 1999.

Topic 4: Soil Consistence

Consistence refers to the behaviour of soil when pressure is applied, especially at various moisture contents usually when the soil is wet, or dry.

The terms used to describe consistence include:

- i. **Wet Soil:** Often described in terms of stickiness as non sticky, slightly sticky, sticky, very sticky; and in terms of plasticity as non plastic, slightly plastic, plastic, and very plastic.
- ii. **Moist Soil:** This is very important because it best describes the condition of soils when they are tilled in the field. Consistence of a moist soil is described in the following terms; going from the material with least coherence to that which adheres so strongly as to resist crushing between the thumb and forefinger: loose, very friable, friable, firm, very firm and extremely firm.
- iii. **Dry Soil:** Terms used to describe the degree of rigidity or brittleness to crushing or manipulations include the following: loose, soft, slightly hard, hard, very hard and extremely hard.

Cementation is also a type of consistence and is caused by cementing agents such as calcium carbonate, silica or oxides of iron and aluminium. Cementation is little affected by moisture content. The terms used to describe cementation include: weakly cemented i.e cemented units can be broken in the hand. Strongly cemented – units cannot be broken in the hand but can be broken easily with a hammer. Indurated – units breakable only with the sharp blows of a hammer.

Cutans

Cutans may be defined as modifications of the fabric of natural surfaces in soil materials due to concentration of particular solid constituents such as clay, sesquioxides and organic materials notably humus. The presence of cutans in subsoil horizons (B or C) of a soil profile is of specific pedological significance. For instance, the presence of recognizable amounts of clay cutans or clay skins on ped faces or in pores is a direct indication that an argillic horizon (Bt) is present and that such a soil is mature. The presence of both Fe-oxyhydroxide (sesquioxides) and humus (organs) in the B-horizon may indicate the occurrence of a spodic horizon and the onset of the process of podzolization in a soil.

Topic 5: Soil Compaction

This is the natural packing of soil particles by natural force into a dense or closer pack. The forces acting to compact soil are:

1. Overburden weight of material above the soil
2. Implement traffic from mechanized agriculture
3. Foot traffic
4. Tillage pressure due to implement moved through the soil
5. Micro-organism as in the ant-hills.

Over the years, the implements cause pressure on the lower layer of tillage soil. There is thus a low infiltration rate on this layer of soil. That is, the porosity becomes low and bulk density increases, other effects of compaction are:

- Reduced permeability aeration and water infiltration
- Difficulty in root penetration

- Severe compaction inhibits production

Soil compaction is measured by the bulk density and the use of **cone penetrometer**.

Topic 6: Porosity and Pore Spaces

Pores are spaces or voids between solid soil materials. The occurrence or abundance of pores in soils are of pedagogical significance because a soil with many coarse pores will be much more aerated and better drained than one with few very fine pores.

When describing pores in detail, a definite sequence of terms should be consistently followed. The usual sequence is **number** (Few, common, many), **size** (very fine, fine, medium, coarse), **continuity** (discontinuous, constricted, continuous), **orientation** (vertical, horizontal, random, oblique), **shape** (vesicular, irregular, tabular) and location (imped, exped).

The pores allow the soil to act as medium for air water transport and it is within the pores that physical, chemical and biological processes occur in the soil.

Pore Space could also be defined as the portion of given volume of soil which is not filled with solid matter. Porosity (pore space) refers to total pore space per volume of soil. Mathematical expression is

$$\text{Porosity} = \frac{V_{\text{pore}}}{V_s} (100) = \frac{V_s - V_s}{V_s} \times 100$$

Where V_s is the total volume of soil

V_s is the volume of solids

Therefore porosity is also $(1 - \frac{V_s}{V_s}) 100$

Macropores are the big pores which are mainly meant for aeration while micropores (small pores) are meant to transmit water after wetting. Pores are connected with one

another in the soil and are usually described by their retention of water and air. An ideal soil for agricultural purposes has fairly equal proportion of macropores and micropores. This is usually put at 25% for each of the two pore sizes.

Porosity also depends on both the texture and structure of the soil and on the shape of the particles.

Topic 7: Soil Density and Permeability

The density of soil is its weight per natural volume or bulk volume and it is related to the amount of empty space in the soil. Soil density is expressed in two ways; namely, particle and bulk density.

Particle Density is the mass per unit volume of soil solids. For example, one cubic centimeter of soil solids weighing 2.0g, has particle density of 2.0g cm^{-3} . Mineral soils have particle density range of $2.60 - 2.75\text{g cm}^{-3}$ with an average value of 2.65g cm^{-3} organic matter tends to lower particle density.

Bulk density is the mass of soil per unit bulk volume of dry soil:

$$\text{Bulk density} = \frac{M_s \text{ or weight of dry soil}}{V_b \text{ volume of dry soil}} = \text{g/cm}^3$$

Where M_s is mass of soil V_b is natural volume or bulk volume.

$$\text{Particle density} = \frac{M_s}{V_s}$$

V_s

Where V_s indicates volume of solids (Solid space) and solid space is bulk volume – air space. Organic matter which promotes soil aggregation tends to lower the bulk density.

Permeability is the ease with which air and water and roots move through the soil. The number, size, and continuity of soil pores determine the permeability of the soil. Since

pore space depends on texture and structure permeability also depends on soil texture and structure. Permeability of a soil is measured by measuring movement of water through the soil; this is known as **Hydraulic conductivity**.

Topic 8 Soil Tilth

Tilth is the physical condition of the soil in relation to ease of tillage and permeability. It is a function of texture and structure and structure of the soil. Soil with good tilth makes room for rapid root growth and ease of seedling emergence.

Tilth can be improved by improving soil structure and avoiding compaction by adopting the following practices:

- i. Avoid working too wet or very dry soils.
- ii. Reduce traffic or overburdened weight on the soil.
- iii. Number of tillage operations could be reduced as in minimum tillage
- iv. Subsoil or deep ploughing is good to break up hardpans
- v. Mulching or cover-cropping protect the soil from raindrop impact.
- vi. Incorporation of organic matter into the soil such as compost FYM or green manures.
- vii. Acid soils should be limed to enhance rapid organic matter decomposition.

Topic 9: Soil Colour

Soil colour is an important indicator of soil conditions. It reveals considerable information about any given soil. The soil can take several shades of colours such as:

1. **Brown-Black** where dark soils result from the level of organic matter contents which is usually high in waterlogged soils.
2. **White-Light Grey** which indicate leaching of colouring materials such as organic matter, or due to accumulation of lime or salts.
3. **Yellow-Red** soils contain iron oxides in well-drained soils
4. **Mottling** colour develops when the soil is waterlogged for part of the year patches of different colours are shown.

Soil colour is described by using the munsell system in a soil colour chart.

Unit summary

In this unit, you have learnt:

- Our understanding of soil physical properties is imperative to the proper management of soils both for present use and future generations.
- The meanings of important soil physical properties and processes in relation to plant growth.
- The relationships and interactions among the soil physical properties especially texture, structure and pore space
- The extent at which these physical properties could be modified by natural events
- The appropriate management strategies of soil physical properties for improved productivity and sustainable agriculture.

Activity

1. Define and explain the following soil physical properties
 - a. Soil textural classes
 - b. Soil aggregation/granulation
 - c. Porosity
 - d. Bulk density
 - e. Soil tilth
2. Discuss the agricultural practices that could improved soil physical properties and enhance crop production in your area.

UNIT 4

WATER DYNAMICS IN THE SOIL - MOVEMENTS (RETENTION AND LOSS), MEASUREMENT AND MANAGEMENT

INTRODUCTION

The importance of water as a factor affecting crop production cannot be overemphasized. Large expanse of dry but fertile land could be brought into productive cultivation if water is supplied through irrigation. On the other hand, lands usually covered by water need some elaborate drainage system to make them productive. This unit will consider the behaviour of water in the soil, plant-water interaction (that is, water in relation to plant growth) and measurement procedures of soil water.

OBJECTIVES

At the end of this unit, you should be able to:

- Identify the role of water in plant growth
- Define the forces that act on soil water
- Classify types of soil water
- Explain how plants absorb both water and nutrients
- Describe how to measure soil water content.

Topic 1: Importance and Uses of Water to Plants

On the average, crop plants use 200 to 300 kg of water to produce a single 0.5 kg of dry plant matter. Water deficiency commonly limits plant growth; in several agricultural areas, water is the most important need in farming. Water is vital to growers because of the several functions it serves in plant growth:

1. Plant cells are largely made up of water. Plant tissue is 50% to 90% water, depending upon the type of tissue.
2. When plant cells are full of water, the plant is stiff (turgid) or semi-rigid because of water pressure in plant tissue. This keeps stems upright and leaves expanded to receive sunlight.

3. Photosynthesis uses water as a building block in the manufacture of carbohydrates.
4. Transpiration, or evaporation of water from the leaf, helps cool the plant.
5. Plant nutrients are dissolved in soil water and move towards roots through the water. Water is thus important in making nutrients available to plants.
6. Water carries materials such as nutrients and carbohydrates throughout the plant.

Effects of Water Stress

Water stress is caused by a shortage of water in plant tissue. As will be explained later, stress can occur even at moisture levels that do not cause wilting. Part of the reason for such stress is that, as the soil dries, it becomes increasingly difficult for a plant, guard cells begin to close the stomata, slowing down the exchange of oxygen and carbon dioxide. As a result of the reduced exchange of the two gases, photosynthesis must also slow down. With less photosynthesis, plant growth is inhibited.

As the soil dries further, or if the weather is hot and dry, the plant becomes even more deficient in water. The plant begins to lose water faster than it can be absorbed and the plant temporarily wilts. At this *temporary wilting point*, the plant will recover when conditions improve. Wetter soil, cooler temperatures, a more humid atmosphere, shade, or less wind can help the plant recover. Although the plant recovers, episodes of water stress can reduce plant growth and crop yields. With further drying, the *permanent wilting point* is reached. Now the plant will not recover even if conditions improve.

Plants suffering from chronic water stress are small and sparse with small, poorly coloured leaves. Old leaves often turn yellow and drop off. Some plants show specific symptoms of water stress. For example, the leaves of corn plants curl when they need water.

Seed germination is very sensitive to water shortage. While seeds efficiently absorb moisture through the seed coat, the emerging seedling is easily injured by dry soil.

Topic 2: Availability of Water to the Soil-Plant System

Forces that Influence Soil Water

A number of forces influence the way water behaves in the soil. The most obvious is gravitational force, which pulls water down through the soil. Other forces, called adhesion and cohesion, work against gravity to hold water in the soil. *adhesion* is the attraction of soil water to soil particles, while *cohesion* is the attraction of water molecules to other water molecules.

The water molecule is like a bar magnet-positive on one end, negative on the other. Like bar magnets, the opposite ends of water molecules attract. The bond between the hydrogen of one water molecule and the oxygen of another, called a hydrogen bond, accounts for cohesion.

Hydrogen bonding also accounts for adhesion. The main chemical in soil minerals is silica (quartz is pure silica). Silica, with the chemical formula SiO_2 , has oxygen atoms on the surface that can form hydrogen bonds with soil water.

Together, adhesion and cohesion create a film of water around soil particles. The film has two parts. A thin inner film is held tightly to the particle by adhesion. The *adhesion water* is held so tightly it cannot move. A thicker outer film of water is held in place by cohesion to the inner film. *Cohesion water*, sometimes called *capillary water*, is held loosely and can be absorbed by plants. Thus, plants use cohesion water that is clinging loosely to soil particles.

Capillarity

Soil water exists in the small spaces in soil as a water film around soil particles. The small pores act as capillaries. A *capillary* is very thin tube in which a liquid can move against the forces of gravity.

Capillary action, the additive effect of adhesion and cohesion, holds soil water in small pores against the force of gravity. The fact that soil water can move in directions other than straight down is also due to capillary action. The smaller the pores, the greater that movement can be.

Types of Soil Water

Consider what happens after a heavy rain. At first, all soil pores are completely filled with water. This is called *saturation*. All of this water does not normally remain in the soil pores. In larger pores, some water is too far from the nearest surface to be attracted by the particles to overcome gravity; the gravitational potential exceeds the matric potential. The extra water, called *gravitational water*, drains through the soil profile, usually within 24 to 48 hours in a well-drained soil. As the soil drains, it pulls air into fill the large soil pores. This action provides new oxygen-rich air to plant root systems.

Eventually drainage ceases. The soil moisture level at that point in time is called *field capacity*. At field capacity, the remaining water is close enough to the surface of a particle to be held against the force of gravity. The soil-water potential is about $-1/3$ bar. Air fills the large pores, and thick water films (cohesion water) surround each soil particle. Plant growth is most rapid at this ideal moisture level, because there is enough soil air yet sufficient water is held loosely at high potential.

Once drainage stops, plant and evaporation continue to remove cohesion water, shrinking the soil water films. As the water films become thinner, the remaining water clings more tightly, being held at lower potential (larger negative value). It becomes increasingly difficult for plant roots to absorb water. Eventually, at the *permanent wilting point*, most of the cohesion water is gone and the plant can no longer overcome the soil-water potential. The plant wilts and dies. The potential at this point varies according to plants and conditions but is generally about -15 bars.

Beyond the wilting point, some capillary water remains but is unavailable to plants. The capillary water may also evaporate, leaving only the thin film of adhesion water. This point is called the *hygroscopic coefficient*, the point at which the soil is air dry. This *hygroscopic water*, as it is called, is held to particles so tightly, between -31 and $-10,000$ bars, that it can only be removed by drying the soil in an oven. In fact, the strength of the soil water potential is so great at this stage that if oven-dry soil is exposed to air, it will bind water vapor from the air until the soil moistens to the hygroscopic coefficient.

Available Water

Available water is that part of soil water that can be absorbed by plant roots. Soil scientists consider gravitational water to be largely unavailable, because it moves out of the reach of plant roots. If the excess water is unable to drain away, roots become short of oxygen and fail to function. Hygroscopic water cannot be removed by roots, so it is also unavailable to the plant. Only some cohesion water can be used by plants. Available water is defined as lying between the field capacity and the wilting point or between $-1/3$ and -15 bars. In a medium soil, available water amounts to about 25% of the water held at saturation.

Water Retention and Movement

Both the retention of water and the movement of water in the soil are governed by the energy relations just described. We can begin by looking at water retention.

Water Retention: How much water can a particular soil retain and make available to plants? Actually, these are two separate questions. Not all the water film surrounding a soil particle can be drawn on by plants, so only a portion of the total water-holding capacity of a soil can be said to be plant-available. Both the total water-holding and the available water-holding capacity are based mainly on soil texture. Let's look at the effect of each soil separately.

Sand grains are large, so the internal surface area of a soil high in sand is quite low. Thus, there is little surface to hold water films. In addition, the pores are large enough that much of the volume of each pore is too far from a surface to retain water against gravity. The opposite is true of clay soils – they have small pores and a large internal surface area. Thus, soils high in sand have a low total water-holding capacity, while soils high in clay have a large water-holding capacity.

Not all of this water is available to plants; however, in a soil high in clay, clay particles are crowded together tightly, leaving tiny pores. Any one water molecule occupying one of the pore spaces will be close to a clay surface, therefore tightly bound. Most of the water in a high-clay soil is held at low water potential. Sand is the opposite. With large pores, much of the water can be fairly distant from a grain, and therefore be held

at high potential.

This leads to two rules. First, water in fine soils is held at low potential and water in coarse soils is held at high potential. Thus, it is easier for plants to remove water in coarse soils than in fine soils. Second, since most of the water in high-clay soils is held at low potential, much of the water is not available to plants. In contrast, most of the water in a sandy soil is available.

Silt particles, and to some degree very fine sand, are a special case. They are small enough that there is a high surface area to hold water. The pores are small enough to hold large amounts of water by capillary force but large enough that much of it is held loosely at high water potentials. Thus soils high in silt hold large amounts of plant-available water.

To hold the largest amounts of plant-available water, then, a soil should have a mixture of large and small pores with many of the medium-sized pores caused by silt and very fine sand. There are several important points to note in the:

- The fine sandy loam holds much more water than regular sand loam, reflecting the influence of very fine sand.
- The finest soil, clay, has the highest total water-holding capacity. But note that it holds no more *available* water than a sandy loam.
- Medium-textured soil has the highest available water-holding capacity. Note that the best soil is a silt loam.

Water Movement: Horticulturists suggest that trees be watered by letting a hose trickle on the ground under the tree for a few hours. How will the water move into the soil? First, water infiltrates the soil, then it percolates downward through the soil profile. The distance, direction, and speed of travel are set by gravity, matric forces, and hydraulic conductivity.

Directly below the nozzle of the trickling hose is a column of percolating water. This

water is gravitational water, moving under the influence of gravity (r moving in response to the gravitational potential). It is called *gravitational flow*. Gravitational flow only occurs under saturated conditions, when the matric potential is so low that it cannot hold water against gravity. Because it occurs under such conditions, it is also called *saturated flow*. Saturated flow resembles the flow of water through water pipes.

Table 1.4 Water retention of several soil textures.

Texture	Field Capacity (cm/cm)	Permanent Wilting Point (cm./cm)	Available Water (cm./cm)
Fine sand	1.4	0.4	1.1
Sandy loam	1.9	0.6	1.4
Fine sandy loam	2.5	0.8	1.8
Loam	3.1	1.2	1.95
Silt loam	3.4	1.4	2.03
Clay loam	3.7	1.8	1.95
Clay	3.9	2.5	1.5

(Adopted from *Water: The Yearbook of Agriculture*, USDA, 1955).

Absorption of Water by Plants

Moistures enter plant roots by the process of osmosis, which may be roughly defined as the movement of a liquid through a semi-permeable membrane caused by unequal concentrations on the two sides. It is customary to think of the cell sap within the root as having a greater concentration of soluble material than the soil moisture, and hence water passes in to equalize the concentration. A more correct view is to consider the concentration of water molecules in the cell sap reduced because of the quantity of soluble substances present, and hence the number of water molecules in the soil solution is greater. As a result, more water molecules strike against a unit area of the exterior of the root membrane than against the interior, for the molecules in both cell sap and soil solution are in constant motion. As a result of the bombardment, water passes into the root from a zone of higher concentration of water to a zone of lower

concentration.

If through any circumstance, the concentration of soluble substances in the soil moisture exceeds that of the cell sap, the situation will be reversed and water will pass out of the root.

It should be recalled to mind that plant roots do not absorb the soil solution as such, as animals drink water containing soluble material. The water enters the roots as pure water without regard to the intake of any of the materials dissolved in it. The entrance of dissolved substances is entirely a separate process.

The Role of Water in Nutrient Absorption: It is generally believed that materials must be in solution to pass through the plant-root membrane.

Nutrients in the soil solution should therefore be in suitable condition for absorption. It must be pointed out, however, that the presence of a nutrient in the soil solution does not assure its use by the plant.

Movement of Nutrients in Soil Moisture: Nutrients dissolved in the soil solution move with it, and so when moisture moves by capillarity to replace that which has been taken up by plants, a supply of nutrients may be moved near the roots. Although this action takes place through short distances only, the net result in the course of a growing season may add materially to the food supply of the crop. Vertical movement of soluble salts in capillary water has been observed more extensively than horizontal movement. During periods of drought a considerable accumulation of salts may develop at the soil surface. In some soils, this may be sufficient to be visible, especially in regions of neutral or alkaline soils. The appearance of small quantities of salt on the surface of clods is a familiar sight even in humid regions. The movement of salts to the surface is much more pronounced in soils not occupied by growing plants because the roots absorb the moisture and so reduce the quantity evaporated from the soil surface. Water from heavy rains has a tendency to displace the soil solution from the pore spaces and force it out of the soil into the drainage water. This process results in considerable loss of nutrients. There is also considerable mixing of the rain water with the soil solution, and a portion of the mixture drains away while the remainder constitutes the new soil solution which dissolves fresh supplies of nutrients from the

soil complexes.

Transpiration: There has been much discussion concerning the value of transpiration to plants. Some cooling of the plant leaves may result from the evaporation of moisture from them, but there is a difference of opinion as to whether the plant is benefited by this effect. Some investigators think that transpiration is of assistance to plants in the movement of nutrients, particularly from the lower into the upper parts. Nutrients must be in solution for translocation to different parts of the plant, and since water serves as the dissolving medium, it is of service in the growth processes aside from its role as food material.

Topic 3: Measuring Soil Water

People who design or use irrigation systems need to be able to measure the amount of water in a soil. They also need terms to name the amount of water present. Four methods are common: gravimetric measurements, potentiometers, resistance blocks, and neutron probes. At the base of all these are gravimetric measurements.

Gravimetric Measurements

Gravimetric methods measure the percentage of soil weight that is water. The percent moisture by weight can then be converted to other use quantities.

Weight Basis

To measure the percent moisture of a soil, sample by weight, the sample is weighed and the weight recorded. The sample is then oven-dried, and the dry weight is noted. The difference between the two weights is the weight of water in the soil. The percent moisture is the amount of moisture divided by the oven-dry weight:

$$\% \text{ moisture} = \frac{\text{moist weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

As an example, suppose one needs to measure the moisture percentage of a soil at field capacity. A sample is taken two days after a heavy rain. If the sample weight was one kg when wet and 0.65kg when dry, the moisture percentage would be

$$\begin{array}{rcl} 1.0 \text{ kg} - 0.65 \text{ kg} & & 0.35 \\ \hline \% \text{ moisture} = \frac{\quad}{0.65\text{kg}} \times 100 = \frac{0.35}{0.65} \times 100 = 54\% \end{array}$$

Volume Basis

It is often more useful to calculate the percent moisture on a volume basis. However, it is impractical to measure a volume of water in the soil. This problem can be solved by making a percent weight determination and converting it to percent volume using soil and water densities (density being weight per volume). The equation for the conversion is

soil density

$$\% \text{ water by volume} = \% \text{ water by weight} \times \frac{\quad}{\quad}$$

water density

If we are using U.S Customary Units, then density can be expressed as kg per cm³. If water has the density of 62.5 kg cm³, so the formula then would be

soil density

$$\% \text{ water by volume} = \% \text{ water by weight} \times \frac{\quad}{\quad}$$

In the example above, if the bulk density of the soil sample were 90 kg per cm³ percent water by volume is:

90

$$\% \text{ water by volume} = 54\% \times \frac{90}{62.5} = 78.4\%$$

Soil Depth Basis

A meteorologist states how much rain falls in cm of water, and irrigation is measured in cm of water as well. In saying that one cm of water fell, the meteorologist means that if rainfall were caught in something like a cake pan, it would fill the pan to a one-cm depth. cm of water is a convenient, easily visualized unit that can also be used to measure the amount of water in a soil.

Let's say one could take one cm³ of soil and squeeze all the water out of it into a one cm square cake pan. How many cm of water would be in the pan? If there were two cm of water, the soil had two cm of water per cm of soil. This can be calculated simply by the equation:

$$\text{cm water per cm soil} = \frac{12 \text{ cm} \times \text{\% water by volume}}{100}$$

In above sample, then:

$$\text{cm water per cm} = 12 \text{ cm} \times 78.4\%/100 = 9.36$$

In the sample, each cm of soil depth contains 9.36 cm of water. If a soil profile were one m deep, and each cm was the same, then the total of the entire profile would be 27 cm of total water.

Cm per m is a common measurement used in irrigation. Irrigation also uses the ha-cm, the volume of water that would cover one ha of soil one cm deep.

From these calculations, one can determine how much water a soil holds at each moisture constant or how much of each type of water a soil can hold. For instance, if a soil contained three cm of water per cm of soil at field capacity and one cm per cm at the permanent wilting point, then the soil holds two cm per cm of soil of available water.

Potentiometers: In practice, it would be a bother to make gravimetric measurements each time one wanted to decide whether or not the soil needs watering. Besides, from the plant's point of view, the important thing is not how much water is in the soil, but the water potential it is being held at. A device called a *potentiometer*, or *tensiometer*, acts like an “artificial root.” It measures soil- moisture potential and so gives a “root’s eye view” of how much water is available.

If a grower wanted to use a potentiometer to measure the percentage of water, it would be necessary to calibrate the device. Calibration involves making gravimetric measurements at different gauge readings to prepare a calibration chart. Calibration must be done for each soil because the same amount of water will be held at a different matric potential in different soils.

Resistance Blocks: Another device for measuring soil moisture is the *resistance block* or *Bouyoucos block*, after the person who introduced the device. Two electrodes are imbedded in a block of gypsum, fiberglass, or other material. When in the soil, the device measures resistance to electrical flow between the two electrodes. It is more difficult for electricity to flow in dry soil than moist soil, so the reading indicates moisture level. Resistance blocks work well between the field capacity and wilting point.

Actually, pure water conducts electricity very poorly. It is ions in solution that carry the electrons of electrical flow. Therefore, most resistance blocks sense both water content and salt content of the soil. These blocks must be calibrated for each soil to obtain moisture readings, because of the different salt content and matric potential of different soils.

Neutron Probe: A *neutron probe* is a long tube containing a radioactive material that emits a stream of neutrons. The tube is inserted into a steel tube in the soil so the neutrons stream into the soil the behaviour of the neutron stream depends on the amount of water in the soil and can be measured. Like the other devices, the neutron probe must be calibrated for different soil types.

Unit summary

In this unit you have learnt that:

- The useful portion of soil water to crops is the capillary and gravitational water, whose molecules are held together by forces of adhesion and cohesion.
- Water is absorbed into plants because transpiration causes low potential inside the plants.
- The water absorbed by plants is used in photosynthesis, to transport materials within the plant and to keep plant tissues turgid.
- Water is the most important need in farming in several agro-ecologies of the world.
- Forces act on water in soil making it available or deficient to crops
- Absorption of water by plants is controlled mainly by transpirational pull
- Soil water could be measured by several techniques and instruments whereby we are able to know crop/soil water need.

Activity

Discuss water levels which may be detrimental to crops.

UNIT 5

SOIL AIR AND TEMPERATURE

INTRODUCTION

You will learn in this unit how the presence or absence of air (oxygen), one of the growth factors in the soil affects plant growth. When O_2 is adequate nutrient elements exist in the forms that plant usually absorb; when O_2 is deficient in soil, toxic substances that adversely affect plant growth are formed. Plants also have optimum ranges of temperature for best performance.

OBJECTIVES

At the end of this unit, you should be able to

- Define soil aeration, oxidation-reduction potential (Redox potential) and net radiation
- Discuss the conditions that affect soil air composition

- Describe nutrient transformations in both aerated (aerobic) and anaerobic soils
- Discuss practical application of redox potential reactions in agriculture

- Discuss the effect of soil temperature on plant growth and those factors that help to moderate soil temperature.

Topic 1: Soil Air

There must be interchange of gases between plants root hair and the soil atmosphere if the plant is to survive. Similarly, there must be adequate interchanges of gases between the soil habiting the plant roots and the free atmosphere above it. This interchange of gases is necessary for the respiration of higher plants and the decomposition of incorporated organic materials by soil micro-organism. In these soil respiratory activities, oxygen, O_2 , is used up while carbon dioxide, CO_2 , is given off.

Soil aeration is the process whereby there is gas exchange in soil that ensures oxygen sufficiency and prevents carbon dioxide toxicity.

A well-aerated soil is one in which gas exchange between the soil air and the atmosphere is sufficiently rapid to prevent a deficiency of oxygen or a toxicity of CO_2 ,

and thereby ensures normal functioning of plant roots and of aerobic microorganisms. In a typical well-aerated soil, the amount of micropores (water space) occupied by water should not be more than 25%, macropores (air space) also 25%, mineral matter 45% and the organic materials usually about 5.0%. Different variations of the percentage composition of these soil constituents give rise to different soil types such as (i) coarse textured soils (loamy sand, sandy loam) which are suited to areas of frequent rainfall, (ii) medium textured soils (loam, silt loam) have good aeration and usually of optimum water condition water conditions; and (iii) Fine textured soils (clay, silt clay) which are easily water-logged but are good in areas with long drought periods.

S/No	Soil	Soil types	Approx Water	% Air	Content of Organic Matter	Mineral matter
1	Coarse Texture	Loamy sand Sand loam	30	15	1	45
2	Medium textured	Loam, silt Loam	25	25	5	45
5	Fine Texture	Clay, Silt Clay	40	15	5	40

Table1.5 Composition of the air in soil (% by volume)

Soils Systems	Nitrogen	Oxygen	Carbon dioxide
Atmosphere (Average)	79.01	20.96	0.03
Soil (Average)	79.0	20.3	0.15-0.65

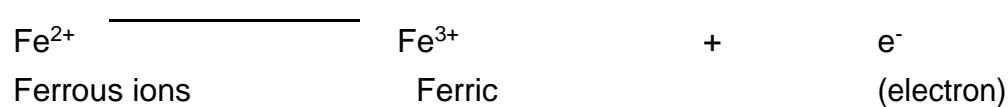
Arable land	80.1	19-20	0.9
Pasture land	80.5	18-20	0.5-1.5
Arable, uncapped	79.25	20.4	0.35
Sandy soil	79.10	20.5	0.40
Arable land fallow	79.20	20.7	0.10
Grass land	80.0	18.4	1.60

Table 1. shows that the free atmosphere above the soil contains about 21% oxygen, 0.03% CO₂ and nearly 79% N₂. In comparison, soil may have about the same percent, or somewhat higher N₂, content, but is consistently in O₂ and higher in CO₂. The upper soil layers contain more O₂ than soils at upper slopes after a heavy rainfall since water tends to accumulate at the low laying areas.

Topic 2: Oxidation – Reduction (Redox) Potentials (Eh)

A soil in a given situation has a given potential. That is, the chemical elements in the soil are, at any point in time, in a certain oxidation and reduction state depending on the level of soil aeration. In well aerated soils, the chemical elements are usually in oxidized forms; for example Ferric iron (Fe³⁺), nitrate NO₃⁻ and sulphate (SO₄⁻). In water logged and poorly aerated soils, the reduced forms of such elements are found. Oxidation Potential is a measure of the tendency for an oxidation reaction to occur. On the other hand, reduction potential is a measure of the tendency for reduction reaction to occur. The oxidation reduction or redox potential (Eh) indicates the oxidation and reduction states to reduce or oxidize chemicals and is measured in volts or millivolts. Positive and high values indicate strong conditions while low and negative values indicating values indicates that element would exist in reduced forms.

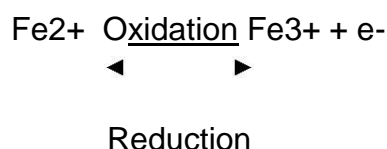
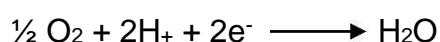
Oxidation is the loss of electrons in an atom



Reduction is the gain electrons by an atom



From the above reactions, oxidation can also be defined as gain or increase in positive valiancy while reductions, is a decrease in positive valiancy. Oxidation-reduction reactions involve the transfer of electrons between oxidized and reduced species. All reduction reactions must be coupled with oxidation reactions to balance the total number of electrons gained and lost. An oxidizing agent will accept electrons easily and reducing agent easily donates electrons Oxygen gas (O₂) is a strong oxidizing agent while hydrogen (H₂) is a strong reducing agent in the formation of water molecule.



The redox potential (Eh) is defined as

$$E_h = E_o + 0.059 \log \text{Fe}^{3+} - 0.058\text{pH}$$



Where E_o is the redox potential of the reference electrode. In soils, only a relatively few species of compounds are usually involved in oxidation-reduction reactions. The redox potential (Eh) of some soil systems, compounds and elements are supplied in Table 2 A good dividing line between oxidized and reduced soil has been put at 320 V at pH 5.0.

Table 2.5 Redox potentials, Eh, of some soil systems, systems, compounds and elements at which change in forms commonly occur

Soil systems	Reduction potential, Eh	(Redox)
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Kmn 0 in 1 NH ₂ SO ₄	+ 1.50 volts
Very well oxidized soil	+ 0.80 volts
Moderately well-oxidised soil	+ 0.30 volts
Nitrate, NO ₃ ⁻	+ 0.28 volts
Soil high in NO ₃ ⁻	+ 0.20 – 0.40 volts
Ferric iron, NO ₃ ⁺	+ 0.18
Sulphate ion, SO ₄ ²⁻	- 0.12
Carbon dioxide, CO ₂	- 0.20
A much reduced soil under water for some time	- 0.20
Extremely reduced soil	- 0.50
Na ₂ S ₂ O ₄	- 0.60

Topic 3: Conditions that Affect Soil Air Composition

i. Organic Matter and Biological Activity in Soil

In tropical soils there is rapid evolution of carbon dioxide, CO₂, by the high active biological population, especially soil micro-organisms which decompose organic matter at very fast rates. This trend affects the concentration of both O₂ and CO₂ in soil air. Microbial decomposition of organic residues accounts for the major portion of the CO₂ evolved omission. Other important biological activities which influence soil air composition are respiration by high plants and the continuous contribution of their roots to the soil biomass.

ii. Soil Type and Soil Depth

Carbon dioxide, CO₂, increases with soil depth while O₂ decreases with depth with the heavier soils becoming more deficient than the lighter textured soils in the sub soil layers.

iii. Soil Moisture and Temperature Required

Marked seasonal variation in the composition of soil air could also be attributed to soil moisture and temperature differences. High soil moisture especially during rainy season usually results in low O₂ and high CO₂ levels in the soil air. During the dry season, there is more circulation of air soil and O₂ levels are usually higher than CO₂.

iv. Application of Manure

The rate of Co₂ production could be increased through the application of farm yard manure (FYM), especially when the soil is wet and the rate of O₂ and CO₂ slows down. Green manuring (especially from fairly succulent crops such as *Leucaena* and *Gliricidia* spp) could increase the CO₂ content of soil air. This can lead to poor germination of seeds sown too soon after a green manure crop has been ploughed in.

Topic 4: Soil Aeration on Biological Activities and Plant Growth

The composition of soil air affects the activities of soil micro-organisms, nutrient availability to plants and the respiration and nutrient uptake of crops. Aerobic soil microorganism absorbs free O₂ through the very efficient cytochrome oxidase enzyme system. This aerobic activity continues in the soil when the O₂ concentration is not less than between 3 to 6 x 10⁻⁶ M. The concentration of O₂ in soil solution when in equilibrium with air at 20° to 25°C is 2.7 x 10⁻⁴ M which is between 60 – 100 folds large than that of the soil. Aerobic metabolism continues until O₂ concentration in the soil falls below the figure corresponding to a partial pressure of 1% of the pressure of CO₂ in free atmosphere.

Effects of Redox Reaction in Aerated Soils on Nutrient Availability and Plant Growth

The redox potential, Eh of most soils (Table 2) under aerobic situation and under the pH range (4-7) prevalent in most agricultural soils lies between 0.5 and 0.5 and 0.8 volts.

Some biochemical transformations that proceed in well aerated (aerobic) conditions)

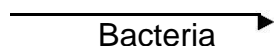
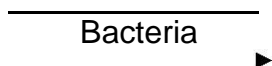
soils are discussed below.

General, there is biological transformation of C,N,Mn, Fe, and S to CO_2 , NO_3 , Mn^{4+} , Fe^{3+} and SO_4 respectively in well aerated soils/ these transformed species are the from utilizable by plants. That is, under aerobic conditions most elements are available in forms that can be absorbed by plants even though nutrients such as ferric, Fe^{3+} and Mn^{4+} may become insoluble and with difficult availability.

Under aerobic soil conditions, there is usually an initial decomposition of organic matter by heterotrophic microbes whereby organic carbon serves as electron donor and O_2 serves as electron acceptor.

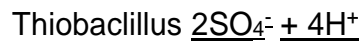
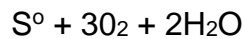


Nutrient elements contained in organic matter are release during decomposition process. Nitrogen, in particular, is released in ammonium (NH_4) from and the process is termed mineralization. It has been estimated that soil organic matter contained about 5 percent by weight of Nitrogen an only about 1 – 3 percent of that total amount is released yearly by decomposition (miller and Donahue, 1984). Furthermore, mineralizing 1.5 percent of the content of 4 percent would release about release about 70kg/ha of nitrogen as ammonium, NH_4^+ .



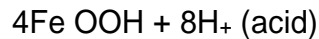
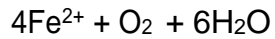
The oxidation of ammonium cations (NH_4^+) to nitrate anions NO_3^- by the autorophic nitrifying bacteria (Nitrosomonas and Nitrobacter spp) is called nitrification.

Another group of aerobic bacteria use reduced elemental sulphur, so, as source of energy thus oxidizing S_0 to SO_4 .



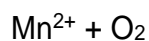
Thiooxidans ►

There are some organisms which grow well in acid medium (pH < 4.0) and usually not considered important in agricultural soils that are normally kept between pH 6.0 – 7.3. These microorganisms under aerobic conditions could oxidize Fe²⁺



Similarly manganese,

Mn, is Oxidized



The reactions above are carried out by aerobic autotrophs that utilise O₂; therefore, the reactions are subject to O₂ tension and the reactions will occur in well-aerated soils. In all these cases, energy for growth is released while the plant utilisable forms of the various nutrients elements are released, viz; NO₃⁻, SO₄⁼, Fe³⁺ Mn⁴⁺ and CO₂. However, ferric ion concentrates in agricultural soils.

Effect of Redox Reactions in Anaerobic Soils on Nutrient Availability and Plant Growth

Reduction reactions set in under anaerobic conditions when O₂ diffusion within the soil is reduced mainly by excess water to a level below 2 to 4 x 10⁻⁶ M concentration. The anaerobic condition (low O₂ concentration) gives rise to a series of microbial reactions that always taken place in the same sequence. Although reduction reactions are associated mainly with waterlogged or wet soils, they sometimes occur in all soils at time during the year.

Immediate after flooding, the exchange of gases between the soil and the atmosphere is cut down, as the diffusion of gases in water is approximately 10⁻⁴ times that in atmosphere. Also, reduction reaction induces an abrupt drop in the redox potential (Eh) to values between 0.2 and – 0.2 volts. Thereafter, the soil layers below the soil-water interface become depleted of oxygen which has rapidly been consumed by the aerobic

micro-organisms and cannot be replenished. Within one or two days virtually all O_2 disappears giving way for the increased activity of facultative and obligate anaerobic microorganisms. This is as a result of the metabolic activity by acting as electron acceptors in the anaerobic dissimilation process, or indirectly by forming organic decomposition products with properties. The most important process taking place upon flooding includes:

1. Accumulation of gases such as CO_2 , H_2 , and CH_4
2. Reduction (Denitrification) of nitrate, NO_3^- to eg N_2
3. Reduction of manganese and iron oxides to Mn^{2+} and Fe^{2+}
4. Reduction of sulphates to sulfides
5. Considerable increases in the concentration of Ca^{2+} , K^+ , Na^+ , $H_2PO_4^-$ and CHO_3^- in the interstitial water
6. Production of ammonia and soluble organic compounds (fatty acids, amino acids and mercaptans) as a result of the anaerobic decomposition of fresh organic material.
7. Stabilisation of the pH between 0.5 and 7.0 and decrease of redox potential.

Several products of anaerobic metabolism (such as CH_4 , N_2 , NH_4^+ , S , S^{2-} , Fe^{2+} (ferrous oxides), Mn^{2+} (manganous oxides) are known to be toxic to root cells, some of these products also upset the balance of growth factors e.g auxins and abscissic acid resulting in epinasty of the leaves or abscission of the reproductive system (i.e flower abscission).

Plants may also be predisposed to disease being weakened enough by this production of anaerobic metabolism to become more susceptible to pests and diseases.

Root cells convert glucose into ethyl alcohol (C_2H_5OH) which can badly upset the plant's development, especially at flowering time for plants such as cowpea and cereals causing serious loss in yields.

In plants adapted to anaerobic conditions, malic acid accumulates from sugars and it is not toxic to the cells. For plant root metabolism to remain aerobic, the oxygen gradient between root cell and outside the cell must be high enough to permit diffusion of O_2 from outside into the plant root. Root growth in O_2 – deficient soils are stunted with

reduced rate of water nutrient transfer from the soil to the xylem tissue. Even on the same soil type, roots grow faster in areas of good aeration than poor aeration. Poor aeration causes denitrification and loss of nitrogen and crops in such soil become pale and yellow in coloration.

Some crops are more tolerant to poor aeration than others; for example, sorghum yields are higher than those of maize grown in poorly drained soils.

Practical Application of Redox Reaction in Agriculture

Adoption of drainage technique to remove excess water and allow free circulation of air is the most important management measure to make waterlogged or poorly drained soils agriculturally productive. Some drainage devices include:

- i. Surface drainage which involves construction of ditches to convey water away.
- ii. Ridging to raise the seedbed above the surrounding topography.
- iii. Moulding: Also, farmers make big heaps (mould) whereby the top of the mould is kept above water all the year round.
- iv. In certain countries such as Japan, Paddy soils are filled to grow sugarcane and some water loving crops.

The maintenance of good soil structure and aggregate stability through the use of organic matter, farm manure and the growth of legumes enhances optimum soil aeration.

Probably one of the most viable options in the management of paddy soils is the cultivation of crops (such as paddy rice) adapted to conditions of poor soil aeration. These crops develop a system of interconnected internal air spaces through which atmospheric O_2 diffuses down into the root, and out of the root into soil immediately aerobic process. Furthermore, some plants such as mangrove and rice are adapted for growing in water and have high tolerance to Mn and Fe.

In some parts of Japan, “tittle drainage” is practised so as to maintain an adequate rate of percolation of water. Green maturing and the use of composts also help to maintain a good enough soil structure in the initial stages of flooding to allow adequate percolation.

Over drainage of calcareous or alkaline soils can be undesirable; for by lowering the CO_2 concentration in the soil water, the pH may rise sufficiently to cause loss of yield through too low availability and uptake of ferrous iron.

Nitrate-nitrogen ($\text{NO}_3\text{-N}$) fertilizer should not be applied to paddy (Swamp) rice to avoid loss of nitrogen through denitrification. In areas where swamp rice is grown extensively, nitrogen is added in ammonium, NH_4 , and urea, $(\text{NH}_2)_2\text{CO}$ forms.

Topic 5: Temperature and Plant Growth

In order to achieve maximum seed germination and growth, soil temperatures must be at optimum. Crops have different optimum temperatures for germination and growth. For example, wheat and peas have $4\text{-}100^\circ\text{C}$, corn $10\text{-}29^\circ\text{C}$, potatoes $16\text{-}2^\circ\text{C}$ sorghum and melons 27°C cabbage and spinach $8\text{-}11^\circ\text{C}$.

By and large, influence of soil temperature on seedling emergence and growth emanates largely from its influence on the physical, biological and chemical processes going on in the soil. Decomposition of organic matter and therefore the release of plant nutrients such as nitrogen, phosphorus and sulphur has the favourable temperature limits of $27\text{-}32^\circ\text{C}$. Likewise, absorption and transport of water and nutrient ions by higher plants are adversely influenced by low temperatures.

Crops adapted to hot regions such as maize, sorghum or cotton give active root growth during the warm seasons.

The quantity of heat absorbed by the soil is dependent on the amount of solar radiation reaching the soil. Portion of solar radiation is refracted back into the atmosphere by cloud atmospheric gases, or is scattered into the atmosphere before it reaches the ground. Furthermore, over 30% of the radiation energy reaching the earth is reflected back to the atmosphere or is lost by thermal radiation. The remainder is termed net

radiation. About 30% of this net radiation is utilized for photosynthesis, while only about 5 – 15% of the net radiation is commonly stored as heat in the soil and plant cover.

In general, the factors which affect the temperature of a given soil are the amount of radiation it receives, fraction of incident radiation that is refracted by the land surface, its moisture and air contents. The factors that affect the rate of evaporation of water from the moist soil are elaborated upon below:

i. **Effect of Mulch:** Mulch of dead vegetation such as cereal straw, stover, legume haulms, etc immobilize the air within the mulch and still air has a very low thermal conductivity; therefore, heat is only slowly transmitted from the surface of the mulch to the soil surface. Thus, the soils under the mulch remain cool, the organic coverings on the soil hotter when the sun is shining, but transparent plastic allows greater warming than opaque plastic (Miller and Donhue, 1990). Soils under organic residue mulches also remain relatively moist. In areas where conservation tillage is practiced much of the crop residues left on the soil surface in this non-tillage practice usually give low soil temperatures.

ii. **Effect of Moisture:** The heat capacity of water is known to be 3 to 5 times more than for soil mineral. Therefore heat that is absorbed by soil can be lost in evaporating soil water. Moist soil conducts heat upwards and downwards much better than a dry soil warms up much quicker, and during a clear night cools much quicker than a wet surface. Temperature differences of 3 to 6°C have been recorded between poorly and well-drained soils and this difference is significant in terms of crop performance especially in temperate regions. The soil has to be drained in this instance in order to raise the temperature. Irrigation has been known to increase the thermal conductivity of a soil.

iii. **Soil Type:** Sandy soils warm up faster than clay soils and thus are usually referred to as warm soils and clay as cold soils. Sandy soils have a much greater diurnal variations in surface temperature but at depths of 5 to 10cm the temperature difference between the soils can be small.

iv. **Effect of Vegetation:** Owing to its insulating property, vegetation reduces both the diurnal and seasonal fluctuation because it intercepts a part or all of the incoming

solar radiation and of the back-radiation from the soil. The effect of vegetation depends on degree of shading and canopy cover. For example, under complete canopy cover, the leaves will absorb all the incoming solar radiation. Furthermore, vegetation influences seasonal changes in the soil surface temperatures. Soil under vegetation warms up slower and cools down slower than uncovered soils.

In temperate and cold regions where crops are usually damaged by low temperatures or frost, the blanketing effect of vegetation cover is used to reduce the penetration of frost into the soil.

In the tropics, vegetation reduces fluctuations in the soil surface temperature, especially maximum temperature about 14 hours universal time. Tree crops such as coffee and cocoa which do not give complete canopy cover are inter planted with food crops such as plantain, banana and cocoyam which are shade loving.

Unit summary

In this unit you have been made to understand that:

- The composition of soil air affects the nature of transformation that soil nutrient elements undergo. This, in turn, dictates the usefulness or toxicity of the transformation products to plants.
- Adequate soil aeration and temperature are essential soil environmental factors that strongly influence the performance of plants and soil macro-and micro-organisms.
- Adequate soil oxygen makes oxidation reactions to proceed while low level of oxygen leads to reduction reactions.
- The products of oxygen makes oxidations reaction reactions to proceed while reduction causes the formation of methan (CH_4) and the reduced forms of nutrients which may becomes toxic to plant roots.

- Traditional farming practices such as heap making and ridging ensure adequate soil aeration.
 - Most tropical crops perform best within temperature range of 20° to 35°. Soil temperatures are regulated by the use of much, regular water supply, soil, tillage and establishment of vegetation cover.

Activity

Write short notes on the following:

- i. Oxidation potential
- ii. Reducing agent
- iii. Facultative anaerobic micro-organisms
- iv. Mineralization

UNIT 6

SOIL ORGANIC MATTER AND COLLOIDS

INTRODUCTION

Soil organic matter is the organic component of the soil. It consists of all the parts of living and dead plants and animals, micro-and macro-organism and products of decaying processes that occur in the soil. The dark colouration of certain soils is attributed to the presence of organic matter because dark coloured colloidal humus compounds are able to coat mineral particles of soil; hence the darker the soil, the more organic matter it is likely to contain. In addition to clay minerals in the soil, organic matter is a major source of plant nutrient elements. Organic matter also contributes to soil water-holding capacity, aggregate stability, permeability and other desirable soil properties. This unit will discuss soil organic matter-its importance, maintenance and the roles played by microorganisms in the transformation of soil organic matter.

OBJECTIVES

At the end of this unit you should be able to:

- Explain and define clearly soil organic matter and how it forms
- Enumerate and describe the importance of soil organic matter especially in
Zambian agriculture
- Describe the mediating role of micro-organisms in organic matter decomposition
- Make a list of several ways to maintain soil organic matter
- Describe the constraints of maintaining high levels of organic matter in Zambian
agriculture.

Topic 1: Soil Organic Matter and Organic Materials

You would have observed the presence of several types of litter on the surface of the forest or agricultural land, especially when left to revert to bush. These litters include green leaves, dead leaves, crop residues (stubble and leaves) and even dead animals. These are all referred to as organic material which are generally moved into the soil by

macro-and micro-organisms or may be incorporated into soil by man. In the soil the organic materials are referred to as organic matters, which are then decomposed by micro-organisms to release plant nutrients. The soil organic matter usually undergoes several stages of decomposition. Humus is the last stage of decomposition. The greatest amount of organic matter in the soil resides in the top soil. Shades of colour indicate roughly the comparative quantity of organic matter in soil. That is, the darker the soil, the more organic matter it is likely to contain.

Sources of Soil Organic Matter

There are two main sources of organic matter in soils. Plant sources are the most prevalent and important. These plant sources include dead and decayed plant roots, leaf droppings, crop residues, green manures and dead and decayed “above ground” parts of plants. Animal sources form the next most important source of soil organic matter. They include all residues of animals and micro-organisms, domestic wastes, animal faces, animals’ feeds, and animal manure. The contribution of animal wastes in terms of nutrient supply depends primarily on the species of the animal as well as the plant.

Composition of Soil Organic Matter

About 7% of green tissue is made up of water while 90% of the remaining dry matter is made up of carbon, oxygen and hydrogen. Nitrogen and other mineral elements constitute the remainder of organic matter. The major sources of soil organic matter (plant tissues) is made of very complex substances such as carbohydrates (sugar, starch, hemicellulose, cellulose, pecticles, muscilages) lignins, proteins (soluble proteins and crude proteins), fats oil, waxes tannin, resins, pigments and organo-mineral compounds.

The largest percentage of soil organic matter is made of lignins and proteins. Lignin builds up as the plant ages it is resistant to decomposition. On the other hand, protein (which is readily decomposed) decreases as the plant ages. Lignin and protein contents (which are readily decomposed) decrease as the plant ages. Lignin and protein contents of organic matter greatly influence its carbon/nitrogen ratio.

The organic matter of most soils ranges between 1-5% mostly in the top 2cm of soil, and the concentration reduces with depth except, relatively in cases in which deep ploughing is being used to incorporate organic materials into the soil.

Decomposition and Mineralisation of Organic Matter

Decomposition of organic matter in the soil involves the breakdown of complex organic compounds to simpler ones by the activities of micro-organisms such as bacteria, fungi, actinomycetes, algae, protozoa etc. Nutrients and energy are made available to the micro-organisms during the process of organic matter decomposition. The benefits of organic matter as a source of plant nutrient and as soil conditioner lie primarily on its decomposition. That is, for an organic material to be useful it has to decompose. The organic material is broken down into its constituent elements. Decomposition is essentially an oxidation process mediated by microbial enzymes and it is similar to burning or digestion of food, $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$.

The products of decomposition are varied and numerous. The initial stage involves an attack by macro-organisms that break the big particles into smaller ones which are thereafter, incorporated into the soil by burrowing animals and are later invaded by micro-organisms. The decomposition processes result in the release of first, energy; followed by simple end-products including carbon dioxide, water, ammoniacal compounds, sulphates, phosphate and other plant nutrients; the more resistant component of the organic matter such as cellulose, hemicellulose, lignin and waxes; finally, there are the complex organic residues which have considerable stability and are resistant to further decomposition, for example, humus. When plant materials are incorporated into the soil, the sequence of decomposition is that sugars, starch and soluble protein are the first to be readily decomposed, followed by crude proteins, hemicellulose, cellulose, tannin, fats, waxes and lastly lignin and phenolic compounds. Humus is the last stable and product of decomposition.

Mineralisation is the process involved in the release of plant nutrients from organic matter. Most of the soil nitrogen, phosphorus and sulphur are present in the organic forms which are only converted to the mineral forms, utilizable by plants, through the mineralization process. Mineralization of organic matter to release mineral nutrients is a two step process, namely:

- i. **Aminization** which is the decomposition of organic matter by heterotrophic **bacteria** to release amino acids and amides + amino acids.
- ii. Aminization is followed by ammonification which is the release of ammonium ion from amino acids and amides. Amino acids + amides heterotrophic bacteria NH_4^+ . The ammonium ion (NH_4^+) further undergoes. ►

Oxidation process as a result of participation of special purpose bacteria in another two-step process called nitrification (i) $\text{NH}_4^+ + 3/2 \text{ } ^0\text{O}_2$ Enzymatic oxidation $2\text{NO}_2 + \text{H}_2\text{O} + 4\text{H}^+ + \text{Energy}$



Nitrosomonas spp

Topic 2: Roles Microorganisms in Organic Matter Transformation

Conversion of ammonium to nitrate (NO_3) nitrogen. Ammonium is first converted to nitrite as in the equation (i) above with the activity of **nitrosomonas** bacteria, a group of obligate autotrophs which have as their sources of energy the oxidation of simple molecular substances such as NH_4^+ , Nitrite (NO_2) is then rapidly converted to nitrate (NO_3) through further oxidation by another group of obligate autotrophs, **Nitrobacter** bacteria, as in the following equation:

$2\text{NO}_2 + \text{O}_2$ Enzymatic Oxidation $2\text{NO}_3 + \text{Energy}$



Nitrobacter spp

In well-aerated soils, step (ii) above follows step (i) very quickly that there is no accumulation of nitrite which, if otherwise, could be injurious to plant roots. In cases where large amount of ammonium fertilizer has been applied into alkaline soil, the conversion of nitrite to nitrate is delayed until after the ammonium ion concentration has reached a relatively low level. It should be noted that plants take up nitrogen in both the ammonium (NH_4^+) and nitrate forms from the soil solution. By and large, the NO_3 decomposition of organic matter results in:

1. The use of some of the carbon, nitrogen and some other elements by microorganism.
2. The release of carbon dioxide water an elements such as sulphur, nitrogen, phosphorus, potassium and micro-nutrients to the soil solution or atmosphere, and
3. A changed and partially decomposed organic residue called humus. Below is the organic matter cycle in the soil (fig.1).

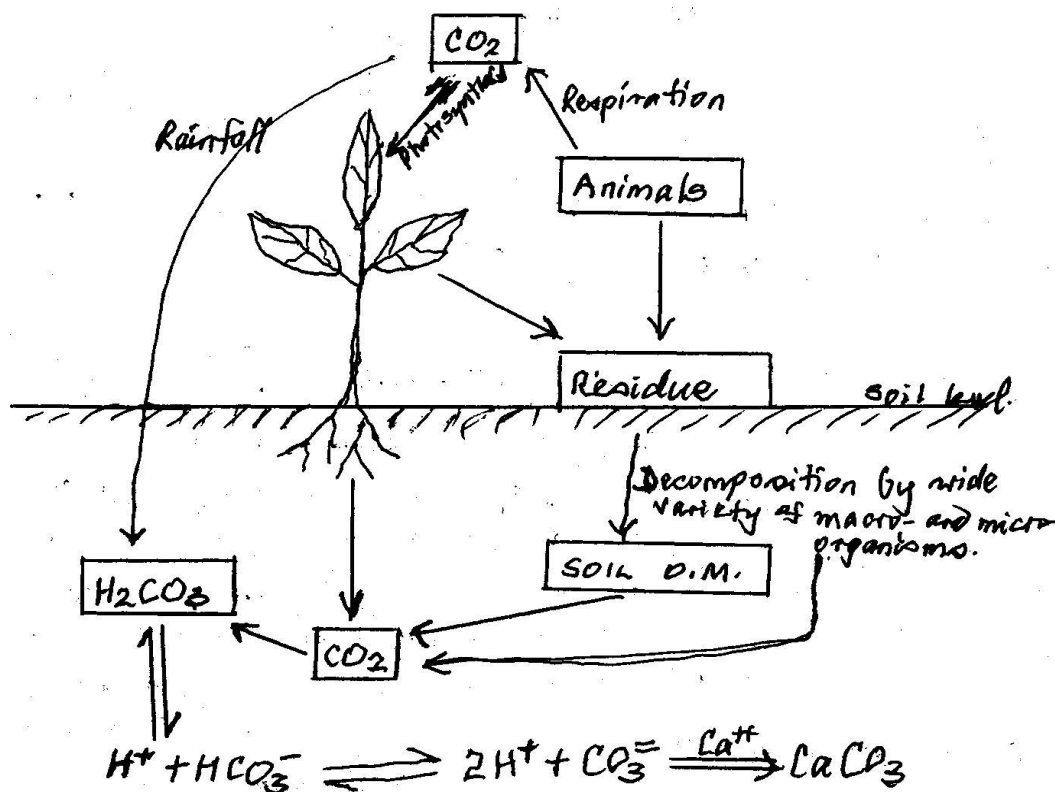


Figure 1: A simplified representation of the carbon cycle. The arrows indicate transfer of carbon among compartments. During Decomposition carbon is released in form of carbon dioxide which forms weak carbonic acid (H_2CO_3) in soil solution. The H_2CO_3 dissociates to $\text{H}^+ + \text{HCO}_3^-$ and further to $\text{H}^+ + \text{CO}_3^{2-}$. In the presence of calcium (Ca^{++}), calcium carbonate (CaCO_3) is formed in the soil.

Topic 3: Factors Affecting the Decomposition of Organic Matter in Soil

Favourable conditions for microbial growth and activity have to be ensured before the rate of decomposition can move fast and consequently maximise the use of organic

fertilizer. The conditions favourable for organic matter decomposition include:

1. Composition and Particle Size of the Organic Material

The smaller or finer the organic matter particles especially due to the combination of soil macro-organisms on organic matter, the greater the surface area exposed for decomposition, and consequently the faster the rate of decomposition, making the plant material smaller in size as in the case of grinding, exposes a lot of surface area to enzymes of micro-organisms in the soil and thereby accelerating the decomposition process. Succulent organic materials get degraded rapidly; and as the plants mature, higher contents of hemicellulose, cellulose and lignin decrease the rate of decomposition. The quality of the organic material in terms of its nitrogen content compared to its carbon content also affects the rate of decomposition. The higher the nitrogen content, and therefore lower the carbon/nitrogen ratio, the faster the rate of decomposition. Separate discussion on effect of carbon/nitrogen ratio on organic matter decomposition is given below:

2. Carbon: Nitrogen Ratio

The carbon: Nitrogen ratio of the organic matter affects the rate of its decomposition. The micro-organisms require nitrogen for tissue or body building. The organic matter must contain reasonably high quantity of nitrogen for micro-organisms to obtain enough for rapid multiplication and accelerated activity. Otherwise, the organic material remains in the soil under composed. The alternative is that the micro-organisms may make use of the native nitrogen in the soil.

3. Soil Reaction (pH)

The different groups of soil organisms have specific ranges of soil acidity under which they exhibit maximum activity. Thus, bacteria and protozoa are most active under soil pH range of 6-7 or under neutral range of soil acidity, fungi thrive best when soil pH is low or soil is acidic while actinomycetes have optimum pH range 6 – 8.0. Since the bulk of organic matter decomposition is affected by soil bacteria, it follows that decomposition is higher under neutral range than under acid and alkaline conditions. Liming acid soils is essential especially in Northern parts of Zambia due to high rainfall

and leaching losses of cationic nutrients from the top soil.

4. Aeration

Decomposition of organic matter is an oxidation and respiratory process mediated by microbial enzymes and it is similar to burning or digestion of food.

$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Enzyme}} 6CO_2 + 6H_2O + \text{Energy}$

Experiment with incubated soil samples had shown that maximum decomposition and subsequent nitrification occur when the percentage of oxygen reaches about 20 which tallies with the percent concentration of oxygen in the atmosphere.

During cultivation, it is important to maintain rapid diffusion of gases into and out of the soil. Tillage helps aeration of soil and hastens decomposition. Resisted aeration through zero or minimum tillage and excess water favour organic matter accumulation. There is usually a significant effect of aeration on organic matter decomposition at an oxygen level below 1% of the partial pressure of oxygen in the atmosphere.

5. Temperature

It is a generally established fact that increasing temperature stimulates microbial activities and therefore decomposition processes. As chemical reaction, decomposition processes should follow the rule of Q₁₀ which states that rate of chemical reactions doubles for every 10°C rise in temperature. The optimum temperature is generally quoted between 20 and 40°C. Not much information has been reported in the literature about the effect of temperature on decomposition in Zambian soils, but it is widely believed to be very rapid. This is due, in part to the generally high temperatures which range between 20 and 35°C with an annual mean of about 25°C. These temperatures are most favourable to most micro organisms responsible for organic matter decomposition. The prevalent high temperatures and humidity encourage microbial growth and action, and therefore, leads to high rate of organic matter decomposition and subsequent loss from the soil. Although the biomass turnover is high in Zambia, it does not meet the organic matter requirement of the soils. Therefore, the organic contents of Zambia soils are relatively lower than soils in colder regions.

6. Soil Moisture

There is a cyclic pattern of soil microbial activity and the availability of soil nutrients (such as N, P and S) to crops mainly due to the alteration of wet and dry seasons.

7. Microorganisms Involved

Microbes are in constant competition for organic and inorganic nutrients and for oxygen in the soil. At any point in time certain groups of microbes dominate but do not remain for too long before another group takes over. When the OM decomposing bacteria dominates decomposition process is fast.

Topic 4: General Importance of Soil Organic Matter

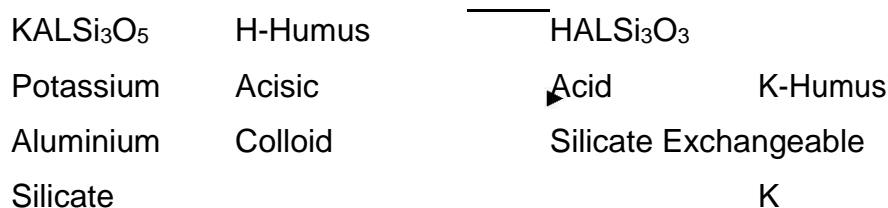
The politicization of the distribution of inorganic chemical fertilizers in Zambia makes the role of organic matter as a source of plant nutrients more desirable. Furthermore, increase in fertilizer prices could with its unreliability to farmers makes the assessment of the role of organic matter in Zambian agriculture more relevant. As pointed out earlier, rate of organic matter decomposition is very high owing to high temperature and humidity in the country. Hence organic matter does not accumulate in the soil to an appreciable extent. Substantial amount of organic materials will therefore be needed to satisfy the organic matter requirement of Zambian soils. Proper use of organic matter ensures sound environmental sanitation as well as the conversion of wastes to food. Other roles of organic matter are discussed briefly below:

i. Decomposition of organic matter

Decomposition of organic matter incorporated into soils results in the release of plant utilizable forms of nutrient elements such as CO_2 , NO_3^- , NH_4^+ , K^+ , Mg^{2+} , SO_4^{2-} , H_2PO_3^- , HPO_4^{2-} and so on.

These nutrients are utilized by crop plants in growth and developmental processes and by new generation of microorganisms. Thus yield of crops grown on soils with actively decomposing organic matter is better compared to crops in soil with low organic matter and micro-organism activities.

Most Zambian soils are acidic. The organic matter aids in nutrient release of acidic soils which otherwise could have been fixed.



Organic matter incorporation has been found (Kang and Osiname, 1985) to reduce a number of micronutrient problems in Zambia which usually result from the fact that most standard fertilizer formulations are devoid of micronutrients.

The practice of burning crop residue in traditional Zambian agriculture produces large quantities of ash which are equivalent to a good dose of fertilizer. Although burning is believed to volatilize most of the C, S and N present in crop residues, the incompleteness of the burning still leaves substantial portion of these nutrient in the soil. Burning is also said to increase pH of acid soils due to the abundance of Ca, Mg, and K in the ash of burnt crop residue into the soil which reduce nutrient losses through erosion of soil surface.

ii. Organic Matter is a Major Source of Cation Exchange Capacity (CEC)

This is especially so in tropical soils where Kaolinitic clay with very low ion exchange capacity predominates. In most mineral soils, organic matter accounts for about 30 – 64% of the total CEC while in sandy soils; over 50% of the CEC is possibly due to the organic matter component of the soils.

The more humified fractions of soil organic matter have higher CEC. The CEC of humus, Kaolinite, illite, vermiculite and mont-morillonite clay minerals have been reported to range from 150-300, 3-15, 10-40, 100-150, and 80-150 cmol/kg respectively. The CEC sites of SOM are the carbonyl, aliphatic, phenolic and hydroxyl groups hence the CEC of SOM is pH-dependent. Owing to this property of SOM, the term ECEC is usually used; the ECEC is the sum of cations extracted close to the soil's actual pH, rather than the CEC extracted with buffer solutions at pH 7 or 8.2 which is

the used. Tropical soils have low ECEC and SOM is the major source of ECEC in such soils with higher values in the top soils than the sub-soils. The higher the ECEC, the more cationic nutrients the soil can retain against leaching forces. A number of research workers (Agbim, 1989; Agbede 1984) have shown that in addition to increasing plant nutrients in the soil, organic materials such as rice husk, cassava peels and cocoa pods, increased soil pH.

One other characteristics of soil organic matter is the formation of chelates with metal ions. Thus, organic matter holds metallic ions both by cation exchange and chelation. That is, organic compounds in soil usually form complexes with metal ions by two or more coordinate bounds. Thus, we have zinc-chelate, copper-chelate and Fe-chelate depending on which metal ions being complexed.

iii. The Buffering Capacity of the Soil is Greatly improved by Soil Colloidal Organic Matter (Humus)

The buffering capacity is the ability of the soil to resist large fluctuations in soil pH and the cationic and anionic nutrients. Since the buffering capacity is a function of CEC, any material that increases soil CEC will also increase the buffering capacity. The buffering capacity prevents large ranges in soil pH and osmotic pressure, which, if otherwise, could have been injurious to crops.

iv. The Humus Produced from Organic Matter Being Amorphous, Confers Absorptive Capacity of Water to the Soil

The water holding capacity of humus on a mass basis is 4-5 times that of silicate clays. Thus organic matter increases the amount of available water in sandy, loamy and clay soils while it also increases aeration in clay soils.

The formation of soil humus which is usually a black or brown colloidal substance has a remarkable capacity to hold water and nutrient ions far more than clay. Thus, very small amounts of humus can augment remarkably the soils capacity to promote plant production farmers usually estimate the richness of a soil by dark colour conferred by the organic matter content. It should be noted that colour development of organic matter (the degree of colour development) is influenced by the geographical location or

climate.

v. The humus produced during the decomposition of organic matter in the soil has low plasticity and cohesion, therefore, helps to alleviate unfavourable structural characteristics of clayey soils in particular. It encourages granulation, the polysaccharide in humus serving as cementing or stabilizing agent for soil aggregates.

The soil structure is improved through the synthesis of complex organic substances which bind soil particles into more stable aggregates. More stable aggregates enhance moderate water infiltration, percolation, aeration as well as moderation of water and nutrient retention. The problem of soil workability is more acute in heavy soil which is usually plastic and sticky. These forces make the soil difficult to work especially when such soils are wet or dry on the other hand, due to the low elasticity and low cohesion of soil organic matter clay soils are loosened while sandy soils bound together. There is, therefore, good crop performance in that the soil is better aerated, erosion and run-off are reduced while there is less resistance to root penetration.

vi. Organic Matter Serves as Source of Energy for Microbes in Soil

Decomposition root tissues provide energy and nutrients to support the growth of organisms such as earthworms; fungi and bacteria that can themselves improve soil structure. Fresh and partially decomposed organic matter serve as food for these organisms such as earthworm which burrows into soil, mixes the organic matter with soil and makes worm casts rich in plant nutrients.

vii. Soil erosion by water or wind is common problem in Zambian agriculture. Coarse organic materials on the soil surface reduce the impact of raindrops and reduce run-off and wind erosion. A surface accumulation of any type of plant residue helps reduce erosion. For example, under forest where thick layers of “duff” (surface organic matter) accumulate, erosion is almost non-existent. An application of a coarse surface mulching in farm practices will cause larger percentage of water to seep more slowly into the soil and thus make water available for plant use.

Conventional good management of soils such as rotations, grass leys, use of crop residues minimum or no-tillage can reduce erosion. Mulch tillage techniques such as

zero tillage, which seek to utilize crop residue as surface mulches have been developed for Zambia..

viii. Applied as mulches, organic matter helps to regulate soil temperatures, and reduce evapotranspirational losses of water. In effect, organic matter acts as insulators in the soil surface and buffers the sudden heat change between the soil and the atmosphere.

ix. Increase microbial population resulting from organic matter inputs also has some influence in protecting plants against pathogens nematodes and soil-inhabiting insects. Soil microorganisms by their activities antagonize plant pathogens. There is competition for soil available carbon and energy materials. Some of the microbes produce toxic substances which inhibit or kill other organisms. This antagonistic relationship is important in the control of the harmful activities of plant root parasites.

The microbial population inhabiting soil organic matter a times provide plant hormones such as auxins, gibberellins and cytokinins.

There is the association of soil microorganisms with higher plants as in the case of mycorrhiza relationship and in rhizobium/legume symbiosis in leguminous root nodules which usually enhances p-nutrition in cultivated crops.

Topic 5: Constraints to the Maintenance of Organic Matter in Zambia

i. Competing Alternative Uses

In addition to soil incorporation and as mulch, plant and animals remains are also used by farmers for fuel, housing, fencing animal feed and for industrial purposes. These alternative uses invariably reduce the quantity of wastes and residues being returned into the soil; thus reducing the organic matter input into the soil.

ii. Bulk

The amount of organic matter needed to achieve most of the benefits discussed above are enormous; sometimes to the tune of 20 tonnes/ha or more. This bulk involves high labour force, high haulage cost, high processing (cutting and shopping) and application

costs. Lack of tractive power to replace simple hard tools used by farmers in soil tillage is a great handicap for effective residue incorporation.

iii. Time

The practices of mixed and inter-cropping pose another problem in serving as a hindrance to the end of season ploughing operation to incorporate crop residues. Most of the crops in the mixture have different maturity dates which make proper timing of ploughing operations difficult. The farmer must allow appropriate time between residue incorporation and planting to enable the crops to benefit from nutrient released from the organic matter. Failure to synchronize the time for mineralization with crop needs will lead to waste of the nutrients. There may also be injury to the crops following heat for equilibration is not allowed.

iv. The Fallow Period

In very many areas of the country nowadays, the fallow period usually allowed for the farmland to rest and rejuvenates the soil fertility through the return of litters to the soil, is being shortened. This is due to acute land hunger and increasing demands for farmland to produce enough food for increasing human population and to meet the increasing demand for industrial raw materials.

As a way of overcoming the problem of soil deterioration brought about by short fallow periods, research now concentrates on bringing the fallow and the cropping periods together in what is referred to as Alley cropping.

Alley cropping is a system in which arable crops are grown in spaces (alleys) between rows (hedgerows) of planted woody shrubs or tree legumes. The fallow species are subsequently pruned periodically to mulch the soil surface during the cropping season. The pruning serves as shade, provides nitrogen-rich green manure for the companion crops and maintains soil fertility which occurs during the traditional fallow period. The system is especially suited to areas where minimum or zero tillage system of land preparation is practiced. Tree legumes already found effective for alley cropping are *Leucaena Leucocephala* and *Gliricidia sepium* with cereals such as maize, sorghum or millet as companion crops.

v. Quality of Organic Matter

For arable crops to derive nutritional benefits from incorporated organic matter, it must be of high quality. That is, the carbon/Nitrogen ratio of the organic matter being incorporated into the soil must be below 20:1 – 25:1. Above this ratio, the native nitrogen will be used up by the decomposing microorganisms (immobilization) instead of releasing nitrogen into the soil (mineralization). The lignin/N or C/N ratio defines residue or litter quality. The food legumes and leguminous shrubs such as groundnut, soybean, mucuna, Gliricidia and Casia trees are suitable as high quality organic matter which should supply almost all the nutrients needed by crops in addition to nitrogen. Cereal straws provide an example of low quality organic matter which, when incorporated into the soil requires some initial dose of nitrogen-fertilizer application for decomposition to proceed at the rate that would benefit the arable crop. To derive maximum benefit of crop residue incorporation it may be necessary to accompany it with application of inorganic chemical fertilizer.

vi. Pests, Diseases and Toxic Materials

Some of the products of decomposition of organic matter are organic acids which lower the soil pH and enhance toxicity of micronutrients which are not favourable for plant growth. Some products are chemicals which hinder the growth of other plants.

Unit summary

In this unit you have learnt that:

- Plant and animal remains such as crop residues, animal and green manures, compost, fallen leaves and forest litter make up soil organic matter.
- Decomposition is carried out by micro-organisms leading to the release of plant nutrients. Several environmental conditions could either enhance or slow down rate of decomposition.
- We must adopt farming practices that could help to maintain reasonably high level of organic matter content of our agricultural soils.

- Organic matter comes from crop residues, animal and green manures, compost and other organic materials.
- Plant nutrient elements, such as nitrogen, phosphorus and sulphate, are released to the soil when micro-organisms decompose soil organic matter.
- Owing that some reasonable level of organic matter in the soil is maintained.
- The soil is as fertile and agriculturally productive as the amount of organic matter in it.
- In Zambia, several constraints militate against the maintenance of soil organic matter. Their thorough understanding will help to map out strategies for amelioration.

Activity

1. What soil factors are conducive to:
 - a. Rapid decomposition of organic matter?
 - b. Accumulation of organic matter?
2. What steps can be taken to restore soil organic matter?

UNIT 7

SOIL REACTION: ACIDITY AND LIMING

INTRODUCTION

Soil reaction (pH) seems to be the single soil chemical condition that most strongly affects the environment of farm crops and soil microorganisms. It is useful in diagnosing the fertility of the soils. This fact must therefore be taken into consideration in the management of any farming enterprise especially in tropical acid soils. Knowledge of the conditions which cause different soil reactions is of tremendous value to the student of soil science.

The large presence of aluminum and low activity clays in tropical soils enhance soil acidity especially in areas that receive high rainfall.

Soil amelioration with lime improves productivity of tropical acid soils by replenishing calcium and magnesium cations, improving plant root environment, improving soil conditions for microbial activities and increasing availability of most essential nutrient elements.

OBJECTIVES

At the end of this unit, you should be able to:

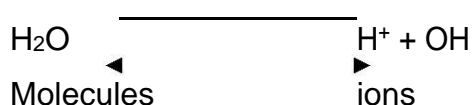
- Describe soil pH and describe how it is developed
- Describe farm practices that tend to increase or decrease soil acidity
- Describe how soil pH affects plant growth
- Describe how to lime or acidify soil
- Describe what is meant by buffering capacity in soil
- Explain the various ways of determining soil acidity.

Topic 1: Meaning of Soil Reaction

Soil reaction (pH) is an indication of the acidity or basicity of the soil and is measured in pH units.

An acid could be defined as any substance capable of yielding hydrogen ions (H^+),

which is a proton, when dissolved in water. Pure water dissociate to a small extent so that the quantity of water molecules (H_2O) present usually far outnumber either the hydrogen (H^+) or hydroxyl (OH) ion present:

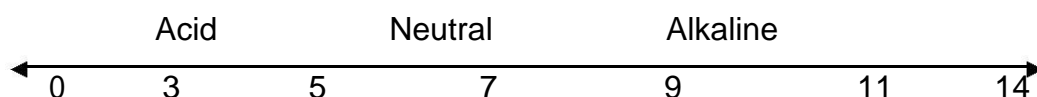


In pure water, the concentrations of hydrogen and hydroxyl ions are always equal and the solution is said to be neutral. Soil reaction is also the degree of acidity or alkalinity in the soil. Soil acidity is usually measured by determining the pH values which, according to Sorenson (1909), is defined as the negative logarithm of the hydrogen ion concentration.

$$\text{pH} = -\log_{10} \text{AH}^+$$

$$\text{pH} = \log_{10} \text{AH}^+$$

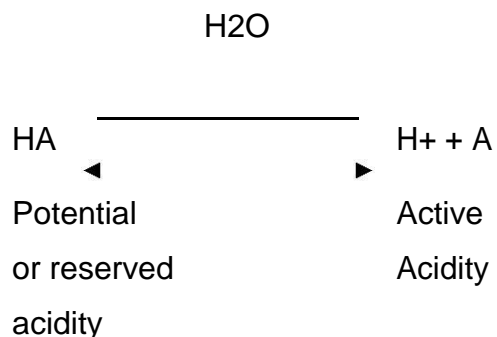
Where AH^+ represents activity of hydrogen ion in moles/litre or molarity. The acid (pH) scale grades from 0-14 as below:



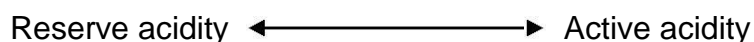
i.e concentration of pure water = 10^{-7} gm ions per litre. In acid solution, the concentration of hydrogen ions is always greater than 10^{-7} gm ions per litre and the pH is always lower than 7. Conversely, in alkaline solutions the pH values are always greater than 7. Thus the lower the pH the more acidic is the solution and higher the pH the more alkaline is the solution.

Active and Reserve Acidity

An acid when mixed with water dissociates or ionizes to give hydrogen ions and accompanying anions such as:

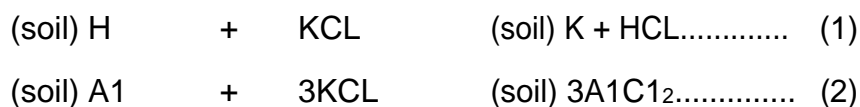


The active acidity is the sum total of all the hydrogen ions in the acid solution or in the soil solution. In the above equation the active acidity is represented by the H^+ to the right; its strength dictates the strength of the acid solution. The HA on the left side of the equation is the potential acidity otherwise referred to as reserved acidity. In soil solution reserved acidity is what is in the exchange site complex that is not yet in solution. It is the potential or reserve of H^+ in soil and it is always in dynamic equilibrium with active acidity.

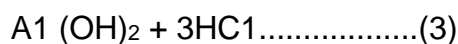
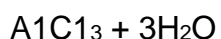


Although active acidity is only a small fraction of the acidity, it is important because it is the one that actually affects the growing plant. **Total acidity** of a soil is the sum of the concentrations of active acidity which is represented by the H^+ ion concentration in the soil solution and the potential/reserved/exchange/latent acidity which is due to the hydrogen and aluminium ions adsorbed on soil colloids. The term **actual acidity** is also used for active acidity (Yagodiin, 1984) and defined as the acidity due to carbonic acid (H_2CO_3); water soluble organic acids and hydrolytically acid salts which bears directly on the development of plants and micro-organisms.

An example of potential acidity is illustrated by the displacement of part of the adsorbed hydrogen or Al^{3+} ions by cations by cations of neutral salts into soil solution, as follows:



in soil solution AlCl_3 is then hydrolyzed to yield a weak base and a strong acids



Potential acidity is very important in determining the strength of active acidity since portions of adsorbed H^+ and Al^{3+} can be released into active pool as the acidity of the soil solution decreases. That is, for as much as potential acidity exists there would always be active acidity. This stresses the practical significance of the relative amounts of both species of soil acidity in ameliorating by liming. Yagodin (1984) suggested the concept of **hydrolytic acidity** which arises when soil is treated with a normal solution of a hydrolytically alkaline salt such as sodium acetate. The hydrolytic acidity involves the less mobile portion of adsorbed hydrogen ions that are readily exchangeable with the soil solution cations.

Buffer Systems

These are compounds that maintain the pH of a solution with a narrow range when small amounts of acid or base are added (Tisdale and Nelson, 1975). The term buffering is defined as the resistance to a change in pH. Acetic acid and sodium acetate form a common example of buffer system.



Addition of an acid such as hydrochloric acid or a base such as sodium hydroxide to the system results in very little change in the active acidity of the solution. The soil buffering ability is attributable to its humus and alumino – silicate clays which have ability to retain hydrogen aluminium and other cations on their exchange sites with the net result that there is little change in the active acidity of the solution.

Acidity Ranges of Soils

When a soil sample is mixed with water the resultant solution is either acid (most common), alkaline (sometimes) or exactly neutral (Very rare). Application of lime in

view of the difficulties of defining it on the basis of the relationship between pH, exchangeable hydrogen and aluminium. Soil with pH 5.0 in O.OIM CaCl₂ (1:2.5) or about 5.5 in water (:1) are classified as acid soils. Evidence abounds in the literature (Agbede, 1984) to show that soil pH is the most important factor influencing crop performance in that it (pH) influences rate of organic matter decomposition, microbial activities, forms and extent of nutrient availability or even nutrient uptake by crop. The importance of soil pH in crop production is dealt with in separate section. Various scales of soil pH exist but only that of Yagodin (1984) is given here for illustration:

Table 1.7 Soil acidity scale by Yagodin (1984).

Reaction	pH	H ⁺ ion concentration (gm/litre)
Strongly Acid	3-4	10 ⁻¹ -10 ⁻⁴
Acidic	4 – 5	10 ⁻⁴ – 10 ⁻⁵
Weakly Acidic	5 – 6	10 ⁻⁵ – 10 ⁻⁶
Neutral	7	10 ⁻⁷
Weakly Alkaline	7 – 8	10 ⁻⁷ – 10 ⁻⁸
Alkaline	8 – 9	10 ⁻⁸ – 10 ⁻⁹
Strongly Alkaline	9 – 10	10 ⁻⁹ – 10 ⁻¹¹

Sources of Soil Acidity

Soil acidity originates from several sources among which are **humus** or organic matter, **alumino silicate clays**, **hydrous oxide of iron and aluminium**, **soluble salts and carbon dioxide** (Tisdale and Nelson, 1975).

1. Organic Matter

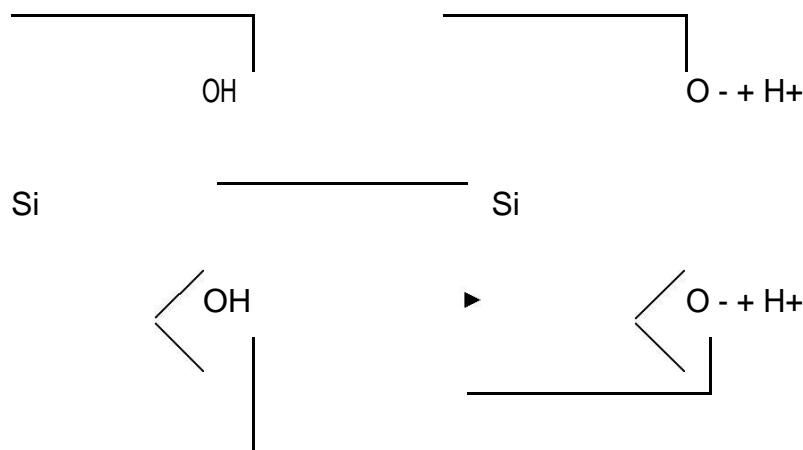
In organic matter or humus the carboxylic, phenolic, amino and sulphhydryl functional groups can undergo ionization to release their hydrogen ions, H⁺, into the soil solution thus increasing soil acidity. The functional groups constitute very

significant source of reserved acidity in the soil.

In soils containing large amounts of organic matter or humus e.g peat, covalent bonded H which is pH dependent dissociates at high pH value depending on the dissociation constant of the acid formed and leave a net negative charge on the humus colloids as a (a) above.

2. Alumino Silicate Clay Minerals

The 1:1 or 2:1 clay minerals typified by Kaolinite and montmorillonite usually carry negative charges on the clays also arise from the dissociation of hydrogen ions from hydroxyl groups or from bound water of constitution, both of which are structural component of the crystal lattice. At the negative charged sites of these clays, hydrogen ions, H^+ come into neutralize the charges so that we have conditions of neutrality; otherwise, it will be impossible to walk on the soil without experiencing electric shock of some sort. Any of the hydrogen ions, H^+ , on the edges of the layer silicates clay minerals could be released to the soil solution under certain conditions.



3. Exchangeable Aluminium

Present in the inorganic component of the soil ate bonded Al^{3+} which could be displaced from the clay minerals by other cations such as Fe, Mg, or Ca. The displaced or exchangeable Al^{3+} then undergoes hydrogylsis in solution releasing H^+ ions in a progressive manner as follows:



Over all equation i.e add equations i,ii,& iii.



That is, from one molecule of Al, 3 molecules of hydrogen ion, 3H⁺, are produced during hydrolysis. Sanchez and Buol (1974) reported that a montmorillonitic layer which released large quantity of aluminium accounted for the high aluminium level in sub soil of the Tropaeolum they studied (4) Another source of H⁺ is the hydrated oxides of aluminium and iron commonly called hydrous oxides which may be brought into solution as pH is lowered and release H⁺ ions by hydrolysis.

Topic 2: How Soil Becomes Acidic

1. Decomposition of Organic Matter (SOM)

Recent report of the effect of organic matter on soil acidity has not been consistent. Decomposition of SOM has been known to lead to the introduction of organic and inorganic acids with concomitant increases in soil acidity. However, the studies of Agbin and Adeoye (1991) showed that cassava peel (CP) had positive effect on the pH of acid soil which had low buffer capacity. On the other hand when (NH₄)₂ SO₄ fertilizer at 120kg/ha was imposed on the CP treatment, the pH was depressed. The same studies showed that rice husk depressed soil pH. Studies with other residues by the same workers revealed that the significant pH improvement obtained with lighter soils was not observed in heavier ones.

Incubation studies using glucose – C (Agbede, 1984) revealed that Glucose – C significantly lowered soil pH (r = 0.963). Differences in the effect of glucose – C and soil pH due to soil types were also observed. The pH of such soil (light textured)

decreased with glucose application; whereas, in Tillycorthie and Craden Bay soils (medium and heavy texture) added glucose tended to increase pH during the incubation period.

2. Carbon Dioxide, CO₂

The release of carbon dioxide, CO₂ to soil atmosphere by (a) respiration of plant root and (b) microbes could result in the production of weak acid

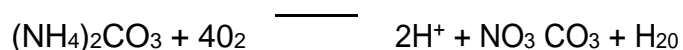
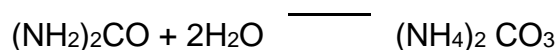


The production of acid from CO₂ depends greatly on the solubility of CO₂ in water which in turn also depends on (a) partial pressure of CO₂ in the soil and (b) soil temperature. The partial pressure of CO₂ is related to the presence of CO₂ and other gases in the soil.

In neutral or alkaline soils containing large quantities of carbonates or bicarbonates and in equilibrium with CO₂ at the pressure of normal above ground air, the pH is 3.5. A decrease of CO₂ partial pressure in such soil atmosphere to 0.02 atmosphere, gives a pH drop to about 7.5.

3. Oxidation of Ammonium Compound

The soil produces hydrogen ions H⁺, which lower soil pH. For example, NH₄⁺ could be released to the soil by the decomposition of SOM and by the addition of ammoniacal fertilizers. Various forms of these ammoniacal fertilizers do exist—NH₃, NH₄⁺, or (NH₂)₂CO (Urea) — and they are all sources of soil acidity as shown by the following equations:



4. Oxidation of Sulphur

when elemental sulphur is finely ground and mixed with soil it is oxidized to sulphate by sulphur oxidizing bacteria in the soil: $2S + 3O_2 + 2H_2O \rightarrow 4H^+ + 2SO_4$ ►

The overall result of sulphur oxidation is the production of sulphuric acid thus making sulphur an effective agent for increasing soil acidity.

5. Leaching of Cations

Soil may become acid through leaching of cationic elements in the soil most especially potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Sodium (Na^+). Leaching affects soil reaction indirectly by impairing the ionic balance when leached cations are more than anions from the soil surface. To re-establish the balance H^+ is released from exchange complex into soil solution to balance the net positive charges left behind by leached cations. Leaching is more pronounced in areas of high rainfall; hence, there is negative correlation between rainfall and soil acidity. However, this trend may not apply to every agro-ecological zone especially in well forested area with effective nutrient recycling system in the fallow farming system in rain forest zones, trees and other deep-rooted plants remove cations from the subsoil by nutrient uptake and bring them back to the soil surface in the form of litter (organic matter).

6. Removal of Cations by Harvest

As crops are being harvested and removed away from the field base, cations are simultaneously being removed away from the soil. For example, a maize grain yield of 5.0 tonnes/ha leads to the removal of 75kg, 25kg and 20kg of potassium, calcium and magnesium respectively from the maize farm. This harvest may occur over a number of years giving a net result of the soil becoming acid. As the cation is removed, hydrogen ion, H^+ , is released from exchange complex to balance the charge as explained for the leaching of cations.

7. Concentration of Aluminium in the Soil

Each aluminium ion, Al^{3+} , released from exchange site gives three hydrogen ions, $3H^+$. There is the general belief that H^+ and Al^{3+} exists in equilibrium in acid soils. It should also be noted that aluminium does not just occur in form of Al^{3+} but in complex form which hydrolyses to release H^+ .



8. Use of Other Acid Forming Fertilizers

An acid-forming fertilizer is one capable of increasing the acidity of the soil which is derived mainly from the oxidation of salts or ordinary elements by soil bacteria. For example, several bacteria take part in

sulphur oxidation resulting in an overall production of sulphuric acid – $S + \frac{3}{2} O_2 + H_2O \rightarrow H_2SO_4$

Sulphur is in effect one of the most effective agents for increasing soil acidity. The most common form of bacterial species participating in S-oxidation is the obligate autotrophic aerobes such as *Thiobacillus thiooxidans*, *T. Thioparus* and *T. Copraliticus*.

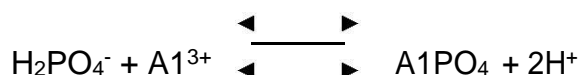
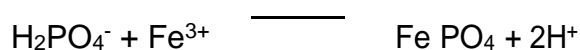
In areas with little or inadequate liming programme such as in humid tropical regions the continued use of acid-forming fertilizers leads to increase soils acidification. However, on alkaline soils, acid-forming mixed fertilizers like ammonium sulphate or the elemental sulphur may be used to depress the soil pH.

Topic 3: Importance of Soil Acidity

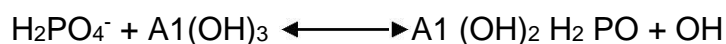
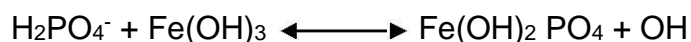
1. **Availability of Plant Nutrients:** Soil acidity affects availability of most soil nutrients especially phosphorus, nitrogen, sulphur, molybdenum and other micronutrients such as iron, aluminium and manganese. The pH of any soil could be a good guide in predicting which plant nutrients are likely to be deficient.

a. Availability of Phosphorus

Phosphorus compounds in soil have low solubility. The concentration of the various forms of phosphorus taken up by plants, that is, the orthophosphate ions, H_2PO_4^- and HPO_4^{2-} in soil solution is usually small and intimately related to the pH of the medium. Under low pH phosphorus is precipitated as iron and aluminium phosphates.



Increase in OH leads to formation of $\text{Fe}(\text{OH})_3$ precipitate and increase in H_2PO_4^-



At low pH, below 4.0, Al and Fe activity in soil is very high and phosphorus is easily fixed up in such medium. As pH increase above

4.0, P-availability increases as shown by the above equations. These reactions occur on the surfaces of strengite, $\text{Fe}(\text{OH})_3$ or variscite, $\text{Al}(\text{OH})_3$. At high pH medium or solutions of alkaline soils, ($\text{pH} > 7.5$), there is precipitation of phosphorus by calcium to form calcium phosphates.

$6\text{Ca}^{2+} + 4\text{CaCO}_3 + 6\text{HPO}_4^{2-} + 6\text{HPO}_4^- \rightleftharpoons \text{Ca}_{10}(\text{CO}_3)_6(\text{PO}_4)_6 + 3\text{H}_2\text{CO}_3$ (apatite) that is, the insoluble phosphate of iron and aluminium will be precipitated in acid soils and the insoluble phosphorus compound having varying solubilities are normally formed under different soil conditions. At times, the presence of sodium phosphates, a soluble compound at $\text{pH} > 8.5$ makes phosphorus available again. Therefore, maximum availability of P to most agricultural crops occurs within the soil pH range of 5.5 – 7.5.

b. Availability of Nitrogen and Sulphur

Nitrogen and sulphur are soluble at almost all pH levels in soil solution. The supply of these two elements comes mainly from organic matter and therefore limited by rate of decomposition of organic matter. The fate of mineralization of N and S from soil organic matter is fastest between pH 6 and 8. Much of the available S in soils with pH higher than 8 comes from mineral sources rather than organic. Similarly, nitrification processes occur within pH range of 5.5 – 7.5 with optimum at pH 6.5 Nitrogen occurs as NO_3 under high pH and as NH_4 under low pH in which it could also be fixed while NO_2 could also easily be leached at high pH levels.

c. Potassium

Potassium compounds are soluble at any pH but K^+ could easily be removed from soil solution by adsorption especially into the 2:1 clay layers. In leached acid soil, K is low. Raising the pH by liming may drive the little amount of K into non-exchangeable positions and further suppress K availability.

d. Calcium and Magnesium

These are the most abundant bases in the soil. They are usually added in soil amendments but so much as fertilizers.

e. Iron, Manganese, Copper and Zinc

These are micro-nutrients which form metallic cations that precipitate into low solubility compounds at high pH levels. Therefore they are usually deficient in high lime or alkaline soils.

Under constant oxidation potential, as pH increases from pH2 to pH6, availability of iron, Fe^{++} , decreases from about 10^{-2} to 10^{-6} moles per litre. Reports of several years of research have also shown that the amount of exchangeable copper and therefore its availability to crop decreased as the soil pH increased. Similarly, direct negative correlation was obtained between ammonium acetate extractable Mn^{2+} and soil pH (Tisdale, 1949). The same trend is true of zinc availability which is generally low in alkaline soils. The greatest zinc uptake both native or applied, takes place at lower pH

levels with deficiencies occurring within the range of 6.0 to 8.0. There may be some cases where relationships between zinc uptake and soil pH may not be significant since uptake of a particular nutrient also depends on other soil conditions. Curiously enough, these micronutrients, except iron, may be leached and become deficient at very low pH.

f. Boron and Molybdenum

Boron may be leached at very low pH while solubility is very low at high pH. Boron deficiency symptoms are reportedly associated with high pH values and its uptake by plants is reduced by increasing the soil pH. In contrast to the behaviour of most of the other micronutrients, the availability of molybdenum increases with increase in soil pH. Making the element available in alkaline soils. On the other hand, Mo is precipitated by Fe and Al as $\text{Fe}_2(\text{MoO}_4)_3$ and $\text{Al}_2(\text{MoO}_4)_3$ at low pH values rendering Mo unavailable to plants.

2. Effect of pH on Micro-Organisms

The pH of soils affects growth activity of soil microorganisms. For example, bacteria and actinomycetes are known to function properly at pH above 5.5 while fungi and sulphur-oxidizers function in acid medium. The most favourable pH range for microbes responsible for organic matter mineralization and hence N-, P- and S- availability is between 5.5 – 7.5. At low pH values, therefore, such process as nitrification and nitrogen fixation are reduced. High soil acidity restricts micro fauna population. A common example here is the earthworm population which is depressed under low pH (high acidity), thereby reducing the mixing of surface litter with soil.

Under those circumstances rate of organic matter decomposition is reduced.

3. Effect on Disease Pathogens

Soil pH affects some disease pathogens. Increase in soil pH had been known to favour potato scab disease which is controlled by application of elemental sulphur.

4. Maintenance of Ionic Balance

Soil acidity especially hydrogen ion concentration, (H^+) has some buffering effect in maintaining ionic balance in soil. If the leaching of cations is greater than those of anions in soil there is net negative charges, H^+ is released from exchange sites to soil solution to maintain the ionic balance.

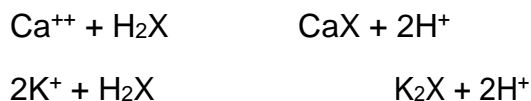
5. Effect of pH on Soil Physical Conditions

Soil structure is most easily affected by soil pH. In soils pH 8.5 sodium, Na^+ , causes dispersion of soil colloids resulting in physical problem. The dispersed clay particles plug soil pores. Similarly, under extreme condition of alkalinity colloidal materials could move to subsoil where they could precipitate to form hard pan. Air and water movement become impeded and plant root growth and penetration into the soil consequently become difficult. Under very acid conditions deficiency of Ca may affect soil structure. Saline soils could result from using salty water for irrigation.

Topic 4: Measurement of Soil Acidity

The pH value of a soil is an excellent single indicator of general soil conditions. The pH value is usually determined by shaking a sample of the soil with distilled water and estimating the acidity of the suspension. It should be noted that the pH of the suspension is always lower than the pH of the supernatant liquid owing to the surface-adsorbed acidity of the soil colloids in the suspension.

The initial soluble salt content of a soil influences the pH value. The soil is therefore usually leached with distilled water before measuring the pH of the salt-free soil. This procedure is time consuming and does not represent field situations. To mask the effect of the initial salt contents of soils on the pH, soil pH is measured in salt solutions of larger concentrations than the concentrations of the native salt contents of individual soil. Depending on the soil type, 0.0M of either KCL or $CaCl_2$ solution suspension is more reliable than that measured in soil water suspension. The pH values of soil-salt solutions are always about 0.5-1.0 units lower than the pH values of soil-water solutions due to soil solution by K^+ or Ca^{2+} ions.



Topic 5: Liming Practice

The productivity of acid soils can be improved tremendously by application of lime both to neutralize excess hydrogen ion and reduced the activity of aluminium ions in the soil solution. That is, liming is praised to increase the pH of acid soils and to eliminate all the deleterious effects of soil acidity as discussed in the proceeding sections. Previous work has revealed that there was increased maize yield in limed plots over no lime treatment. Apart from increased crop yield, other benefits of liming are:

- Reduction of soil acidity.
- Provision of cationic bases such as ca and mg especially if dolomite is used as the liming material.
- Increase in solubility of certain plant nutrients such as phosphorus and molybdenum and hence their availability to plant.
- Increase rate of nutrient release form soil organic matter due to increased rate of microbiological activities. The supply of nitrogen, phosphorus, sulphur and boron comes mainly from soil organic matter.
- Increase in symbiotic nitrogen-fixation in the root nodules of legumes through increase in symbiotic nitrogen-fixing bacteria especially *Rhizobium* spp.
- Increase rate of nitrification by autotrophic nitrifying bacteria (*Nitrosomonas*) and (*Nitrobacter* spp).
- Precipitation of toxic substances – excess A1, Fe and Mn – from soil solution.
- Retardation of certain plant diseases as well as plant pathogen.

Over liming may occur when lime is applied more than required to neutralize the excess Al^{3+} or eliminate Mn toxicity. Over liming may manifest in yield reduction, soil structure deterioration and decreased

availability of P, B, Zn and Mn. Friesen *et. al.* (1980) working on two Zambian ultisols (one series) an oxic Paleudult and Nkpologu series, an Ustoxic Paleustult found that zinc activity in both soils declined very sharply when soils were limed to pH above 5.0. Another work by Juo and Uzu (1977) on two Nigerian ultisols (i) Ustoxic Paleustult from Nsukka (Nkpologu Sandy loam) and (ii) Oxic Palendult from Benin (Alagba sandy loam) showed severe Mn deficiency on maize growth on the ustoxic Paleustul soil limed to near neutrality even though a little amount of Mn was applied. Following are the definitions of some terms associated with liming practices:

1. Liming Material

Liming material is any material added to the soil for the purpose of neutralising or reducing soil acidity. That is, the liming material which is called lime reduces the activity of hydrogen ion concentration. (H^+), in soil solution, most liming materials used are Ca-salts in which the anion is a base (proton acceptor).

2. Neutralizing value of Liming Materials

This is the ability of the liming material to neutralize acidity. It is the amount of acid neutralized by the molecular weight of a liming material in relation of the amount neutralized by 100g of calcium carbonate, CaCO_3 . It is often expressed as a percentage of the neutralizing ability of an equal weight of pure CaCO_3 . Therefore neutralizing value is usually called calcium carbonate CaCO_3 equivalent. For example, let 100g of CaCO_3 neutralize an amount, X, of acidity. If 100g of another liming material is able to neutralize 1/3 of what 100g CaCO_3 can neutralize then the CaCO_3 equivalent of that liming material is 33%. Furthermore, CaCO_3 equivalent of

MgCO_3 is $\frac{100}{84} \times 100 = 119\%$

CaCO_3 equivalent of $\text{MgO} = \frac{100}{40} \times 100 = 250\%$

Ca Co₃ equivalent of Ca (OH)₂ = $\frac{100}{74} \times 100 = 136\%$

3. Lime Requirement

Lime requirement is generally defined as the minimum amount of lime needed to raise the pH of an acid soil to pH 6.5 – 7.0 over a period of 2-3 years. The practical reality of liming practices requires smaller amount of lime mainly to raise the soil pH to a level tolerable to most

agricultural crops or a level that gives maximum economic yield returns from any cropping venture. Factors contributing to lime requirement of soils are as follows:

i. The Initial Soil pH

The initial soil pH would determine the magnitude of pH change required which is usually the difference between the original soil pH and the final pH wanted.

The final pH required will in turn depend on the cropping system since certain crops grow in specific narrow range of pH while others adapt to wide pH range. Furthermore, small amounts of lime may be required if acidity is restricted to the surface soil (plough layer).

ii. The Quality of Liming Material

Lime requirement is inversely proportional to the neutralizing value of the liming materials being used. The type and purity of the lime affects its neutralizing power. Therefore, it is important to consider the purity and finesse of the particle size of the lime being selected for use especially in the tropics. The contents of Ca and Mg in both the lime and the soil to be limed should also be taken into consideration.

iii. Particle Size of the Liming Material

Certain liming material such as Ca CO₃ is only slightly soluble and therefore their rate of reaction in soil depends on their particle size. Lime requirement decreases with a decrease in finesse of the particle. Up to a limit, the finer the particle, the greater the neutralizing value.

iv. Crop need can also Dictate the Lime Requirement

Some crops such as groundnut and tobacco require more Ca for their nutrition.

v. Solubility of Lime Being Used

For example, $\text{Ca}(\text{OH})_2$ is more soluble, and will therefore react faster, than CaCO_3 as liming materials.

4. Liming materials

- a) Calcic limestone, CaCO_3
- b) Dolomitic lime (Ca Mg CO_3).. most commonly used.
- c) Hydrated lime $\text{Ca}(\text{OH})_2$
- d) Air slaked lime ($\text{Ca}(\text{OH})_2 + \text{CaCO}_3$)
- e) Refuse paper mill (CaCO_3 is the lime here)
- f) Sugar beet refuse lime
- g) Slage, $\text{CaSiO}_3 + \text{Ca}(\text{OH})_2 + \text{CaO} + \text{Mg}$
- h) Wood ashes, $\text{CaCO}_3 + \text{Ca}(\text{OH})_2 + \text{K}_2\text{CO}_3$

Unit summary

In this unit, you have that:

- Soil reaction (ph) could be acid, neutral or alkaline. Each of these reactions has either positive or negative influence on plant growth, nutrient availability and microbial activity.
- Proper soil management for crop production requires the use of lime to bring soil ph to near neutral (ph 6-7.0) so as to benefit from the full potential of the soil.

- The meaning of such terms as active acidity, reserved acidity, exchange acidity, buffer systems and liming materials
- Several ways by which a soil could become acidic
- About farm practices that tend to increase soil acidity
- About the agronomic and non-agronomic importance of soil reaction
- The practice and major benefits of liming

Activity

1. Suppose you had agro-climatic data for a region you had never visited before; explain how the combinations of climate relief, soil parent materials and vegetation would indicate the possibility of soil acidity problems.
2. What farm practices could lead to soil acidification?
3. Enumerate the various sources of soil acidity.

UNIT 8

SOIL SALINITY AND ALKALINITY

INTRODUCTION

Soluble salts such as MgSO_4 , MgCl_2 , CaSO_4 , or CaCO_3 may be present in large quantities in some soils, especially in arid and semi-arid regions. These soils are called salt-affected (halomorphic) soils whose salt content is high enough to cause negative effect on plant growth. These halomorphic soils are saline, alkaline or even saline-alkaline depending on the percent of total soluble salts that is sodium content.

OBJECTIVES

At the end of this unit, you should be able to:

- Describe salt-affected soils
- Describe the general properties of salt-affected soils
- Understand the reclamation and management measures of salt-affected soils.

Topic 1: Sources of Salt-Affected Soils

The salt-affected soils occur mainly in arid and semi-arid regions. Under these agro climatic conditions there is usually accumulation of salts in the upper layers of the soils such as NaCl , Na_2SO_4 , MgSO_4 , MgCl_2 , CaSO_4 , or CaCO_3 .

Two **major** conditions could give rise to excess salts in the plough soil layer, namely:

1. Evapotranspiration

In the dry regions, evapotranspiration might be in excess of precipitation especially during the dry period of the year. This leads to whitish surface as a result of residue of inorganic salt left behind after escape of water vapour.

2. Rise in Ground Water

Underground water contains salts. When the water rises, it brings up salts and when it

goes down again it leaves the salt on the soil surface. Other conditions that give rise to salty soils are poor drainage and seepage from other areas, soluble salts from the weathering of primary minerals, coastal soils with oceanogenic salinity and desert salinity usually caused by wind-born salts.

Saline Soils

The ability of ions in water to conduct electrical current gives rise to the use of electric conductivity in quantifying total amount of soluble salts in a soil sample.

A soil is described as saline if it has electrical conductivity (of saturation extract) greater than 5 MS cm^{-2} (4 million hos/cm) or 4 decisiemens per meter (4ds/m) or has low **sodium absorption ratio** (SAR) at 25°C, a soluble sodium content of less than half the total soluble cations and a pH value usually between 6.3 – 8.5.

The predominant salines have neutral to alkaline reaction but acid salines also occur. Acid saline soils exist in coastal or marine flood-plains as acid sulphate soils. In these coastal areas, water logged, sulphur-rich soils become extremely acid after a dry period due to oxidation of sulphur to sulphate. The pH value could drop from about 6.7 to less than 2.0 during oxidation. When such soils are submerged, the presence of hydrogen sulphide becomes toxic to plants preventing the cultivation of crops such as rice. When such soils are dried and therefore oxidized, characteristic yellow streaks of sulphates of iron and aluminum are produced and may form a crust on the soil surface. Saline soils are agriculturally unproductive because they give poor growth of plants and poor crop yields. In saline soils osmotic pressure of soil solutions is usually too high for plants to absorb sufficient nutrients and water. The concentration of salts outside the roots is usually too

high that water may be withdrawn from the plant roots causing plasmolysis or osmosis and poor root growth or even outright death of roots. Other deleterious effects of soil salinity on plant growth are reduced root elongation rate, reduced root permeability due to upset in plant hormonal balance and reduced transpiration rates.

Increase soil salinity results in ionic imbalance of the soil solution, and in turn, affects the nutritional balance of the plant. The high pH of saline soils affects solubility of many nutrients, soil structure, soil strength aeration, hydraulic and ionic conductivities

Alkaline (Sodic) Soils

These are soils in which the sodium content or Na saturation is greater than 15%. That is, if the exchange sites of the soil is occupied by sodium to the tune of 15%. The term “exchangeable sodium percentage” (ESP) or sodium adsorption ration (SAR) is usually used and expressed as.

$$\text{ESP} = \frac{\text{ex Na meq/100g soil} \times 100}{\text{C.E.C. mg/100g soil}}$$

For example, (i) if C.E.C. of a soil is 10meq/100g

$$\begin{aligned} \text{In which Mg} &= 2.5, \text{ Ca} = 2.0, \text{ K} = 1.0 \text{ Na} = 2.5 \text{ and Al} \\ &= 2.0 \text{ meq/100g soil} \end{aligned}$$

$$\text{Then \% Na} = \frac{2.5 \text{ meq/100g}}{10 \text{ meq/100g}} \times 100$$

$$\begin{aligned} &= \frac{2.5}{10} \times 100 \\ &= 25\% \text{ Na} \end{aligned}$$

(ii) if Na = 1.0meq/100g soil

$$\text{then \% Na} = \frac{1.0}{10} \times 100$$

$$= 10\% \text{ exchangeable sodium}$$

Conclusion: Soil (i) is alkaline whereas solid (ii) is not.

Saline-Alkaline Soils

A soil which is both saline (electrical conductivity > 4 mmhos/cm) and alkaline (ESP > 15%) is referred to as saline- alkali soil or saline-sodic soil. Such a soil has pH value of less than 8.5: and if the salts are leached out, excess sodium reacts with carbon dioxide to form sodium carbonate and the pH of the soil may be as high as 9 or 10 thus turning the soil to pure sodic soil.

Topic 2: General Feature of Saline and Alkaline Soils (Halomorphic Soils)

1. The pH of these soils is usually high, between pH 7.5 and 10, which results in the deficiency of micro –nutrients such as Zn, Cu, or Mn.
2. In alkaline soils, the presence of sodium carbonate causes changes in the soil structure. There is decrease in the permeability and pore-space. Clay and organic matter particles (soil colloids) are dispersed or deflocculated and then washed down between the soil aggregates and may eventually form a hard pan. The dispersed humic materials give a black coating on the soil giving a black soil surface hence the term “black alkaline soils”
3. The surfaces of alkaline (sodic) soils dry out into large massive hard clay pan always difficult to cultivate-being plastic when wet and forms hard compacted clods when dry.
4. Saline soils develop under conditions of low rainfall, but can also develop under poorly drained area, unusual topography whereby salts accumulate in the depression and saline areas are left behind after evaporation.
5. In most alkaline soils the activity of Ca is high. Under this high pH condition there is precipitation of relatively insoluble dicalcium phosphate $\text{Ca}(\text{H}_2\text{PO}_4)_2$ and other basic calcium phosphate such as carbonates apatite $\text{Ca}_{10}(\text{CO}_3)(\text{HPO}_4)_6$ and hydroxylapatite $\text{Ca}_{10}(\text{OH})_2(\text{HPO}_4)_6$.
6. Soil alkalinity affects plants due to the toxicity of the Na^+ , OH and HCO_3 ions. These ions and the high pH (above 8.5) usually emanate from the hydrolysis of sodium carbonate in soil:



Extreme alkalinity (pH 8.5 – 10.5 or higher) is due to the presence of Na_2CO_3 while the black colouration of the surface is due to the dispersed humus carried upward by capillary water. Irrigation water containing excess Na^+ and HCO_3 often causes soil alkalinity.

In general, many nutrients become unavailable in these soils of high pH, while the unstable structure leads to low water permeability, poor aeration and unworkable tilth.

Topic 3: Reclamation and Management of Alkaline and Saline Soils

1. Establish Appropriate Drainage Systems

Where poor drainage is the cause of the salinity, it would be necessary to establish good drainage systems to carry away the excess salty water. Such drainage systems that are in use include pumping, tile drains, drainage ditches and canals depending on the topography and soil type. Deep ploughing could be used to improve the soil permeability and therefore increase downward movement of percolating salty water.

2. Leaching Excess Salt

Where the soil remains permeable with adequate internal and surface drainage present excess salt of salines could be leached with heavy application of low salt irrigation water. Good-quality irrigation water must be used to leach excess salts out of the root zone.

In areas of water scarcity over irrigation is avoided by giving attention to **leaching requirement** (LR) which is defined as the additional water needed for leaching over that needed to wet the profile (Miller and Donahue, 1990).

$$LR = EC_{ix}$$

$$EC_{dr}$$

Where EC_{ir} is the electrical conductivity of the irrigation water, and EC_{dr} is the electrical conductivity of the soil saturation extract at which a 50 percent decrease in yield is obtained in uniformly saline soil.

Example of Leaching Requirement Calculation

Assume that an irrigation water has a conductivity of 1.08 d Sm⁻¹ (or 1.08 mmhos/cm). The field corn planted has a 50 percent yield reduction at a soil saturation extract conductivity of 6 d Sm⁻¹. Calculate the additional amount of water to add if the water needed to wet the profile is 6.35cm.

Solution: Substituting in the leaching requirement equation:

$$LR = \frac{EC_{ix}}{EC_{dr} - EC_{iw}} = \frac{1.08}{6 - 1.08} = 0.18$$

This decimal (or fraction) is that fraction of the amount of water needed to wet the soil which must be added additionally. Therefore, the total water needed is:

$$6.35\text{cm} + (0.18)(6.35) = 7.49\text{cm}$$

The determination of leaching requirement of a soil a times depends on the salt sensitivity of tolerance of the crop to be grown. For example, wheat and sorghum have a LR or 0.08; while lettuce, a more sensitive plant, has 0.20 implying that more water must be added to leach more salt under lettuce.

3. Application of Organic Mulch on Soil Surface

The idea here is to lower surface evaporation and thereby reduce salt movement to the soil surface in evaporative water. In some place, cotton gin trash, chopped woody plants and crop residues have been found helpful in reducing soil salinity.

4. Replacement of Excess Exchangeable Sodium

In saline-sodic, sodic and sodic (alkaline) soils, leaching directly with water low in salt may lead to further increase in the percent sodium saturation thereby increasing the concentration of the hydroxyl ions (OH) in the soil solution. In such situation, the toxic sodium carbonate and bicarbonate are first converted to sodium sulphate by treating the soil with heavy application of gypsum (CaSO₄ 2H₂O) or sulphur. The resulting sodium sulphate is then leached out of the root zone with irrigation water. Use of

sulphur also reduces the intense alkalinity in sodic soils. During the process of sulphur oxidation to sulphate there is production of hydrogen ion (H^+) which leads to lowering the pH of the soil.

5. Water Control

Application of light irrigation but frequent intervals would keep the soil moist, dilute salts and lessen the toxic and osmotic effects of salts in the soil. Young plant seedlings are more sensitive to salts than mature plants. Therefore, light irrigation should be more frequent immediately after planting the crop.

6. Appropriate Planting Position of Crops

Most salt concentrations are usually in the ridge and heap tops; planting methods should therefore avoid the center of wide ridges and the tops of narrow ridges or mounds.

7. Choice of Crops

Crops such as cotton, sorghum and barley that are tolerant or resistant to salty environment could be cultivated to successfully manage saline and alkaline lands other consideration may be the adaptation of the crop. The revenue derived from a high price crop would more than compensate the cost of managing the soil during cropping. In alkaline soils, crops such as *Atriplex* sp that accumulate Na^+ could be grown and then removed completely away from the irrigated area.

8. A Good Crop Rotation

A good crop rotation can be an insurance against alkali trouble, by building up the soil structure (through root action root action of tolerant plants) and improving its stability. Crops such as sweet clover, grass, Lucerne leys and melon have been found useful in this regards.

Unit summary

In this unit, you have learnt that:

- Salt-affected soils may be saline, sodic or salinesodic which must be specially treated and managed carefully to reduce salt problems to make the soils useful for crop production.
- The sources of salt-affected soils
- Characteristics of saline, sodic and saline-sodic soils
- How to reclaim and manage salted soils.

Activity

1. Discuss the possible effects of salted soils on plant growth.
2. Explain how gypsum improves the soil structure of sodic soils.

UNIT 9

SOIL MICRO-ORGANISMS: BACTERIA

INTRODUCTION

The soil beneath our feet is the home for millions of micro-organisms, whose activities affect both animals and plants life. The members of organisms in the immediate root zone, the rhizosphere, is usually 100 times more than the other parts of the soil. The activities, functions and nutrition of the micro-organisms are discussed in this unit and the following units.

OBJECTIVES

At the end of this unit, you should be able to:

- Describe soil organisms, especially soil bacteria
- Explain the economic significance of bacteria
- Explain the activities and functions of bacteria
- Enumerate conditions that affect activities of bacteria and promote the population of beneficial bacteria.

Topic 1: General Description of Soil Micro-organisms

The study of the relationship between living organisms and Soil properties is referred to as soil biology. Soil organisms consist of soil animals (soil fauna) and plants (soil flora). The micro-organisms cannot be seen by the naked eyes because of their small size. Different types of microscopes are used to study soil micro-organisms by soil microbiologists. The soil environment consists of different and numerous microscopic organisms which affect several biochemical reactions such as decomposition of organic matter, weathering of rocks and the nutrition of crops. The micro-organisms are classified into bacteria, fungi, algae, actinomycetes and protozoa.

Topic 2: Description and Classification of Soil Bacteria

Bacteria are the smallest organisms living in the soil. It is estimated that there are 25,280,000 bacteria in one gram of soil, making them to be the most abundant inhabitants of the soil. Bacteria are single-celled organisms usually rod-shaped and grow as small colonies on the surface of soil particles. Several factors are used to classify bacteria into groups. They could be classified according to their mode of nutrition, respiration, shape, etc.

Classification According to Respiration (Requirement of Oxygen)

1. Aerobes – must have access to oxygen for survival
2. Anaerobes – grow only in the absence of oxygen
3. Facultative anaerobes – can grow in the absence or presence of oxygen.

Presence of moisture is essential for bacteria growth

Classification according to feeding and energy source

a. Autotrophic

Derive energy from the oxidation of certain soil inorganic substances such as NH_4 , S and Fe and the carbon for building their body tissue from carbon dioxide, CO_2 . They are also referred to as primary producers.

The autotrophs are few but are very important because of their mediation in nitrification and sulphur oxidation.

b. Heterotrophic Bacteria

They are the most numerous in the soil. They get their energy and carbon from soil organic matter. All general purpose decay and ammonifying bacteria, fungi and actinomycetes are heterotrophic.

On the basis of the shape and size of the micro-organism, the following groups are recognised.

- (a) Bacilli or rod shaped bacteria, which are the most numerous in soils.
- (b) Cocci or spherical shaped bacteria.
- (c) Spirilla or spirals.
- (d) Vibrio or comma shaped bacteria.

Topic 3: Economic Importance of Bacteria

Majority of soil bacteria are saprophytes, comprising groups that breakdown organic matter in the soil. As a group, bacteria participate tremendously in all the organic matter and compounds transformation vital for the soil to sustain plant growth. They have monopoly of mediating in three main enzymatic processes of nitrification, sulphur oxidation and nitrogen – fixation in the soil without the success of these transformation lives for higher plants and for animals would be jeopardised. The importance of bacteria could be summarised as follows.

1. The fermentation process effected by bacteria ensures recycling of nutrients. Elements in dead organic matter are returned to the soil for the use of plants over and over again.
2. They have the ability to fix atmospheric nitrogen converting N_2 to the forms NH_4^+ , NO_3^- , utilizable by plants.
3. They cause plant diseases such as crown gall (*Agrobacterium tumefaciens*) which cause tumor-like growth on roots of many plants. Tuberculosis and tetanus etc are caused by bacteria.
4. Some are used to cure diseases such as curing of tobacco.

5. They decay food materials.
6. They are involved in antitoxic development for resistance against infection.

Topic 4: Conditions that Affect the Growth and Activities of Soil Bacteria

The most important soil conditions affecting soil bacteria are oxygen, moisture, temperature, available organic matter, soil acidity and amount of exchangeable calcium present. The effects of these conditions are outlined below:

1. Oxygen Needs

- a. Some bacteria use mainly oxygen gas (Aerobic)
- b. Some bacteria use combined oxygen (Anaerobic)
- c. Some use either of the above forms (Facultative)
- d. All three of the above types operate in a soil at one time.

2. Moisture Relationships

- (a) Optimum moisture level of higher plants is usually ideal for most bacteria.
- (b) The Moisture content affects oxygen supply.

3. Suitable Temperature Range

- a. From 70 to 100 °F (38.8 – 55.5°C) bacteria act generally attained the greatest.
- b. Ordinary soil temperature extremes, seldom affect bacteria

4. Organic Matter Requirements

- (a) Used as energy source for majority of bacteria (Heterotrophs)
- (b) Organic matter is not needed by autotrophs.

5. Exchangeable Calcium and pH Relationships

- a. High Ca pH from 6 to 8 generally is the best for bacteria.
- b. Calcium and pH values determine the specific bacteria present.
- c. Certain bacteria function at very low pH (3.00) and others at high pH values.
- d. Exchangeable Ca seems to be more important than pH.

Unit summary

In this unit, you have learnt that:

- The most numerous soil flora are bacteria. They decay organic matter, a process that enables nutrients to be returned to the soil and improves the level of humus.
- Some important groups of bacteria are the symbiotic nitrogen fixers (Rhizobia), non-symbiotic nitrogen fixers and others involved in biochemical transformation of nitrogen in soil.
- Bacteria are classified according to several factors such as oxygen needs, nutrition or shape.
- Bacteria are of economic importance in agriculture making nutrient in organic matter available to crops.
- Bacteria mediate in some biochemical processes such as nitrification and nitrogen fixation that sustain plant life.
- Certain conditions affect the growth of soil bacteria.

Activity

1. Distinguish and give examples of autotrophic and heterotrophic, and aerobic and anaerobic organisms.
2. Discuss the various environmental conditions affecting the growth of soil bacteria.

UNIT 10

SOIL ACTINOMYCETES, FUNGI AND ALGAE

INTRODUCTION

Actinomycetes are also called mold bacteria because of their resemblance to bacteria by having similar cell structure. They also look like fungi because they grow a threaded network and can work on resistant organic matter like fungi. Description, activities and importance of actinomycetes, fungi and algae would be treated in this unit.

OBJECTIVES

At the end of this unit, you should be able to:

- Describe actinomycetes, fungi and algae
- Explain the way soil conditions affecting the growth and activities of actinomycetes, fungi and algae
- List ways that these micro-organisms are important
- Describe how to promote populations of beneficial soil organisms.

Topic 1: Description of Soil Actinomycetes

Actinomycetes represent a transitional group of micro-organisms between bacteria and the filamentous fungi. They produce numerous thin colourless mycelial threads just like fungi do. One teaspoon of soil contains about 12 million actinomycetes or about 15 – 20 million per

gram of dry soil. They resemble the fungi by having extensive and serial mycelium and conidia. Their growth in liquid culture really results in the turbidity associated with bacteria.

Actinomycetes are like bacteria unicellular and of same diameter especially when they break into spores. They can resist severe drought, but are sensitive to acid soil

condition of pH 5.0 or below. They prefer slightly alkaline conditions with optimum at pH 6.0 – 7.5. They abound in soils high in humus and farm manure.

Topic 2: Activities and Functions of Actinomycetes

Several actinomycetes species produce chemicals that inhibit the growth of other micro-organisms. This phenomenon is called antagonisms. An anti-biotic forming actinomycetes is the *Streptomyces*, whose antibiotic could protect plant roots from attack by disease organisms. Almost all species of actinomycetes are saprophytes.

Actinomycetes are especially important due to their ability to dissolve soil organic matter, including the resistant lignin compounds to simpler forms with the release of plant nutrients like nitrogen.

The potato scab diseases caused by actinomycetes are usually controlled by using sulphur to effect pH reduction below the level these organisms can tolerate.

Actinomycetes are heterotrophic feeders which depend mainly on the presence of organic substances. They are believed to have a lesser biochemical importance than the bacteria and fungi. Additional activities are as follows:

1. Decomposition of very resistant components of plants and animals tissues.
2. Formation of humus through the conversion of plants remains and litter.
3. Causing of certain soil borne diseases of plants e.g potato scab and sweet potato pox.
4. They can cause infection of human and farm animals.
5. They take part in micro antagonisms and in regulating composition of soil community. They excrete antibiotics and produce enzymes that are responsible for lysis of fungi and bacteria.

Topic 3: Description of Fungi

In most well aerated cultivated soil, fungi account for a large part of the total microbial population due to their large diameter and extensive network of their filaments. The organic matter status, hydrogen ion concentration, organic and inorganic fertilizer, the moisture regime, aeration, temperature, and position in the profile, season of the year and composition of the vegetation are factors controlling fungi population in soils.

Organic matter serves as food and thus provides energy for fungi, acidic soils favour fungi multiplication, and fertilizers can either reduce or increase the pH

Too much water affects fungi because air is excluded while too high soil temperature may have adverse effect on fungi population. The position in the soil profile is important because as one moves down the profile, organic matter decreases and fungi population also decreases. Finally, members of the grass family (e.g. rice, maize) favours fungi growth.

There are over 200 species representing 42 genera, like bacteria actinomycetes, fungi contain no chlorophyll, and depend on carbon and organic matter of the soil for their energy.

The superficial characteristic that distinguishes fungi is the filamentous nature of their vegetative forms. Fungal organisms vary from the simple microscopic yeasts to mushroom and bracket fungi of extraordinary dimensions.

Fungi may be considered under three groups:-

(1) Yeasts – not important in soils

(2) Molds – found in all horizons of soil profile with highest number in surface layers with abundant organic matter. They develop vigorously in acid neutral or alkaline soils. More in acid soils where bacterial and actinomycete offer less competition. Common mold genera are *Penicillium*, *Mucor*, *Trichoderma*, and *Aspergillus*. The numbers fluctuate greatly with soil conditions perhaps 1,000,000/gram of dry soil.

(3) Mushroom Fungi - also important in soils. Molds are an important part of the general-purpose heterotrophic group of soil organisms that fluctuate so greatly in most

soils.

Topic 4: Activities and Functions of Fungi

1. The fungus has no chlorophyll. Hence, it depends on sugars, organic acids, disaccharides, starch and other performed organic molecules. Some fungi also parasitize on higher plants. They thus participate in the microbiological balance in the soil.
2. Degradation of complex molecules
3. Utilisation of proteinaceous substances that results in the formation of ammonium and other simple nitrogen compounds
4. Formation of hums
5. Pathogenicity – they can cause diseases. Some can cause diseases of humans especially where people are scantily dressed.

Topic 5: Mycorrhiza

Numerous varieties of mushroom fungi producing fruiting bodies as mushroom, toadstools and puffballs, are found in forests in great profusion. The mycelia of certain members often infest the roots of trees giving an association called mycorrhiza.

The fungal threads merely form a mat around the absorbing root surfaces while in some others they actually penetrate the root cells. The presence of fungal is considered beneficial to both the host and the parasite. The latter may digest and at times pass on to the trees certain nutrient constituents that the host trees might not obtain so readily. Others consider the benefit as due to increased effective absorptive surface associated with roots and fungi.

This one service alone of actinomycetes of decomposing soil organic matter and putting unavailable tie-up nutrients into circulation for higher plants rank it with molds and bacteria as fertility agents in average arable soil.

Topic 6: Algae, Protozoa and Nematodes

All algae contain chlorophyll but the green colour of chlorophyll may be modified by the presence of other pigments.

Soil algae belong to four main groups. Chlorophyll or green algae, Cyanophyceae or blue-greens, xanthophyceae or yellow green and bacillariophyceae or diatoms, which are golden, brown in colour

moisture is adequate and light is accessible. They are found mostly on alkaline soil environment preferably alkaline reaction of pH 8.5.

Soil algae can affect plant growth in at least four ways by adding organic matter to the soil, by binding soil particles on the surface together, by improving the aeration of flooded soils and by fixing atmospheric nitrogen. Algae are of special importance in flooded rice soils. They convert carbondioxide photosynthetically in oxygen, which is supplied to the surfaced roots of the rice plant. About 13 species of blue-green algae common in rice fields of South East Asia fix atmospheric nitrogen and make it available to the rice plant. These include Nostococcaceae and Tolypothrix.

Algae are not as numerous as bacteria, antinomycetes or fungi. As such, they are not usually sufficiently appreciated as a group. Since they are photosynthetic, they require access to sunlight and moisture. They can be frequently noticed in virgin or uncultivated land with the naked eye. Their presence can be demonstrated readily by the addition of small amounts of soil containing NO_3 , KPO_4 , and MgSO_4 , Ca and Fe salts and traces of other inorganic nutrients. The resultant growth is visible macroscopically as a green colour. Morphologically, algae may be unicellular or occur in short filaments but the soil strains are smaller and structurally less complex than their aquatic counterpart.

Blue-Green Algae and Rice Paddy

They are numerous in rice soils and when lands are waterlogged and exposed to the sun, these organisms fix appreciable amount of nitrogen.

Environmental Conditions Affecting Activities of Algae

Soil organic matter content has no control on algal population since they have

photosynthetic ability. Rather, need for sunlight and CO₂ is imposed. Carbon dioxide and bicarbonates are usually produced in excess of the autotrophic demand. Light accessibility is hence a dominant factor governing the distribution of photoautotrophic microorganisms. Each strain also has an optimum pH and a range outside of which they fail to multiply.

The blue-green algae develop in a neutral or alkaline soil (pH 7 – 10). They are often absent at pH values below 5 and uncommon below 6. Moisture is a common limitation to growth and herbicides usually have devastating impact on algal species. They are also susceptible to attack by the other macro and microscopic organisms such as protozoa, nematodes, mites and earthworms.

Significance of Algae

They do not contribute much to the many biochemical transformations necessary for soil fertility except in flooded soils planted to rice. This is due to much composition from bacteria, fungi etc. Yet, the photosynthetic microflora is capable of exerting the following effects.

1. Generation of organic matter from inorganic substances i.e they can convert CO₂ into carbonaceous materials and thus increase the total quantity of organic carbon in soils.
2. With the colonization of barren surfaces, algae are able to corrode and weather rocks. A thick layer of algal cells is found covering the surfaces of rocks.
3. They can contribute to soil structure and erosion control.
4. Their photosynthetic activities lead to the release of oxygen which benefits the growth of submerged roots of rice.
5. They can utilise atmospheric N₂ for growth thus enriching the soil with combined form of nitrogen.
6. Some algae do parasitize cultivated plants like tea, citrus and cocoa trees.

Protozoa

Protozoa are small unicellular animals of microscopic dimension, which are widely distributed soils throughout the world. Two important groups found in soils are the flagellates and the amoebic. The flagellates have one or more flagella or tails, which enable them to move about. Protozoa are mainly heterotrophic organism, their food consisting of bacteria, algae as well as other protozoa.

Nematodes

Nematodes or eelworms vary greatly in size ranging mostly from about 0.5 to 1.5mm in length. However, some soil nematodes, which are about 2500 times the size of the smallest, are known.

Two groups of nematodes are found in the soil (a) free living forms, which are the most numerous, they feed on decaying organic matter and possibly on bacteria, protozoa, and fungi (b) parasitic forms which enter plant roots and have specific nutrient.

Soil micro flora consists mainly of bacteria, actinomycetes, fungi and algae while protozoa and nematode (eelworms) are the chief groups of micro fauna usually prevalent in soils. Their activities in the soil are both beneficial and detrimental to crop plants. They participate in organic matter decay, nutrient release to crops, nitrification, nitrogen fixation and production of antibiotics. However, they can also cause various diseases and infections of plants.

Unit summary

In this unit, you have learnt:

- The morphology, growth and population of soil actinomycetes, fungi, algae and protozoa.
- The activities and function of these soil microorganisms.
- The beneficial and detrimental roles of these soil microorganisms to plants and animals.
- The environmental conditions that affect the growth and population of the microorganisms.

Activity

1. Describe growth habits and good soil conditions for micro organisms.
2. Describe the benefits and harmful aspects of soil actinomycetes and algae.

UNIT 11

NITROGEN TRANSFORMATIONS IN SOIL

INTRODUCTION

Apart from the release of nitrogen from soil organic matter during decomposition by decay bacteria, molecular nitrogen, N_2 , in the atmosphere is converted to the forms useful to crops by symbiotic and nonsymbiotic bacteria, mainly *Rhizobia* spp. We would learn in this unit how nitrogen is made available to crops by all the microorganisms that participate in the nitrogen cycle.

OBJECTIVES

At the end of this unit, you should be able to:

- Describe the nitrogen cycle
- Explain biochemical processes of nitrification and de-nitrification including the microorganisms involved
- Discuss nitrogen fixation in soils and its significance in crop nutrition
- Explain how we could promote the growth and increased population of beneficial microorganisms
- Describe ways of controlling harmful organisms.

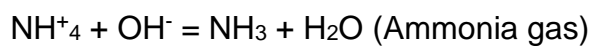
Topic 1: Nitrogen Cycling

Nitrogen and other nutrients are taken up by plants into the living bodies of microorganisms. The nutrients are bound in complex organic forms and are said to be *immobilized*. The nutrients can only be utilised by plants when changed to simple, inorganic forms by microbial decomposers by a process known as *mineralization*.

The series of gains, losses and changes of nitrogen forms is called nitrogen cycle with the following components:

- i. Nitrogen gas (N_2) in the air is converted to organic nitrogen and protein by symbiotic and non-symbiotic bacteria for their own body building.

- ii. When the bacteria die, their remains are mineralized to ammonium ions (NH_4^+) by other soil micro-organisms (ammonification).
- iii. The NH_4^+ could be taken up by plants or nitrified first to nitrite (NO_2) and then to nitrate (NO_3^-) which are also taken up by plants.
- iv. Part of the nitrate may be converted again to nitrogen gas (N_2) through denitrification by facultative anaerobes that make use of oxygen in NO_3 for respiration in the absence of molecular oxygen (O_2).
- v. There could be leaching of nitrates away from the feeding zone of plant roots during heavy rainfall.
- vi. Nitrate could also be lost through volatilization whereby ammonium ions react with hydroxyl ions to form ammonia gas which escapes to the atmosphere away from the soil plants system



The loss of nitrogen by volatilisation is facilitated in a dry or alkaline soil

- vii. Increase input of nitrogen is done by manuring, growing legumes, or by fertilization,
- viii. Rainwater, during tropical thunderstorm, adds a fair amount in the form of ammonia and oxides of nitrogen.
- ix. Nitrogen in plant residues, roots and stubble is returned to the soil through decomposition and mineralization.

Topic 2: Nitrification and De-nitrification

Nitrogen containing compounds released from organic matter decomposition are usually broken down into amino acids and amides through ammonization process by

heterotrophic micro-organisms. The nitrogenous organic compounds are further degraded into ammonium (NH_4^+) ions through the process called ammonification.

The NH_4^+ may be absorbed by plants for growth or oxidised by *Nitrosomonas* bacteria first to nitrite ions (NO_2^-) which in turn, is rapidly oxidized by *Nitrobacter* bacteria to nitrate ions (NO_3^-). The two steps in the conversion of ammonium nitrogen (NH_4^+) into nitrate nitrogen (NO_3^-) is called *nitrification*. Nitrite ions are toxic to plants and animals but are short-lived in the soil. Nitrate, end product of nitrification, is the preferred form of nitrogen by many plants.

In wet soils or waterlogged soils, there is a deficiency of oxygen. Denitrifying bacteria or facultative anaerobes use nitrate instead of oxygen for respiration thereby converting nitrate back to nitrogen gas or gaseous nitrogen oxides. This process is called *de-nitrification*. In the process nitrogen escapes from the soil-plant system back to the atmosphere. The nitrification organisms are aerobic thriving very well in well-drained soil at temperatures between 30 – 35°C in neutral soil of about pH 6.5 – pH 7.2.

Topic 3: Nitrogen Fixation

Nitrogen fixation is the conversion of nitrogen gas (N_2), which plants cannot utilise, to ammonia (NH_3), that plants can use, by certain bacteria, blue-green algae, and actinomycetes.

These micro-organisms absorb the nitrogen gas as they form symbiotic relationship with plant roots and convert the gas to ammoniacal nitrogen utilizable by plants.

Up to 60 kg N per hectare can be added to the soil yearly by the legume-Rhizobium association.

Some free-living bacteria (such as *Clostridium*, *Azotobacter*, etc) also fix nitrogen. These sets of bacteria live freely in the soil but add less amount of nitrogen yearly to the soil.

Topic 4: Ways of Promoting Soil Organisms

Healthy soil should be populated with healthy and beneficial micro-organisms through inoculation; that is, purposely infecting soil with useful organisms. Soils could be inoculated with nonsymbiotic nitrogen fixers, mycorrhizae and other friendly micro-organisms. Inoculants are usually applied to seeds, such as legume seeds, to ensure good module growth on the roots of host crops. Good soil conditions for the growth of microorganisms could be achieved in the following ways.

1. For successful microbial population, there must be a steady supply of fresh organic matter.
2. Good aeration will supply oxygen to the most important organisms in agriculture.
3. Adequate moisture is needed for active growth and multiplication. The best moisture level is near field capacity.
4. Conducive soil temperature for most soil organisms is between 25 – 35°C.
5. Most organisms grow maximally at neutral pH level. Liming may be required in acid soils except where potato scab-forming actinomycetes are to be controlled. Fungi are acid-loving of all soil organisms.
6. Nutrient level in soil must be adequate. Phosphorus is essential to nodulation of root legumes but keeps mycorrhizae formation low.

Topic 5: Ways of Controlling Harmful Organisms

The control of harmful organisms such as nematodes, parasitic fungi and bacteria is a way of making the soil healthy for crop growth. This is usually achieved by applying sterilant chemicals which could be in the form of gases and solids injected in to the soil. This method is only profitable for high value crops and it has a disadvantage of killing both good and bad organisms. Other practicable methods are as follows.

1. Plant disease – free seeds.

2. Obey plant quarantines which are intended to prevent transportation of parasitic nematodes and other diseases into uninfected soils.
3. Control of soil pH to match the type of crops to be grown.
4. Crop rotation could kill some organisms that are host – specific.
5. Decay organisms can be promoted with the application of large quantities of organic matter, the decay organisms can “fight off” the harmful ones.
6. Planting of some plant [spp] which release chemicals into their rhizosphere that repels nematodes.
7. Soil sterilization is necessary in green house work to prevent soil – borne diseases.

Unit summary

In this unit, you have learnt:

- Organic nitrogen must be converted to inorganic nitrogen through mineralization and nitrification processes before it could be taken up by plants. Also nitrogen gas must be converted to ammoniacal forms by nitrogen fixers (Rhizobia) for it to be useful to crops.
- Micro-organisms require proper soil conditions to grow and multiply.
- The most important conditions are organic matter, good soil aeration, moisture, pH nutrient levels and conducive temperature.
- The various biological transformations in the nitrogen cycle.
- Nitrogen inputs into and losses from the soil-plant system.
- The beneficial and harmful soil organisms.
- How to promote beneficial and how to control harmful soil organisms.

Activity

1. Discuss the various pathways by which nitrogen could be increased and lost in the soil.
2. Describe good soil conditions for microorganisms.

UNIT 12

GENERAL PRINCIPLES OF SOILS AND WATER CONSERVATION AND MANAGEMENT

INTRODUCTION

Livestock and crops depend on soil and its fertility, thus emphasizing the proper management of soil for its sustainable productivity.

Tropical soils are opened to erosion agents (water and wind) due to over grazing, deforestation and inappropriate methods of crop production with resultant reductions in soil productivity of the degraded land. The degree of occurrence however differs from one location to the other. Despite these differences, soil erosion is a major national problem. This problem can be reduced to an acceptable level by adopting appropriate farming techniques and practices as will be pointed out in this unit.

OBJECTIVES

At the end of this unit, you should be able to:

- explain why it is necessary to practice soil and water conservation and management especially in Zambian agriculture
- describe the various forms of water and wind erosion
- discuss the concept of universal soil loss
- explain the agronomic techniques for the control of both water and wind erosion.

Topic 1: Importance of Soil and Water Conservation

Erosion, either by water or wind, is the washing away of the top soil from a piece of land. Erosion causes a lot of damage to the farmland such as listed below.

1. Erosion first removes the topsoil. Topsoil affords the best root environment by providing the best structure the most air, and an active population of living organisms. Once the topsoil is lost, only the less productive subsoil remains.

2. The topsoil contains most of the soil's organic matter and plant nutrients. Erosion carries away nitrogen, phosphorus, and any nutrient stored mostly in organic matter.
3. As erosion strips away the soil surface, the profile becomes thinner decreasing the root zone. This is a particular problem on already shallow soils. A major effect of this shrinking root zone is a reduced value of total water-holding capacity.
4. Gullies cut up fields into odd-shaped pieces and make it very difficult to operate farm equipment.
5. Eroded soil contains nutrients and pesticides that pollute lakes and streams. For instance, large fish kills have occurred in streams fed by runoff water from fields treated with soil insecticides. A conservation Foundation study of 1985 estimates that 30% of American waters are exposed to enough runoff to chronically affect fish.
6. The soil washed away by erosion settles in streams, lakes harbors, and reservoirs. About 760 million tons farmland sediment reach surface waters each year.

The concept of soil conservation implies the prevention of loss, waste and damage of the soil. It is synonymous with soil preservation. The actual processes or skilful treatments that are employed in this regard are termed soil management practices. The fertility of a soil can be measured by its capacity to support the climax population of plants and animals above ground and the flora and fauna below ground. It is also implied by the nutrient supplying power of the soil in terms of amount and proportion. Conversely, soil productivity is a characteristic of the soil to adequately support plants (crops) growing on it.

Topic 2: Types of Water Erosion

A raindrop strikes the soil surface forcefully. The impact shatters soil aggregates and throws soil grains into the air. On a slope, water begins to flow downhill, carrying detached soil grains with it. This water joins other flowing water, increasing in speed, volume, and soil-carrying capacity. This order of events lead, to five types of erosion. All types can occur at the same time on any given slope.

1. **Splash Erosion** is the direct movement of soil by splashing. A soil grain can be thrown as far as five feet by raindrop splashed particles fill the voids between other aggregates and seal the soil surface.
2. **Sheet Erosion** is the removal of a thin layer of soil in a sheet. On gentle slopes or near the tops of steeper slopes water moves in tiny streams too small to be noticed. This gives the impression of losing soil in a thin sheet. Sheet erosion may go unnoticed until the subsoil appears.
3. **Rill Erosion** is visible as a series of many small channels on a slope. Water tends to collect in channels, picking up energy as it runs down the slope. As a result, running water carves out small but visible channels called rills. A rill is small enough to be filled in by tillage.
4. **Ephemeral Gullies** are large rills. The channel is small enough that tillage equipment can cross it and largely, but not completely, fill it in by tillage. During another heavy rainfall, water collect in the old channel, and erosion will begin here.
5. **Gully Erosion** is the most highly visible erosion. Gullies are so large that equipment cannot cross them. Gullies usually begin to form near the bottom of a slope or on steep slopes, where running water has enough force to carve a deep channel. Gully heads may back up the hill as water running into the gully collapses the sides.

Each type of erosion is important to understand for different reasons. Sheet erosion is a hidden soil loss, since there are no visible signs until the subsoil appear. Rill erosion can also be hidden, because each tillage causes the rills to disappear. The amount of

the hidden erosion can be easily underestimated by a grower.

Topic 3: The Universal Soil Loss Equation

The universal soil loss equation was developed to predict the average soil loss from sheet and rill erosion on any specific site. A farmer can use the equation to decide what conservation practices are needed to keep soil loss within tolerable levels. The USLE also helps the farmers to adopt the most economic soil preservation measure.

The USLE is based on a standard test plot, which represents an average eroded site. This plot has a 9% slope 72.6 feet long. The slope is kept in clean-tilled fallow, using conventional tillage up and down the slope. The equation works by comparing a specific spot to this test plot. The equation reads as follows:

$$A = RKLSCP$$

“A” is the tons of soil lost per hectare each year. Obviously, “A” should be less than “T” To solve for A, values are inserted for the six variables and are multiplied. The variables are:

1. **R – Rainfall and Runoff Factor.** R is based on the total erosive power of storms during an average year. R depends on local weather conditions. The isoerodent map shows R values for a region.
2. **K – Soil Erodability Factor.** K depends on texture, structure, and organic matter content. Soil survey reports give the value of K for mapped soils. They may also be calculated.
3. **LS – Slope Factor.** L compares the slope length and S compares the grade with the standard plot. L and S are separate factors, but they can be treated as one variable, “LS.”
4. **C – Cover and Management Factor.** C compares cropping practices, residue management, and soil cover to the valid only within the area for which they are calculated. Many SCS offices prepare simplified tables for use in the field, and

some have computerized the computations. Check local SCS offices for local charts. If necessary, the values can be calculated.

5. **P – Support Practice Factor.** P compares the effect of contour tillage, contour strip-cropping, and terracing with the test plot. The LS factor accounts for terraces primarily, but they are included here because they are contoured.

Topic 4: Factors in Wind Erosion

The following factors determine the amount of wind erosion:

1. Soil erodability relates mainly to texture and structure. Soils high in fine sand are most liable to wind after they have been drained. If soil grains are cemented into large soil aggregates, they are less likely to be blown away.
2. Soil roughness makes a larger still air layer at the soil surface. Each clod or ridge also acts like a tiny windbreak to slow the wind and capture blowing soil.
3. Climatic conditions that promote wind erosion include low rainfall, low humidity, high temperatures, and high winds. Dry windy conditions cause faster soil drying, and dry soil is more erodable than moist soil. Dry soil also supports a thinner vegetative cover.
4. Length of field affects erosion. On the leading edge of a field there is no wind erosion. As the wind travels across the field, it picks up more and more soil grains, like an avalanche.
5. Vegetative cover protects the soil, as does a mulch. Bare soil, on the other hand, is fully exposed to the erosive force of wind.

These factors together can be arranged to create a soil loss formula similar to the USLE. It is called the Wind Erosion, equation or WEE. WEE is more complex to apply than the USLE, and generally considered less reliable.

Topic 5: Agronomic Techniques for the Control of Soil Erosion (Water and Wind)

Among the different methods of erosion control, agronomic techniques are considered effective and are usually given precedence because they are less expensive and deal directly with reducing raindrop impact, increasing infiltration, reducing run off volume and decreasing wind and water velocities. It is also easy to fit them into existing farming systems.

Agronomic techniques used in erosion control include:

1. Maintenance of high soil fertility
2. Mulching
3. Crop rotation
4. Contour tillage
5. Strip cropping
6. Fallowing
7. Alley cropping and
8. Minimum tillage

1. Maintenance of High Soil Fertility

Continuous maintenance of ground cover in addition to high organic matter helps to conserve soil and prevent erosion. It is believed that wise use of fertilizer, lime and manure increase the fertility of the soil which enhances proper plant growth leading to bumper harvest and insurance for maximum ground cover.

2. Mulching

Mulching protects the soil surface from the direct impact of rain drops. The raindrop on bare soil tends to break soil aggregates apart and produce a crust of paddled soil. Such crusts have low permeability that reduce infiltration and increase run-off.

Maintenance of cover like the use of mulching materials at all times reduces crust formation, increases permeability and consequently there will be little run-off and erosion. This is one of the major crop management practices used in the control of soil Erosion.

3. Crop Rotation

Crop rotation which is a systematic sequence of planting one crop (of different morphology and nutrient requirement) after another helps to maintain a better soil condition to absorb water when grass legume crops are included in crop rotations than the continues mono-culture farming. In addition to ensuring quick and efficient ground cover, legumes, have abundant vegetative growth which provides large quantity of crop residue to protect the soil surface in addition to enriching the fertility of the soil.

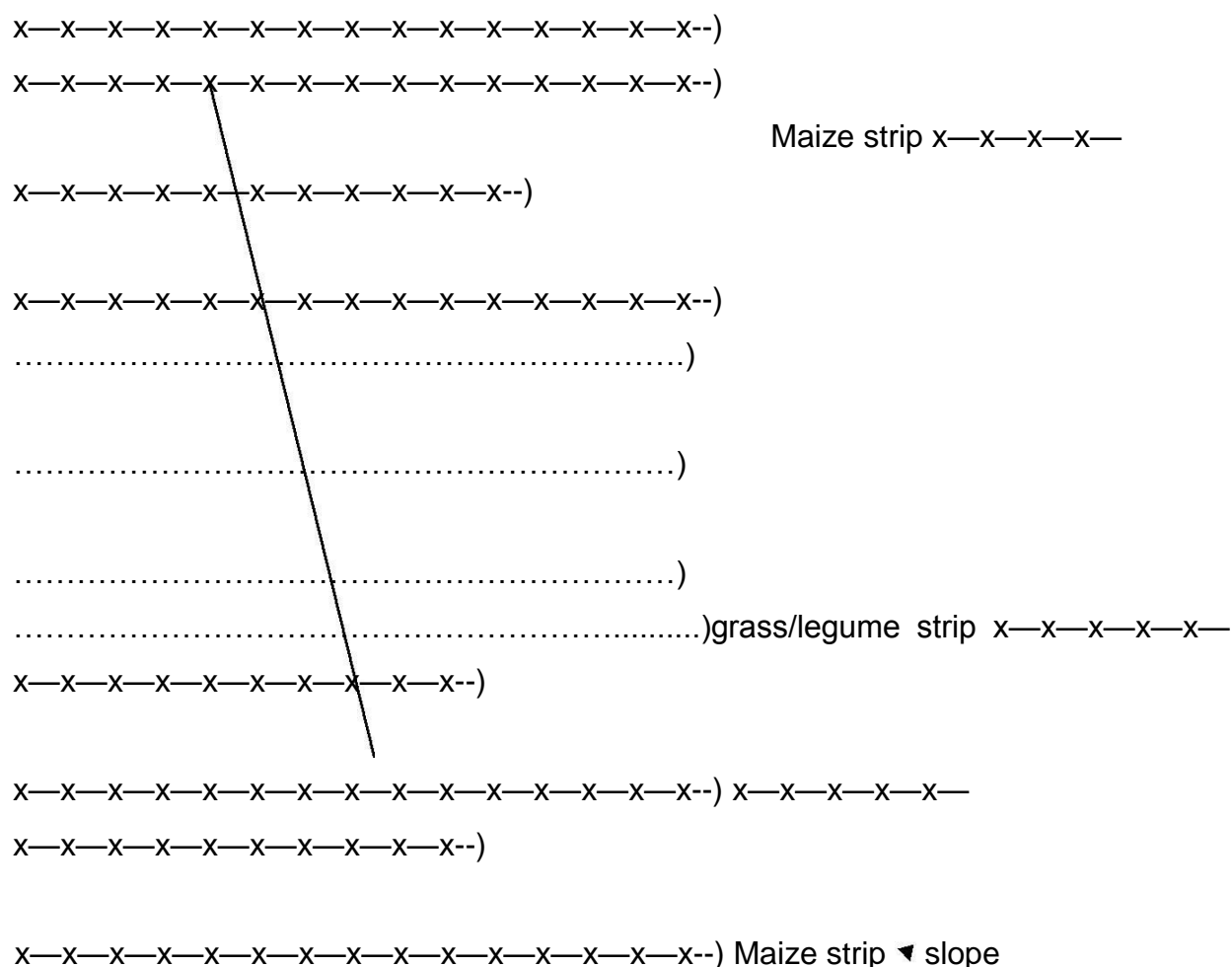
4. Contour Tillage

This is cultivation of a sloppy small piece of land with ridges made across the slope rather than along down slope.

Contour farming is adopted on a sloppy land and it is mainly done to reduce soil, water and nutrient losses. If done properly, it serves as an obstruction to the flow of water down the slope. Such restricted water subsequently infiltrates into the soil thus minimizing run-off and erosion

Strip cropping is used on a sloppy land also. In this case the entire field is divided into series of strips separated by uncultivated bunds. The system is called contour strip-cropping when the strips are laid out on the contour.

The crop is grown on strips which alternate with the strips of grass – legume.



The water flowing across the strip of grass legume spreads across the strip due to its reduced velocity and the much of the suspended silt is deposited between the grass blades at the top end of the strip. Some of the clean water percolates into the soil while smaller portion of the run-off water reaches the lower end of the strip. Therefore, water moves out more slowly from the protective strip (Grass-legume strip) than it enters it.

6. Fallowing

Fallowing is an age-long method of protecting the soil from physical, chemical and biological degradation. This is the practice of abandoning a piece of land (after a long period of cultivation) to regain its fertility status after which it is now used again for another period of cropping.

Soil fertility maintenance is through the long fallow period. A fallow period is the number of years a piece of land that had been under cropping is allowed to revert to bush/forest. Fallowing is a means of storing water in the soil from one year to the next. It [protects soil from erosion and helps to restore soil fertility.

7. Alley Cropping

Alley cropping, a promising system developed over the last several years, consists of growing rows of food crops between deep rooted trees. The trees are pruned or pollarded at regular intervals to control shade and to produce many materials that are spread on the cultivated land between the rows. Where this is practiced, this association of plants has maintained excellent continuous productivity and fertility maintenance. Leguminous tree crops are preferred because they can tap atmospheric nitrogen into the cropping system. In alley cropping both the fallow and the cropping period are integrated at the same time. In addition to erosion control this system has an added advantage of recycling soil nutrients more especially if legumes shrubs are used.

8. Minimum Tillage

The conventional tillage operations of ploughing, harrowing and ridging usually lead to increased soil compaction which eventually reduce infiltration and encourage run-off and erosion.

Minimum tillage system (currently described as conservation tillage) eliminates all tillage operations except planting and has the following advantages:

- i. Reduces the rate of erosion
- ii. Conserves water due to surface cover of plant residues
- iii. Reduces the cost of production and
- iv. Increases crop yield.

Unit summary

In this unit, you have learnt about:

- Water erosion removes the topsoil, reduces yields, and deposits sediments in streams, lakes, and reservoirs. Wind also strips the topsoil, blows away the smallest soil particles, and buries ditches and other structures.
- Falling raindrops and running water detach soil particles from the soil surface and carry them away. Depending on the slope, erosion removes soil as a sheet or creates rills and gullies.
- Water erosion is promoted by bare and erodable soil, long or steep slopes, and the lack of conservation practices.
- Soil scientists use the Universal Soil Loss Equation to compute soil loss. The USLE accounts only for losses from sheet and rill erosion and will understate soil loss where there is ephemeral or gully erosion. Using the USLE, a specialist can suggest practices to keep a farm productive.
- Growing vigorous crops, maintaining organic matter, and avoiding over tillage and compaction help to control erosion.
- Both conservation tillage and crop rotation sharply curb erosion. Contour tillage, contour strip-cropping, and terraces are effective ways to slow runoff. Where these are not enough to stop runoff, they may be combined with grassed waterways these are not enough to stop runoff, they may be combined with grassed waterways or outlets to carry the excess off the field without erosion.
- The devastating effect of water and wind erosion in farmlands
- Different types of water erosion
- The definition and use of the universal soil loss equation (USLE)
- Agronomic practices that could combat soil erosion on a farmland

Activity

Discuss the agronomic practices that could lead to:

- i. Soil erosion control
- ii. Accelerated soil loss in Zambia

Unit 13: A Look at Zambian Soils

Most of Zambia's plateau and some hilly areas have been degraded due to geomorphological processes. Zambia has four agro-ecological regions (**Figure 12**) that comprise different soil types. The main soils are loamy-sand or sand Alfisols, interspersed with clay.

Upland soils are of low inherent fertility; most are moderately leached sandveldts, loams and clays. Their texture and structure and physical properties vary. Soils in most dambo areas are characterized by a dark colour in the top 30 cm of the profile. In more cases the layer is covered by silt loams underlain by silt clay loam with clay developing in deeper layers. Clay appears to have eluviated to lower horizons into water tables. Black colour is chiefly on account of their high organic matter content. Dambo soils have supported crop production on a sustainable basis for decades without having to apply external inorganic fertilizers on account of their organic matter and high nutrient pool. There is currently an increasing trend to dambo cultivation due to their wetness and high fertility status. The variation in fertility of both upland and lowland dambo soils has to be viewed and approached cautiously with different land management practices if production is to be sustainable.



Figure 12: Map showing soil zones and types in Zambia

Source: El wells de les ciencias sociales 2002. The University of Texas at Austin. General Libraries. UT library Online.

The soil types in Zambia can be broadly categorized into four regions:-

- **Region 1:** embraces the Southern and Eastern river valleys characterized by low rainfall, less than 700 mm, flat and steep topography with Haplic Luvisols (FAO, 1973) and Haplic Solonetz on the flat land and Dystric Leptosols on the hills and ridges. The Solonetz are highly erodible; arable production is concentrated on bulrush millet (*Pennisetum glaucum*), sorghum and livestock. Food security concerns predominate due to recurrent food shortages.
- **Region 2a:** constitutes the central plateaux with rainfall of 800 to 1,000 mm. The soils are mainly Haplic Lixisols (FAO, 1973), Haplic Luvisols, Haplic Acrisols and other soil types. These soils are more productive, permanent cultivation of sorghum, maize, groundnuts, cow peas and a range of cash crops including tobacco, sunflower, irrigated wheat, soybean and horticultural crops.
- **Region 2b:** this is the aggraded Western plateau with rainfall of 800 to 1,000 mm. The soils are Ferrallic Arenosols which are infertile, coarse sands. Cassava, bulrush millet and Bambara nuts (*Voandzeia*) predominate on the upland with some maize and sorghum; in the flood plain rice, maize and sorghum are grown.
- **Region 3:** this includes the north and north-western plateaux characterized by high rainfall, 1,000 to 1,500 mm. The soils are mostly Haplic Acrisols which are highly leached and acidic. Traditional farming systems are based on slash and burn. The main crops are finger millet (*Eleusine coracana*) beans and cassava. Cash crops include maize, sunflower, coffee, tea, tobacco, irrigated wheat and soybeans.

Based on soil type the following agricultural systems are observed according to Chomba (2004):

(i) Semi-permanent hoe and ox plough. This is prevalent in Region II (Zone II) where (See **Figure 14**) the dominant crops are finger millet, maize, cassava, groundnuts and beans. Livestock have been the major source of draught though this has declined recently due to disease and drought. Soil structure is generally good though the long use of the same pieces of land results in soil exhaustion. Farmers cannot counteract soil acidification due to unavailability of lime, or where lime is available, they lack knowledge or they cannot afford to buy it.

(ii) Semi-commercial hoe and ox plough. Farmers in this category are mainly in region II (See **Figure 14**). The dominant crops are maize, groundnuts, cotton and beans. Livestock is a major asset. Farmers in this category have been dependent on fertilizer at the expense of other practices aimed at improving soil quality, and

(iii) Commercial farming. This is characterized by well-developed agronomic management and intensive usage of mechanized farm equipment. Farmers in this system tend to mitigate the effects of soil acidification by liming.

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