



**NATIONAL OPEN UNIVERSITY OF NIGERIA**

**SCHOOL SCIENCE AND TECHNOLOGY**

**COURSE CODE:SLM 201**

**COURSE TITLE:PRINCIPLES OF SOIL SCIENCE**



**SLM 201  
PRINCIPLES OF SOIL SCIENCE**

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Published by  
National Open University of Nigeria

Printed 2009

ISBN: 978-058-163-4

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### **Introduction**

This course – principles of soil science - is meant to provide essential information for those who want to acquire knowledge about soils and how to use and manage them. Going through this course would afford the student to become familiar with soils as natural units or entities and with their inherent characteristics.

Second, it will develop in the student an understanding of the significance of fundamental soil properties; third, to set forth basic relationships between soils and plants; and fourthly to give the student an understanding of the principles involved in the use of proved soil-management practices. General principles of soil science are emphasized and explained in unambiguous terms while most of the technical detailed are retained for students pursuing soil science at higher levels.

This course material is essential for students in university on Bachelor of Agriculture (B. Agric) and technology programmes, agronomists, foresters, farmers and other users of soils. Principles of soil science course is principally meant for the lower levels of Bachelor of Agricultural programmes in the University, but equally useful as a reference source for other scholars and soil user. It covers those topics of soil science which directly and critically affect nutrition and growth of field crops.

The course is divided into four main modules. Module one deals with some fundamental soil concepts such as the definition of soil, origin and development of soils, uses of soils in general and soil forming factors.

Module two deals with soil physical properties and interactions, soil types and their implications to agriculture. Subsequent modules deal with components of soil fertility including factors controlling soil

fertility such as soil organic matter, soil reaction, soil aeration soil colloids and cation exchange capacity, essential soil nutrients for crop growth, fertilizer and manures including their management. Students are also taken through some fundamental principles of soil and plant analysis as diagnostic tool for detecting nutrient sufficiency and deficiency on field crops. The concluding module contains some briefs on improvement and maintenance of soil fertility to sustain present crop yield and preserve the soil for future use.

## The Course

As a 2-credit unit course, 20 study units grouped into 4 modules (of 5 units each) have been prepared as the course material. Let me say here that a good agronomist must be knowledgeable about the soil in which crops are grown while a good soil scientist must be well groomed in the agronomy of crops. “Principles of soil science” adequately meets the needs of these two groups of scientists and more.

This course guide gives a brief summary of the total contents contained in the course material. Principles of soil science provides a current and comprehensive introduction to soil science for students in the fields of environmental and agricultural science, ecology, geology, soil and land management, natural resources management and environmental engineering.

The course is structured around twenty basic soil concepts, beginning with the meaning of soil and its systematic study (soil science). This is followed by discussing the significance of soil in our everyday lives and progressing through soil formation, physical and chemical properties of soil, soil-plant interactions and what roles should man play in managing soil-environment interactions for sustainable productivity now and in the future. In short, the course covers.

- all aspects of soil science including soil habitat such as the mineral component of the soil, soil origin and development, fundamental concepts of soil physics, soil classification and survey and a run-down of plant requirements for growth.

- Processes in the soil environment such as soil aeration and temperature and their effects on the availability of plant nutrition, organic matter and soil organisms, soil reaction, soil colloidal materials and their exchange reactions with ionic elements.

- Soil-plant nutrients interactions including fertilizers and essential nutrient elements (their availability and nutrition in plants).

Soil and plant analysis and management to cover areas of maintenance of soil productivity, problem soils, hazards of soil use and management of the soil resource.

### Course Aims

The aim of this course is to make students understand the nature and uses of soil in natural and modified environments. The course provides information on soils as natural units or entities with their inherent characteristics, provides an understanding of significance fundamental soil properties, provides information on basic soil-plant relationships and the available soil-management practices.

### Course Objectives

In addition to the aims this course hopes to achieve some objectives. That is, after going through this course, you should be able to:

State clearly the nature of the parent materials from which soils are formed, the soil-forming factors and processes soil classification and survey.

List those parameters used for soil classification.

State clearly, soil reaction and its effects on plant growth, Explain briefly the application of lime to ameliorate acid soils and the role of organic matter in soil productivity.

Identify the individual roles of essential nutrient elements in plant growth and the need to use fertilizer amendments.

Enumerate the principles and practices of soil testing and plant analysis as a tool for profitable crop production.

Identify the many ways of maintaining soil productivity and even making problems soils productive.

### Working through the Course

This course involves that you would be required to spend lot of time to read. The content of this material is very dense and requires you spending great time to study it. This accounts for the great effort put into its development in the attempt to make it very readable and comprehensible. Nevertheless, the effort required of you is still tremendous. I advise that you avail yourself the opportunity of attending the tutorial sessions where you would have the opportunity of comparing knowledge with your peers.

## The Course Material

You will be provided with the following materials:

Course guide

Study units.

In addition, the course comes with a list of recommended textbooks, which though are not compulsory for you to acquire or indeed read, are necessary as supplements to the course material.

## Study Units

The following are the study units contained in this course. The units are arranged into four identifiable but related modules.

### **Module 1    The Soil Habitat**

#### **Unit 1        Some Basic Concepts of Soil**

This unit takes you through the definitions of some soil basic terminologies, composition of the soil and its importance to man.

#### **Unit 2        Origin and Development of Soil (Soil Genesis)**

The second unit of this course deals with different types of rock which serve as parent materials from which soils are formed. You will also learn about the different factors and processes that form soil and give the soil its different characteristics.

#### **Unit 3        Fundamental Concepts of Soil Physics**

This unit serves to acquaint the student with the physical nature of different soils such as types and stability of aggregates, compaction and porosity.

#### Unit 4          Soil Classification and Survey

You will be exposed to those observable and reasonable characteristics used for soil classification. Similarly, land survey as prerequisite to classification will be explained.

#### Unit 5          Plant Growth Requirements

This unit caps module one of this course. You will be exposed to the factors that contribute to the growth and general performance of field crops including the concept of “principle of limiting factor” in crop production.

### **Module 2      Processes in the Soil Environment**

#### Unit 1          Water in the Soil-Plant System

This unit discusses the gains and losses of water in the soil-plant system, effect of well-and poorly-drained soils and the management of soil water for efficient use by crops.

#### Unit 2          Soil Aeration and Temperature

You will learn about how redox potential (i.e. oxidation – reduction potential) in soil affects availability of plant nutrients and that plants thrive well under optimum soil temperatures.

#### Unit 3          Soil Organic Matter and Soil Organisms

In Module 2 unit 3, you will learn about the importance of maintaining organic matter especially in Nigerian agriculture, the reasons for low organic matter content in our soils and the roles played by organisms in the transformation of soil organic matter.

#### Unit 4          Soil Reaction: Acidity and Alkalinity

You will learn in this unit soil acidity and conditions that make soils acidic, conditions in acid soils which are beneficial or detrimental to the growth of plants, effects on plants of neutral and alkaline soils and lime and liming practices.

#### Unit 5          Soil Colloids and Ion Exchange in Soils

This unit exposes you to one of the most important interactions between the solid phase and the solution phase of the soil. Cation exchange



reactions and cation exchange capacity as peculiar to each soil type have implications in plant nutrition.

### **Module 3 Soil-Plant Nutrients Interaction**

#### **Unit 1 Fertilizers as Agricultural Input**

In unit 1, different types of fertilizer materials, fertilizer formulations and economic use of fertilizers are discussed with practical example in contemporary Nigerian agriculture. You will also learn about fertilizer specifications and calculations.

#### **Unit 2 Nitrogen as Plant Nutrient**

As the most important and most limiting nutrient element throughout the world particularly in the tropics, this unit describes the various forms and functions of nitrogen in plants, nitrogen-cycle, inputs and losses of nitrogen to the soil-plant system and the factors that affect these N-transformations in the soil-plant ecosystem. You will also be able to detect N-deficient symptoms in crops.

#### **Unit 3 Phosphorus Nutrition in Plants**

Like unit 2, this unit will enable you to be conversant with forms and functions of phosphorus in soil and plants, the peculiar characteristic problem of p-recovery especially in acid and alkaline soils, the various indices of phosphorus availability and the detection of p-deficiency syndromes in field crops.

#### **Unit 4 Potassium Nutrition in Plants**

As the third most limiting major plant nutrient element, potassium demand by crops especially root crops is high. You should learn about potassium cycling problems both in agricultural and forestry systems.

#### **Unit 5 Sulphur, Calcium and Magnesium**

You will know in this unit that though sulphur (S), calcium (Ca) and magnesium (Mg) are referred to as secondary nutrients, they must be supplied from fertilizer sources for optimum crop performance. There are factors affecting their functions in crops and availability in soils.

### **Module 4 Soil Fertility Evaluation and Management**

This unit offers have a good knowledge of the different methods of evaluating the fertility status of a piece of cropland. It also enables you to differentiate between soil analysis and soil testing. You will also learn the procedures in carrying out soil testing programmes.

#### Unit 1            Micronutrients Elements

This unit will describes the general characteristics common to all micronutrients, the effect of soil factors on their deficiency and toxicity in soils and their specific functions in agricultural and forestry crops.

#### Unit 2            Soil Analysis and Soil Testing

This is Unit offer a good knowledge of the different methods of evaluating the fertility status of a piece of crop land. It also enables you to differentiate between soil analysis and soil testing. You will also learn the procedures of carrying out soil testing programmes

#### Unit 3            Principles and Practice of Plant Analysis

This unit explains the techniques of using plant analysis as a diagnostic tool for detecting nutrient deficient symptoms in crops as well as a reliable guide in making fertilizer recommendation to crop farmers. This unit also includes growth response terminologies and the general limitations of using plant analysis to make predictions on crop response to nutrient supply.

#### Unit 4            Soil Salinity and Alkalinity

This unit exposes you to the causes and effect of salinity, sodicity and alkalinity. Compared to the easy control of nutrient deficiencies, salt-related constraints are more costly to remedy. Management of salt-related factors limiting plant growth will be described.

#### Unit 5            Soil and Water Conservation

You will be able to discuss land clearing, land tillage, agronomic and cultural farming practices in your locality that help to conserve soil and water on crop farms. How do we avert pollution in the biosphere and atmospheric environment? The Federal, State, Local Governments and individuals have roles to play here.            Good luck!

### **Text Books and References**

More recent editions of these books are recommended for further reading.

- Brandy, N.C. and Weil, R.R. (1999). *The Nature and Properties of Soils*. 12<sup>th</sup> ed. New Jersey: Prentice-Hall.
- Donahue, R.L., Miller, R.W. and Chickluna, J.C. (1990). *Soils, An Introduction to Soils and Plant Growth*. 5<sup>th</sup> ed. New Delhi: Prentice-Hall of India Private Limited.
- Russell, E.W. (1980). *Soil Conditions and Plant Growth*. 10<sup>th</sup> edition, London: Longman.
- Tisdale, S.L. and Nelson, W.L. (1976). *Soil Fertility and Fertilizers*. New York: Macmillan.
- Webster, C.C. and Wilson, P.N. (1980). *Agriculture in the Tropics*. 2<sup>nd</sup> Ed. Longman.
- Millar, C.E. and Turk, L.M. (2002). *Fundamentals of Soil Science*. New Delhi: Biotech Books.
- Singer, M.J. and Munns D.N. (1999). *Soils: An Introduction*. 4<sup>th</sup> Edition. New Jersey: Prentice Hall.

## **Assessment**

There are two components of assessment for this course. The Tutor-Marked Assignment (TMA) and the end of course examination.

## **Tutor-Marked Assignment**

The TMA is the continuous assessment component of your course. It accounts for 30% of the total score. You will be given 4 TMA'S to answer. Three of these must be answered before you are allowed to sit for the end of course examination. The TMA's would be given to you by your facilitator and returned after you have done the assignment.

## **Final Examination and Grading**

This examination concludes the assessment for the course. It constitutes 70% of the whole course. You will be informed of the time for the examination. It may or nor coincide with the university semester examination.

## **Summary**

This course intends to provide you with underlying basic knowledge of soil science, physical and chemical reactions in soil and how they affect the growth of plants. By the time you complete studying this course, you will be able to answer the following type of questions.

Define these terms: **Soil individual, soil genesis, parent material, soil science and soil horizon.**

Describe four processes that commonly lead to degradation of soil quality.

What is an essential element? What determines whether an element is essential?

What are soil environmental factors that most strongly hinder crop production in your area? What should be your role in combating those factors?

Why should we maintain high quantity of organic matter in Nigerian agricultural soils? How?

Explain how a soil formed from basic parent material could become acidic.

Explain why there is rapid decomposition of organic material in tropical soils. Compared to cold climatic regions.

What are the major roles of soil cation exchange capacity in environmental quality maintenance?

Give three major advantages of organic and inorganic fertilizers over each other.

What are the natural sources of Nitrogen? How will you rate the importance of natural and artificial sources of nitrogen in Nigerian agriculture?

A farmer has just contacted you to complain lack of response of his maize to phosphorus rates. How would you go about helping him?

We wish you success as you go through this course. In particular, we hope you will appreciate how the whole human race depends on soil and why we should play our important roles in preserving this non-renewable resource for our present use and for the future generations.

We hope you enjoy the course.

Best wishes.

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Published by  
National Open University of Nigeria

Printed 2009

ISBN: 978-058-163-4

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## **MODULE 1      THE SOIL HABITAT**

Unit 1	Some Basic Concepts of Soil
Unit 2	Origin and Development of Soil (Soil Genesis)
Unit 3	Fundamental Concepts of Soil Physics
Unit 4	Soil Classification and Survey
Unit 5	Plant Growth Requirement

### **UNIT 1      SOME BASIC CONCEPTS OF SOIL**

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#### **1.0      INTRODUCTION**

Soil is composed mainly of mineral particles, organic matter, organisms, airpores and water all of which relate to one another and with plants and microbes to form an ecosystem. The soil, as the upper layer of the earth's surface, supports the entire human race for food, fibre, water, building materials construction sites and waste disposal.

Soil science deals with the systematic study of soils as a non-renewable (or very slowly renewable) resource which should be judiciously managed so that it could serve our generation and future generations. This unit is a logical starting point for the whole course of **Principles of Soil Science** as the unit deals with important concepts basic to the understanding of soil, its composition and the various uses the soil could be put.

## 2.0 OBJECTIVES

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

- define soils and what soil science entails
- write briefly on soil as a lifeline of human population – state the nature and uses of soil in natural and modified environment
- list and briefly explain some basic terminologies commonly used in the study of soil science
- state clearly the interplay of the various components of soil.

## 3.0 MAIN CONTENT

### 3.1 Definition of Soil

**The Soil** is the upper layer of the earth's surface. The soil is highly variable from one location to another on the earth. That is, **the soil** comprises individual **soils** which are natural bodies of different characteristics and behaviours. It is a dynamic natural body composed of mineral and organic materials and living organisms in which plants grow.

A soil or an individual soil has three dimensions (Length, Width, and Height) just like a body of water. A soil occupies a small three – dimensional part of the land surface. The water or a soil can be sampled and analyzed in the laboratory.

Each soil has specific properties, qualities and characteristics. It is usually recognized in the field and indicated on a soil map. Such a soil map contains several soils with different names and classes according to the system of taxonomy and classification adopted by the particular country. Soils are usually examined by describing soil pits or soil profiles using uniform definitions, terminology and nomenclature.

During the early development of soil science, the concept of soil differs among investigators with different disciplines or background.

Chemist considered soils as the storehouse of chemical compounds.

Geologists on their own part hold a restricted rock weathering concept. They consider soils as a disintegrated and more or less decomposed rock material mixed perhaps with organic matter from plant decay.

Engineers define soils as any unconsolidated material regardless of depth or mode of formation. To a highway engineer, the soil is regarded as a material on which a road bed is to be placed.

However, the most used concept of soil is the agronomic view. Soil is defined as the natural medium for the growth of land plants whether or not it has identifiable soil horizons. This old meaning is still the common meaning. Thus this book will adopt this consensual concept as our framework.

Although there are many uses of soil, the people of the world are more concerned with food because it supports plants that supply food, fibres, drugs and other wants of man.

Soil covers land as a continuum, except on large rock, in areas of perpetual frost, or on the bare ice of glaciers. In this sense, soil has a thickness that is determined by depth of plant roots.

### **3.2 What is Soil Science?**

Soil science deals with the systematic study of soils as a natural resource on the surface of the earth including soil formation, classification and mapping. Additionally it includes the physical, chemical, biological and fertility properties of soils as well as the properties in relation to their management for crop production. Knowledge of soils in the tropics and sub-tropics is increasing but far behind the soils of temperate regions. Tropical soil science emphasizes the demand for special knowledge and experience with tropical soils which are quite different in properties, qualities, characteristics and management from soils of temperate regions.

Two major forces have stimulated the rise and development of soil science as a discipline. The first driving force is the use and relevance of soil to human societies. Soils are very crucial to life and therefore its study cannot be ignored. The second force is the quest after abstract knowledge to discover the laws of nature.

Soil science deals with the examination, description and mapping of the different soils which occur in a country or district. Soil survey is fundamental to land evaluation or land use planning. It is very practical. Land resources, survey or soil survey supply the information needed for the identification of areas for development based on quantity of the land. Soil Scientists usually investigate the biological, chemical, physical and mineralogical properties of soils which are then grouped and classified. The increased knowledge of soils had led to changes of approaches to the study of soils with emphasis on quality and capacity to support plant ecosystem, animal life and human society. Knowledge of soils have been applied in solving practical problems especially in crop production and land use planning.

As each soil possesses specific biological, chemical, physical and mineralogical properties, soil scientists also specialize in dealing with particular branches of soil science such as pedology (soil genesis and classification), soil physics, soil chemistry, soil biology, soil fertility and plant nutrition, soil survey, soil technology and soil mineralogy. A team of soil scientists work together in soil Research Institutes and University Departments bearing in mind that real soils are in the field, and that soils are as indispensable medium to grow food for people and animals and to support natural vegetation. In summary, the need for the study of soil science by the forester, farmers, engineers, ecologists and natural resource managers is very essential to our everyday life

### **3.3 Approaches to the Study of the Soil**

Study of the soil is generally divided into two parts:

- Field study
- Laboratory study.

#### **Field Study**

A description (quantitative and qualitative) of the soil is best done in the field in its natural environment. Laboratory analysis entails much disturbance of soil properties. Some of the properties are actually lost in the process of transferring soils from the field to the laboratory. For instance, the moisture content and colour distribution where mottling exists. One unique feature with soil study in the field is that soil is studied as a component of the land. In essence, apart from describing the soil itself, the immediate environment may be fully described. This is to say that at any point of soil description, the characteristics of the site must be fully described. Such characteristics include:

- The climate of the locality
- The nature of the parent materials
- The mass and character of the vegetation
- The relief of the locality
- The age of the landscape.

The site of study must be precisely recorded so that future references and relationship with the environment can be correctly made.

#### **The Laboratory Study**

The laboratory study of the soil are chemical and mineralogical. In such studies considerable damage is done to the soil in as much as field characteristics are badly disturbed.

Morphological studies however strive to present the soil as it is; sometime, trying to study the finer aspects or characteristics of the soil.

In soil survey and land evaluation studies, much attention is paid to the field studies.

### 3.4 Concept of Soil Morphology

More recently, soil has come to be recognized as a 3 – dimensional body having length, depth as well as breadth. This has given rise to the concept of pedon. The term **pedon** is used to describe the smallest 3-dimensional body of soil with lateral dimensions large enough to permit the study of the nature and arrangement of horizons and variability in other properties that are preserved in samples.

The pedon is considered to be smallest volume which satisfactorily represents a soil. Thus it can be compared to a unit cell of a crystal but too small to appear as a **mapping unit**. So in general, it is normally considered as a **sampling unit**. The area of the pedon ranges from 1 – 10m<sup>2</sup> depending on the variability in the soil. Its lower limit is somewhat vague. It is taken as the limit between the soil and “not-soil” below. The lateral dimension (width) is large enough to represent the nature of any horizon.

### 3.5 The Soil Individual or Polypedon

Modern soil science makes use of the concept of **polypedon** which is the smallest distinctive division of the soil of a given area. The individuals being mapped are the polypedon or what some prefer to call **soil individuals**. They consist of one or more similar pedons bounded on all sides by ‘not soils’ or by pedons of unlike character in respect to one or more characteristics diagnostic for a soil series. Characteristics here refer to the nature and arrangement of **horizons** if horizons are present. By nature of horizons we mean composition including mineralogy, structure, consistence, texture, moisture regime, etc. A polypedon has a minimum area greater than 1m<sup>2</sup> and an unspecified maximum area. It has some characteristics such as shape, transitional margins and natural boundaries that are not possessed by any one of its component pedons. The soil individuals or polypedons are the real objects that pedologists classify hence it is called a unit of classification.

### 3.6 Composition of Soils

Soils comprise a mixture of inorganic and organic components: Minerals, air, water, and plant and animal material. Mineral and organic particles generally compose roughly 50 percent of a soil's volume. The other 50 percent consists of pores – open areas of various shapes and sizes. Networks of pores hold water within the soil and also provide a means of water transport. Oxygen and other gases move through pore spaces in soil. Pores also serve as passageways for small animals and provide room for the growth of plant roots.

### **Inorganic Material**

The mineral component of soil is made up of an arrangement of particles that are less than 2.0mm in diameter. Soil scientists divide soil particles also known as soil separates, into three main size groups: sand, silt, and clay. According to the classification scheme used by United States Department of Agriculture (USDA), the size designations are: sand, 0.05 to 2.00mm; silt 0.002 to 0.05mm and clay, less than 0.002mm. Depending upon the rock materials from which they were derived, these assorted mineral particles ultimately release the chemicals on which plants depend for survival, such as potassium, calcium, magnesium, phosphorus, sulfur, iron, and manganese.

### **Organic Material**

Organic materials constitute another essential component of soils. Some of this material comes from the residue of plants – for example, the remains of plant roots deep within the soil, or materials that fall on the ground, such as leaves on a forest floor. These materials become part of a cycle of decomposition and decay, a cycle that provides important nutrients to the soil. In general, soil fertility depends on a high content of organic materials.

Even a small area of soil holds a universe of living things, ranging in size from the fairly large to the microscopic: earthworms, mites, millipedes, centipedes, grubs, termites, lice, springtails, and more. And even a gram of soil might contain as many as a billion microbes – bacteria and fungi too small to be seen with the naked eye. All these living things form a complex chain: Larger creatures eat organic debris and excrete waste into the soil, predators consume living prey, and microbes feed on the bodies of dead animals. Bacteria and fungi, in particular, digest complex organic compounds that up living matter and reduce them to simpler compounds that plants can use for food. A typical example of bacterial action is the formation of ammonia from nitrogen compounds called nitrites, and still other bacteria act on the nitrites to form nitrates, another type of nitrogen compound that can be

used by plants. Some types of bacteria are able to fix, or extract, nitrogen directly from their and make it available in the soil.

Ultimately, the decay of plant and animal material results in the formation of a dark- colored organic matter known as humus. Humus, unlike plant residues, is generally resistant to further decomposition.

### **Water**

Soil scientists also characterize soils according to how effectively they retain transport water. Once water enters the soil from rain or irrigation, gravity comes into play causing water to trickle downward. Water is also taken up in great quantities by the roots of plants: Plants use anywhere from 200 to 1,000kg of water in the formation of 1kg of dry matter. Soils differ in their capacity to retain moisture against the pull exerted by gravity and by plant roots. Coarse soils, such as those consisting mostly of sand, tend to hold less water than do soils with finer textures, such as those with a greater proportion of clays.

Water also moves through soil pores independently of gravity. This movement can occur via capillary action, in which water molecules move because they are more attracted to the pore walls than to one another. Such movement tends to occur from wetter to drier areas of the soil. The movement from soil to plant roots can also depend on how tightly water molecules are bound to soil particles. The attraction of water molecules to other is an example of cohesion. The attraction of water molecules to other materials, such as soil or plant roots, is a type of adhesion. These effects, which determine the so-called metric potential of the soil, depend largely on the size and arrangement of the soil particles. Another factor that can affect water movement is referred to as the osmotic potential. The osmotic potential hinges on the amount of dissolved salts in the soil. Soils high in soluble salt tend to reduce uptake of water by plant roots and seeds. The sum of the metric and osmotic potentials is called the total water potential.

### **Air**

In soil, water carries out the essential function of bringing mineral nutrients to plants. But the balance between water and air in the soil can be delicate. An overabundance of water will saturate the soil and fill pore spaces needed for the transport of oxygen. The resulting oxygen deficiency can kill plants. Fertile soils permit an exchange between plants and the atmosphere, as oxygen diffuses into the soil and is used by roots for respiration. In turn, the resulting carbon dioxide diffuses through pore spaces and returns to the atmosphere. This exchange is most efficient in soils with a high degree of porosity. For farmers,

gardeners, landscapers, and others with a professional interest in soil health, the process of aeration – making holes in the soil surface to permit the exchange of air-is a crucial activity. The burrowing of earthworms and other soil inhabitants provides a natural and beneficial form of aeration.

### **3.7 Uses of Soils**

Man was created from the dust (soil) and from that creation man had depended on soil for prosperity and survival. To a certain degree good soils are also dependent upon people and the use they make of soils. Human society enjoys and uses the plants that grow on the soils for the supply of food and much of our fibre. Most of the clothing materials, medicines, drugs and animals needed for man's survival come from plants and soil organisms. Standard of living is often determined by the quality of soils and the kinds of plants and animals prevalent in the area.

In addition to its importance as habitat for growing crops, the soil is useful to human societies as:

Solid and good foundation material for building roads and highways and also exerting strong influence on the life span of these structures. The engineering uses of soil demand knowledge of the diversities of soil properties which vary from one location to another.

The foundations of houses and factories thus determining whether the foundations are adequate. Soil is an important building material in form of earth fill and baked bricks.

Absorbing medium to domestic wastes through septic sewage system and other wastes from industrial, municipal and animal sources.

For making pots, jugs, plates and other household usable structures.

Growth medium for plant by supplying water, air and mechanical support for plant roots as well as heat to enhance chemical reactions.

Major supplier of plant nutrients that are essential for plant growth. These nutrients are slowly released from unavailable forms in the solid framework of minerals and organic matter to exchangeable sites associated with soil colloids and finally to readily available ions in the soil solution. The nature of



vegetation and types of animals on a land is dictated by the properties of the soil.

Habitat for several living organisms including micro-organisms, reptiles and even mammals, which in turn help in improving soil structure and fertility.

#### **4.0 CONCLUSION**

Though the definition of soil depends on the users such as farmers, engineers, foresters, geologists or the environmentalists, soil universally could be defined as the unconsolidated, thin and variable layer of the earth's surface that supports land plants, serves as foundation for buildings and as sites for waste disposal.

The systematic study of the soil enables use to know the chemical, physical and biological properties of the soil and the uses for which the soil could be put.

#### **5.0 SUMMARY**

In this unit we have learnt that:

The variability of the soil confers different capabilities for different uses;

There is the need to study the different aspects of soil by foresters, farmers, engineers, pedologists, chemists and a host of others.

Both field and laboratory studies of soil to complement each other in the acquisition of thorough knowledge of soil characteristics.

The smallest unit of the soil is the pedon while polypedon or soil individual is made up of two or more pedons of similar properties.

Soils comprise a mixture of inorganic materials (mineral component), organic materials, air and water in varying proportions depending on soil type.

Man's existence on earth depends on the soil which supports the growth of plants needed for food, fibre, medicine, clothing and drugs.

#### **6.0 TUTOR-MARKED ASSIGNMENT**

Define these terms soil science, soil individual, polydon, horizons, and soil morphology.

- 2.a. What are the five main roles of soil in an ecosystem?  
Comment on the statement that “soil is better studied in the field than in the laboratory”.

## **7.0 REFERENCES/FURTHER READINGS**

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## UNIT 2    **ORIGIN AND DEVELOPMENT OF SOIL (SOIL GENESIS)**

### CONTENTS

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Importance of the Knowledge of Soil Genesis
  - 3.2 Types of Rocks
  - 3.3 Factors of Soil Formation
  - 3.4 Processes of Oil Formation
  - 3.5 Physical Weathering
  - 3.6 Chemical Weathering
  - 3.7 Essential Characteristics of Soils
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### 1.0 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 material**. 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.

### 2.0 OBJECTIVES

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

- enumerate the benefits derivable from the knowledge of soil origin
- describe the individual roles of soil forming factors and their interrelationships
- outline the processes (physical and chemical) involved in soil formation
- define with good examples soil characteristics.

### 3.0 MAIN CONTENT

#### 3.1 Importance of the Knowledge of Soil Origin and Development

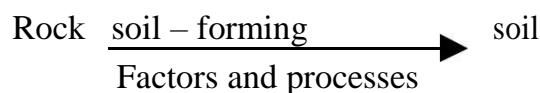
In everyday language, **Soil genesis** is the study of the history of the soil. i.e. what has been going on in the soil that gave it the properties which it possesses today.

As we understand the history of our soils and about their properties, we are able to make wise and better decisions concerning their use and management. Bearing this in mind, the reasons behind the quest for soil genesis include:

- To help us point out some of the properties of our soils.
- To help us point out some of the things we do not understand about the soils.
- To be able to formulate law governing soils behaviour
- To help us provide adequate method for management of our soils and make better interpretative usage.

#### 3.2 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 of processes and factors act on rock to produce soil.



Rocks are **residual** or in-place parent material that weathers 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 2. 1: Major Rock Types, their Origin and Properties**

(Source: Singer and Munns, 1999)

Rock type	Origin	Example	Properties
Igneous	Cooling of magma	Granite Basalt	Light colour coarse grained. Dark colour fine grained
Sedimentary	Deposition and	Shale Sandstone	Any colour, fined grained. Any colour,

	compaction	Limestone	coarse grained Light coloured, shells or CaCO <sub>3</sub> present
Metamorphic	Change in igneous or sedimentary	Slate or Marble	Any colour, hardened shale. Any colour, changed limestone

**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, while 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.

Generally, 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:

**Granite:** which consists mainly of quartz, silica (SiO<sub>2</sub>), feldspar, and mica (muscovite and biotite).

**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.

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

#### **Arenaceous**

Mainly sandstone which originates from mostly sandsized sediments.

#### **Argillaceous**

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

#### **Calcareous**

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

### **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 high water-holding capacity and example coal of different kinds.

### **Siliceous Rocks**

Flint-compact form of silica.

### **Metamorphic Rocks**

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

## **3.3 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 separate 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:

- Climate
- Organisms (vegetation and Fauna)
- Relief (shape of the land surface)
- Parent material
- 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 are conditioned by relief over a period of time. The ability to predict soil characteristics and 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 soil forming factors and soil properties. In considering 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:

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

Where S = the total effect of all the factors

F = function of 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.

Rainfall (precipitation)

Temperature

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:

Weathering of parent material  
 transportation of parent material  
 pedogenesis  
 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 whether leaching occurs in the soil. It affects plant growth and vegetation and hence the content of soils. Rainfall distribution in space and time results in climate periodicity in certain localities that tremendously influence the processes of pedogenesis; for example; the alternation of wet season with dry season is important in Nigeria. 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.

### **Living 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, crewfisa, 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 trausas. It provides the very essential component of soil, the organic matter. It 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. Also, structural stability tends to be encouraged by the forest vegetation here in Nigeria. Climate determines the types of vegetation and the type of soil. The soil determines the types of vegetation which also influences the trends 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:



Water relation  
Erosion  
Temperature  
Vegetation

**Topography**, or **relief** is commonly considered to be a 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.

#### **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, in situ.

#### **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. 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 of thousand or a million years to form.

### 3.4 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.

### 3.5 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.

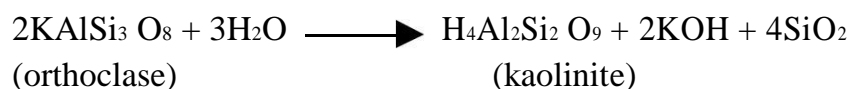
### 3.6 Chemical Weathering

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:

#### Hydrolysis

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

#### Orthoclase:



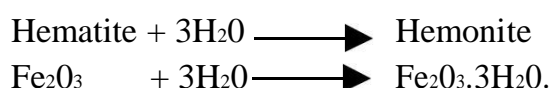
In the presence of  $\text{CO}_2$ ,  $\text{K}_2\text{CO}_3$  will be formed instead of  $\text{KOH}$  in the equation. That is, the process of hydrolysis usually results in the formation of compounds different from the parent material.

#### Solution

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

## Hydration

In this case, water molecules are being added to a mineral's structure but the water molecule does not dissociate. Significantly, the rock swells when water molecules get inside it making it very susceptible to the activity of other weathering processes. For example, Hematite, 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.

## Oxidation Reduction

Oxidation – reduction reactions are very important in minerals that have  $\text{Fe}_{2+}$  such as biotite mica. Depending on the environment, various compounds can be formed in oxidative processes. For instance the oxidation of  $\text{Fe}_{2+}$  to  $\text{Fe}_{3+}$  will strain the crystal and results in further weathering of the mineral. The formation of mottles is as a result of reduction of iron (fe) and manganese ( $\text{CO}_2$ ) in soil.

## Carbonation

Carbondioxide ( $\text{CO}_2$ ) may combine with water to dissolve marble, or it may combine with other compounds to form carbonate precipitates.

### 3.7 Essential Characteristics of Soils

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.

#### 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 soils. 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.

## 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.

□

□

□

### 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: platelike, in which the aggregates are flat and mostly horizontal; prislake, meaning greater in vertical than in horizontal dimension; and blocklike, 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 10 mm. 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.

## 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 make it possible for calcium and the other elements to be changed into water- soluble forms that plants can use for food. Therefore, a soil's cation exchange capacity is an important measure of its fertility.

## **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.

## **4.0 CONCLUSION**

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 results from the different combinations of factors and processes.

## **5.0SUMMARY**

In this unit, we have learnt that:

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.

## **6.0TUTOR-MARKED ASSIGNMENT**

Give examples of situations in which each of climate, parent material and topography is the dominant soil forming factor.

What are the differences between physical and chemical weathering products?

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## **UNIT 3     PHYSICAL PROPERTIES OF SOILS**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Soil Physical Properties
  - 3.2 Soil Texture and Textural Composition
  - 3.3 Soil Structure and Aggregates
  - 3.4 Soil Consistence
  - 3.5 Soil Composition
  - 3.6 Porosity and Pore Spaces
  - 3.7 Soil Density and Permeability
  - 3.8 Soil Tilth
  - 3.9 Soil Colour
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

As you learnt in unit 1 of this course, 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 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.

### **2.0 OBJECTIVES**

After studying 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.

### 3.0 MAIN CONTENT

#### 3.1 Soil Physical Properties

#### 3.2 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 3.1: Size Limits of Soil Separates in the USDA and ISSS Schemes.**

USDA Scheme		ISSS Scheme	
Name of separate	Diameter Range ( $\mu\text{m}$ )	Name of separate	Diameter Range ( $\mu\text{m}$ )
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 Cobbles Stones	Coarse fragments 2000-7500 $\mu\text{m}$ (2-75mm) 75000 - 254000 $\mu\text{m}$ (75 – 254 mm) > 254000 $\mu\text{m}$ (> 254mm)		

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



## Definition of Soil Texture Classes

Apart from the modification of sandy 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, loam, loam, silt, loam, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay and clay.

The basic soil textural class names, in use presently, 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 **Gravometric Analysis**. The percentage of size fractions combined to determine the texture using a standard soil textural triangle as shown in Fig.3.1.

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 silt 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.

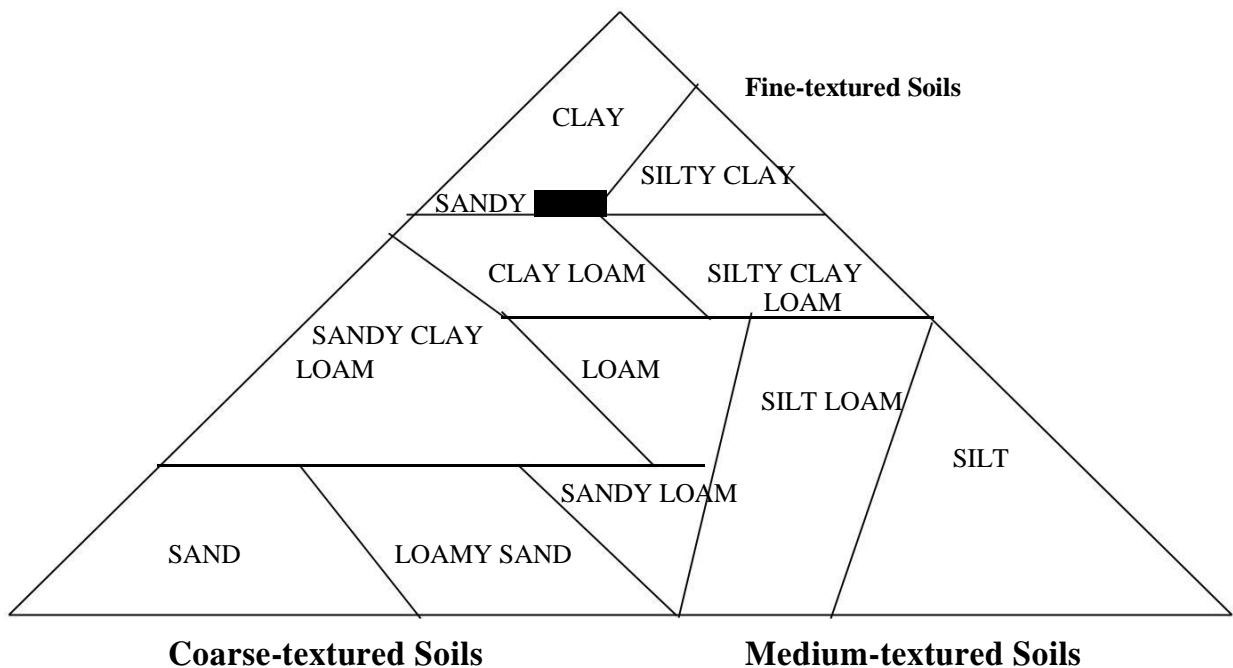
**Sandy Clay**- Soil material that contains 35% or more clay and 45% or more sand.

**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 a knowledge 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 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 difficult to manage, while the loams are in between the two extremes.



**Figure 3.1:** The soil triangle is drawn 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 because:

the rate at which water enters the soil (**infiltration**) and drains through (percolation) depends on whether it is sandy, silt or clay soil.

the 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.

soil texture influences the ease at which a soil can be worked; clay soils are more difficult than sandy soils.

the knowledge of soil texture and crop requirement of soil enable the grower to select suitable soils/land for his crop.

growers would be able to know management practices suitable for the soil types especially in terms of fertilization, irrigation and organic materials incorporation.

### 3.2 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:

**Type** which refers to the shape of the soil aggregate e.g. granular, platy, crumb, etc.

**Class** refers to the size of the peds e.g. fine, medium, coarse, etc.

**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 or structureless terms are used for grade. A structureless condition exist when there is no observable degree of aggregation.

Thus, the full description of the structure of a given 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 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 macrospore 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:

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

Colloidal oxides of iron, aluminium and manganese, which are collectively termed sesquioxides. These are especially typical of tropical soils.

Microbial gums; which are gums secreted by micro-organisms in soils.

Organic compounds, especially humus which are also colloidal in nature.

Carbonates.

**Table 3.2: Diagrammatic Definition and Location of Various Type of Soil Structure**

<b>Structure Type</b>	<b>Aggregate Description</b>	<b>Diagrammatic Aggregate</b>	<b>Common Horizon Location</b>
Grangular	Relatively nonporous, 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		Bt horizon

	rounded caps. Other prismatic aggregates form the cast for the ped. Some prismatic aggregates break into smaller blocky
Columnar	Columnlike peds with Bt horizon rounded caps bounded laterally by other columnar aggregates that form the cast for the peds

Adapted from Soils Laboratory Exercise Source Book, Am. Soc. of Agron, 1964.

Source: Ivera Esu, 1999.

### 3.3 Soil Consistence

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

The terms used to describe consistence include:

**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.

**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.

**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 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 (organic) in the B-horizon may indicate the occurrence of a spodic horizon and the onset of the process of podzolization in a soil.

### 3.4 Soil Compaction

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

- Overburden weight of material above the soil.
- Implement traffic from mechanized agriculture
- Foot traffic
- Tillage pressure due to implement moved through the soil
- 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**.

### 3.5 Porosity and Pore Spaces

Pores are spaces or voids between solid soil materials. The occurrence or abundance of pores in soils are of pedological 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 (impede, exped).

The pores allow the soil to act as medium for air and 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

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

Where  $V_s$  is the total volume of soil  
 $V_b$  is the volume of solids

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

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.

### 3.6 Soil Density and Permeability

The density of a 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  $2.0\text{g cm}^{-3}$ .

Mineral soils have particle density range of 2.60-2.75g cm<sup>-3</sup> with an average value of 2.65gcm<sup>-3</sup>. organic matter tends to lower particle density.

### **Bulk Density**

Is the mass of soil per unit bulk volume of dry soil:

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

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

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

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 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**.

### **3.7 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 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:

- Avoid working too wet or very dry soils.
- Reduce traffic or overburdened weight on the soil.
- Number of tillage operations could be reduced as in minimum tillage.
- Subsoil or deep ploughing is good to break up hardpans
- Mulching or cover-cropping protect the soil from raindrop impact.



Incorporation of organic matter into the soil such as compost, FYM or green manures.

Acid soils should be limed to enhance rapid organic matter decomposition.

### 3.8 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:

**Brown-Black** where dark soils result from the level of organic matter contents which is usually high in waterlogged soils.

**White-Light grey** which indicate leaching of colouring materials such as organic matter, or due to accumulation of lime or salts.

**Yellow-Red** soils contain iron oxides in well-drained soils

**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.

### 4.0 CONCLUSION

Our understanding of soil physical properties is imperative to the proper management of soils both for present use and future generations. Physical properties of soils could adequately be harnessed for sustainable agriculture through optimum utilization of the soil physical processes and water resources.

### 5.0 SUMMARY

In this unit, we have learnt:

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 to which these physical properties could be modified by natural events.

the appropriate management strategies of soil physical properties for improved productivity and sustainable agriculture.

## 6.0 TUTOR-MARKED ASSIGNMENT

Define and explain the following soil physical properties:

soil textural classes  
soil aggregation/granulation  
porosity  
Bulk density  
Soil tilth.

Discuss the agricultural practices that could improve soil physical properties and enhance crop production in your area.

## 7.0 REFERENCES/FURTHER READINGS

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## **UNIT 4 SOIL CLASSIFICATION AND SURVEY**

### **CONTENTS**

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### **1.0 INTRODUCTION**

Owing to the existence of several thousands of types of soils throughout the world, it is necessary to classify them into groups that have similar observed properties. This practice helps us to understand and remember the traits of a particular soil and be able to develop good land policy for efficient soil management. This unit deals with the practice of soil classification which is normally derived from soil survey reports. Soil maps are produced to define areas with similar soils and the location of other land resources.

### **2.0 OBJECTIVES**

By the time you have gone through this unit, you should be able to:

- explain the concepts and meanings of soil classification, soil survey and soil mapping
- describe one or two (including that of Nigeria) soil classification systems
- explain how soil surveys are prepared and used
- describe different types of soil survey.

### 3.0 MAIN CONTENT

#### 3.1 Soil Classification

#### 3.2 Concept and Definition of Soil Classification

According to Esu (1999) soil classification is defined as the systematic arrangement of soils into groups or categories on the basis of their observed properties. **Observed properties** are those that can be seen in the field or measured in the laboratory. Classification systems based on observed properties are usually called **natural classification** or **soil taxonomy**. When soils are classified based on inferences from the observed properties, the classification system is called **technical classification**. For example, it could be inferred that crops grown on dark loam soils would have high yields. Therefore, soils classified on the basis of potential yield are a technical system.

The current system worldwide has six levels of classification. The **soil order** is the highest level and broadest group which are 10 in number. The soil order is divided into **suborder** which is further divided into **Great Group, Subgroup, Family** and **Series** which is the lowest soil grouping similar to **species** in animal and plant grouping. The **order** and **suborder** levels of soil classification are usually used at state and regional levels and by soil scientists. **Soil series** group is more relevant to farmers, builders, extension workers and those that require information on soils at local level.

#### 3.3 Purpose of Soil Classification

Soil classification is useful for the following specific purposes:

To organize information and knowledge on the soil that are understandable and useful.

Soils are classified into groups to help us remember their names and important properties.

Organizing soils into groups with similar properties minimizes the problem of locating information about any one soil.

It makes us to easily understand the relationships among individual soils being classified.

Soil classification enables us to predict soil behaviour and even estimate their productivity.

By means of soil map, extrapolation of knowledge and information of one soil to others in other places by different soil scientists, becomes possible.

Soil classification helps us to identify the best use of a particular soil.

### **3.4 Process of Soil Classification**

The following steps as articulated by Esu (1999) constitute general process of carrying out a natural soil classification especially those meant for agricultural purposes.

A comprehensive study of the physical environment in which the soils to be classified are located. The parameters so studied include the geology, geomorphology, vegetation, land use, drainage, and climate of the area.

A field mapping, soil characterization and field sampling of soils is then carried out.

More adequate knowledge of the soil characteristics is then sort through morphological and micro morphological study of the soils; laboratory characterization of the fine earth fraction of each horizon within pedons; elucidation of genetic factors of soil formation and the relation between the soils and the environment in which they are located.

Armed with an adequate knowledge of the characteristics of the soils, the soil classifier (pedologist) then formulates differentiate at the lowest category.

The next step involves the clustering of soil individuals at lower categories into higher level taxa or classes on the basis of similar characteristics (Hierachial or Multiple Category system).

This is followed by the regrouping of higher classes into yet higher class.

More extensive soil mapping is then carried out in areas of similar environmental setting to test the classification carried out at a different location.

The classification is then tested and adapted several times so as to discover and learn new relationships. At this point, the classification is sent out to colleagues for necessary inputs and valid criticisms.

The new relationships learnt, the criticisms and other ideas are finally incorporated into the classification and a Final Classification is thus obtained.

### 3.5 Systems of Soil Classification

In general, two broad kinds of soil classification are recognized; a **Natural or Taxonomic** Classification also termed **Scientific** classification and a **Technical Classification**.

A Natural Classification is one in which the purpose of the classification is, to bring out relationships of the most important properties of the population being classified without reference to any single specified and applied objective. In a natural classification, all the attributes of a population are considered and those which have the greatest number of covariant or associated characteristics are selected as the ones to define and separate the various classes. Most soil classification systems try to approach a natural classification system as an ideal, though some more weight tend to be given to properties of higher agricultural relevance. The most common examples of a natural soil classification system are the USDA Soil Taxonomy System (Soil Survey Staff, 1975) and the FAO – UNESCO Soil Map of the World Legend (FAO – UNESCO, 1988). These two systems have received world wide attention and are the most used in Nigeria. The salient features of these systems of soil classification will be briefly discussed later.

A technical Classification, on the other hand, is one which is aimed at a specific, applied, practical purpose. For example, classifying soils for agriculture or engineering purposes or even more specifically classifying soils for maize production or for irrigated agriculture. The most common examples of a technical classification which are widely used worldwide are the USDA Land Capability Classification System and the FAO Land Suitability Classification for rainfed agriculture.

#### USDA Soil Taxonomy System

In 1951, the Soil Survey Staff, Soil Conservation Service of the United States Department of Agriculture (USDA) started the development of a new system of soil classification. The system was developed by a series of approximations, testing each one to discover its defects and thus gradually approaching a workable system. In 1960, the **7<sup>th</sup> Approximation** was published to secure the widest possible criticism. It was adapted and changed in various supplements and in 1975, the final text was published under the title “**Soil Taxonomy: A basic System of Soil Classification for Making and interpreting Soil Surveys**”. In the 1975 edition, ten Soil Orders were recognized (Soil Survey Staff, 1975), but several revisions have since been carried out and in 1994, one additional Soil Order of Andisols was added making it a total of eleven Soil Orders (Soil Survey Staff, 1994).

The System is a multiple category or Hierarchical System and contains six categories. From highest to lowest levels of generalization, they include; the Order, Suborder, Great group, Subgroup, Family and Series. Table 4.1 contains a listing of the categories, the number of taxonomic classes (taxa) they each contain and the nature of the differentiating characteristics. A brief description of the eleven soil orders are given as follows:

**Table 4.1: Categories, number of taxa and nature of differentiating characteristics (differentiae) of the USDA Soil Taxonomy System (Source: ESU, 1999)**

Category	Number of Taxa	Nature of Differentiating Characteristics (Differentiae)
Order	11	Soil-forming processes as indicated by presence or absence of major diagnostic horizons.
Suborder	50 (approximate)	Genetic homogeneity. Subdivision of orders according to presence or absence of properties associated with wetness, soil moisture regimes, major parent material, and vegetational effects as indicated by key properties; organic fiber decomposition stage in Histosols.
Great group	206 (approximate)	Subdivision of suborders according to similar kind, arrangement, and degree of expression of horizons, with emphasis on upper sequum base status; soil temperature and moisture regimes; presence or absence of diagnostic layers (plinthite) fragipan, duripan.
Subgroup		Central concept taxa for great group and properties indicating intergradations to other great groups, suborders, and orders; extra gradation to “not soil”.
Family		Properties important for plant root growth; broad soil textural classes averaged over control section or solum; mineralogy of solum; soil temperature classes (based on mean annual soil temperature at 50cm depth).

Series 10,000 (approximate) Kind and arrangement of horizons; colour, texture, structure, consistence, and reaction of horizons; chemical and mineralogical properties of the horizons.

**Soil** Description

**Order**

- Entisols - Recently formed soils without pedogenic horizons like sand soils, alluvial soils, very shallow soils, etc.
- Inceptisols - Embryonic soils with few diagnostic horizons. No accumulation of translocated materials other than carbonates or silica.
- Aridisols - Soils of arid region such as desert soils. Some are saline.
- Vertisols - Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and expand, becoming very sticky in the wet season.
- Mollisols - Grassland soils of Steppes and Prairies. Soils with nearly black, organic – rich surface horizons and high basic cation supply.
- Spodosols - Soils with a bleached surface horizon (E Horizon) and an alluvial accumulation of sesquioxides and organic matter in the B horizon. These soils occur mainly under coniferous forests of temperate regions.
- Alfisols - High base status soils with subsoil horizon accumulation of illuvial clay.
- Ultisols - Low base status, highly leached soils with subsoil horizon accumulation of illuvial clay.
- Oxisols - Sesquioxide-rich, highly weathered and very highly leached soils of intertropical regions.
- Andisols - Soils formed from volcanic materials often low in bulk density ( $<0.85\text{g. cm}^{-3}$ ), well-drained and high in allophane.
- Histosols - Organic soils often termed peat or muck.



## **FAO-UNESCO Soil Map of the World Legend**

In response to a recommendation of the International Society of Soil Science (ISSS) at its 7<sup>th</sup> congress held at Madison, Wisconsin in 1960, the preparation of the FAO/UNESCO Soil Map of the World project at scale of 1:5,000,000 was started in 1961. Successive drafts of the soil map and of the legend were prepared from a compilation of existing materials combined with systematic field identification and correlation. The first draft of the Soil Map of the World was presented to the 9<sup>th</sup> Congress of the ISSS held at Adelaide (Australia) in 1968. Since then, the Legend of the map has undergone many revisions, the latest being in 1988 (FAO-UNESCO, 1988).

The objective for developing a soil map of the world legend was to correlate all units of the various soil maps in the world (and they are numerous) and to obtain world wide inventory of soil resources with a common legend. The nomenclature has, however, been drawn from a number of national systems in a successful exercise of international diplomacy. It was perceived that this exercise will provide for ready transfer of land use and management knowledge.

The soil Map of the World Legend thus has a bicategorical system, with the highest or upper class being approximately but not completely equivalent to the Great group level of

Soil Taxonomy (USDA). The lower category is composed of intergrades or soils with special horizons or features of note. The latest revisions also includes phases to subdivide the secondary classes according to difference in characteristics or qualities important in use and management of the soils such as texture, stoniness, presence of indurated (pan) layers, presence of hard rock, slope and presence of salinity.

Today, the Legend consists of 28 major soil groupings, subdivided at the second level into 153 soil units. Additional information is contained in the texts recommended for further reading.

### **Classification of African Soils**

The most prevalent groups of African soils are usually the four groups described below.

#### **Ferruginous Tropical Soils**

These are soils which have the A, B, C, D - horizons designation. Some may have B1, B2, where the B could be a textural one in which clay is accumulating.

Spores which are rich in sesquioxide may be present in the soil; the silt content is usually low. Clay type of this group is mainly kaolinite though pockets of 2:1 lattice clay may occur. This trend makes the cation exchange capacity of these soils to be very low. The silica-sesquioxide ratio is less than 2 while colour characteristic is 10YR – 7.5YR. The soils of the cocoa belt in West Africa are classified in this group.

### **Ferrisols**

Soils in this group are characterized by high base content, good structure and high biological activity. The surface of aggregates may have a glossy appearance due to the aggregation of sesquioxide clay. The silica-sesquioxide ratio (i.e  $\text{Si O}_2 : \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ ) may be less than 2 especially in the clay component which confers low cation exchange capacity on the soils.

Similarly base saturation is low (less than 50). These soils are further divided according to the type of parent material from which they are formed. Some of these soil types are found in northern Nigeria.

### **Ferrallitic Soils**

These soils reflect the final stage of weathering and leaching whereby only the least mobile and least weatherable constituents remain; even kaolinite may be altered. Soils are very deep with poor horizon differentiation whereby only A<sub>2</sub> or textural B (heaviest texture formed due to clay eluviations) may be present.

There are no glossy surfaces as the clay type is mainly kaolinite associated with large quantity of iron oxide. The silica-sesquioxide ratio is  $<2$ , while base saturation is also  $<40$ . The soils in this group are poor in weatherable materials. Most soils formed from sandstone parent material in Nigeria have been classified into this group e.g. soils along Ankpa – Anyigba – Idah axis in Kogi State of Nigeria.

### **Hydromorphic Soils**

These are soils which are under the influence of water table. They are known by the degree of mottling present. There is usually the rise and fall of water table over the soils resulting in variegated colour of mottling in the soils.

## **3.6 Soil Survey**

### **3.6.1 Soil Survey Definition**

Before soils could be classified, knowledge of individual soils which constitute the group is very essential. Soil survey makes us to know the properties of soils in an area with a view to classify them if need be. It involves a systematic examination, description, classification and mapping of soils in an area.

Soil surveys help the extension and adaptation of research knowledge from one area to others. However, soil surveys emphasize only the less changeable properties of pedon and site such as the physical and mineralogy of the pedon and its climate. Changes such as fertilizer and lime regimes are not usually indicated in a survey report.

### **3.6.2 Types of Soil Survey**

Soil surveys are of six types; namely, Schematic soil surveys, Exploratory soil surveys, Reconnaissance soil surveys, Semi-detailed soil surveys, detailed soil surveys and Very Detailed soil surveys. The type adopted depends on the level of details required from the soil map.

#### **Schematic Soil Surveys**

These are soil surveys which result in very generalized soil maps which have essentially taxonomic significance. They are often derived from intuitive extrapolation about the soils in areas where no soil surveys have taken place. Thus, such survey maps are often interpretations of climatic, geologic and vegetation maps. Most often, road-traverses linking “mapping units” are used for soil checking. Invariably, the mapping units employed in these surveys are broad; normally the Soil Orders or the Great Soil Groups of the World, and a very general picture of soil distribution pattern is given.

Generally, many national soil maps are compilations obtained through Schematic Soil Surveys and their publishing scales lie in the region of 1:1,000,000 or smaller, just like in the case of atlas maps. Indeed, a very good example of a schematic soil survey is the one that has resulted in the publication of the FAO/UNESCO Soil Map of the World at a scale of 1:5,000,000 (FAO/UNESCO, 1974).

Schematic soil surveys, also termed Syntheses or Compilations, are useful in promoting public awareness about soils of a broad region and has only some direct practical value at global and international levels of planning.

### **Exploratory Soil Surveys**

These are soil surveys often undertaken to identify the forms of development that are physically possible within large regions of a country. The level and nature of national effort required to implement such development are assessed in general terms, providing a basis for establishing priorities and a timetable for the use of limited facilities in development.

The surveys are often undertaken at a final mapping scale of 1:250,000 to 1:1,000,000 as general inventory maps of soils as a natural resource. At these small scales, the surveys rely on satellite imageries or extensive air-photo reconnaissance as most boundaries are drawn in the laboratory on the evidence of interpretative methods. The soil mapping units often consist of land units of various kinds, preferably enclosing identified soil Orders and Great Soil Groups.

### **Reconnaissance Soil Surveys**

This type of soil survey fulfill a similar purpose to those described under Exploratory surveys. However, they are often commissioned for more specific purposes rather than as a general inventory survey. Their major purpose is to identify possible areas for further intensive soil survey work as might be done before locating new irrigation or farm settlement schemes. Aerial photographic interpretation is the basis of soil boundary location, but the soil observations become slightly more numerous than in exploratory surveys and the mapping units comprise individual great groups or association of great groups.

### **Semi-Detailed Soil Surveys**

Semi-detailed soil surveys are also termed Medium Intensity soil surveys. They are carried out to identify specific areas apparently suited to specific forms of agricultural development. A reliable interpretation is obtained of the overall proportion and general distribution of soils of differing potential for the development purpose (s) in view. Such information may be sufficient to assess the economic feasibility and even permit implementation, of the less intense forms of agricultural development. However, for more intensive land utilization on types such as irrigation, these surveys usually serve only a “pre-investment” purpose – to identify “project areas” within which expenditure on more intense studies for investment feasibility assessment and implementation appears to be justified (FAO, 1979).

Final maps are often published at scales of 1:25,000 to 1:100,000 and mapping units often consist of associations of soil series, and physiographic units (enclosing identified soil series).

### **Detailed Soil Surveys**

These are high intensity soil surveys which are carried out at scales between 1:10,000 and 1:25,000. At such scales, it becomes possible for the cartographer to indicate field boundaries upon the topographical map. Consequently, in a soil survey produced at these scales, soils can be related directly to the parcels of land which enclose them. The soil surveyor can indicate with considerable accuracy, the location of soils on the landscape and can show the intricacy of their boundaries on the map.

Detailed soil surveys are very useful in areas where soil-related problems are known to exist as one can see at a glance if a particular field is likely to have a soil with a specific problem. Also, extrapolation of information from one area to another is possible and it is also possible to indicate whether or not a development scheme is feasible. Detailed soil surveys are therefore also known as “Feasibility Surveys” (Bridges, 1982).

Soil mapping units in detailed soil surveys often consist of phases of soil series and soil complexes.

### **Very Detailed Soil Surveys**

These are very high intensity soil surveys which are carried out at scales larger than 1:10,000. They are concerned with the precise location of high-cost projects or management problems of specialized crop production.

Surveys in this category have specific objectives and the data to be collected would be contractually agreed on. Boundary lines between different soil series, or even phases of soil series occupy zones less than 2m wide and so the soil surveyor can show the soil boundaries with exactitude.

### **3.6.3 Procedures of Soil Survey**

The processes of surveying and mapping enable us to recognize and correlate different soil categories. Soil surveying is the process of studying and mapping the earth surface in terms of soil types. A soil survey report consists of two parts:

the soil map which is accompanied by a description of the area shown on the map. Two main conventional methods of soil survey are (i) the rigid grid procedure and the (ii) free survey method.

## **The Rigid Grid Procedure**

Traverses are used here. A traverse is a straight path opened along a baseline in the area to be surveyed. Traverses are cut at regular intervals which depends on the kind of survey. Soils along the traverses are dug and studied. Tools such as the mud auger, bucket auger, shovel and spade are used. The surveyor digs holes and profiles, examines pedons and construct **legend** containing names of the soil map units that the soil surveyor wants to use in the survey. There may be for example 50 types of soil in the area. The intensity of observation could be increased by digging more holes.

Along each of the traverses, soils are described at fixed intervals, such that the traverses and points of observation with the soil auger are fixed in a grid pattern. This method of survey gives all soils present in the area a statistically good chance of being represented on the final soil map.

The Rigid Grid procedure is particularly useful in carrying out soil surveys in landscapes covered with thick forest where visibility is severely limited. Under such conditions, position location is difficult by other means including aerial photography, and it would be difficult to use the morphological features of the landscape as a guide to the positions of soil boundaries. Instead, boundaries have to be interpolated between points of contrasting soil mapping units.

Rigid Grid surveys are best suited for high to very high intensity surveys at scales large than 1:10,000. Examination of the soil at fixed points throughout the survey area eliminates the subjective element of interpretation and soil boundaries are interpolated between differing observations.

## **Free Survey**

In this procedure, observations are also made along traverses, but the soil surveyor uses his judgement in siting soil observations in relation to landform and other environmental features. In other words, observations are not made at fixed intervals. This method of survey is only convenient in open country where both access and visibility are almost unrestricted.

Although this is an effective and relatively rapid method of soil surveying, it can lead to a concentration of observations around the edge of soil mapping units within which “impurities” of other soils could occur. The great advantage of the method is that the surveyor is free to vary the intensity of his observations according to the intricacy of the soil pattern. This results in a greater accuracy when soil patterns are

complex and does not waste time and energy when conditions are uniform.

The use of the free survey method necessitates a good base map or air photographs upon which the surveyor can work without any problems of location so that observations and boundaries are correctly placed.

### **3.6.4 Cartographic Production of Soil Map**

The principal result of a soil survey is a soil map upon which is shown the distribution of the soil mapping units. Once the field surveyors have compiled a “field” copy of their map, it is passed on to the cartographers who have the responsibility of preparing it for publication.

One of the most critical features of a map is its scale, for this determines what can be shown, especially in terms of the smallest area capable of being represented. On a soil map, this is limited by practical considerations to an area of about  $0.25\text{cm}^2$ . Thus, any

soil area which occupies less than  $0.25\text{cm}^2$  when represented upon the map must be combined with adjacent soil mapping units.

It is pertinent to add that in virtually all soil surveys, the published map is produced at a smaller scale than that at which the field work took place. For example, the field work of a map published at 1:25,000 could be carried out at base maps of scale 1:10,000. The use of a larger scale map for field work has the advantage that the surveyor has

### **3.6.5 The Soil Survey Report**

A soil survey report is a written report which accompanies the soil map when a soil survey project is undertaken. Such a report explains in detail the mapping units, their properties and relationships. According to the Soil Survey Manual (Soil Survey Staff, 1951), every soil survey report should contain.

- an explanation of how to use the soil map and report;
- a general description of the area;
- description of the individual mapping units shown on the map, tables showing their characteristics
- prediction of the yields of common crops under specifically defined sets of management practices for all the soils mapped
- explanations of the management problems of each soil with special emphasis on how the characteristics of the soil influence the problems and their solutions.

## 4.0 CONCLUSION

For efficient and effective land uses, soil scientists survey land and prepare a soil map on which the soils in the area are classified based on observable and unchangeable soil properties.

## 5.0 SUMMARY

In this unit, you have learnt:

- the meanings and concepts of soil classification soil survey and soil mapping
- the importance of soil classification soil survey and soil maps in soil and land management
- the procedures of soil classification and soil survey
- the various systems that exist worldwide in soil classification
- types of soil survey and their limitations

## 6.0 TUTOR-MARKED ASSIGNMENT

Write short notes on the following concepts.

- Soil Classification
- Technical classification
- Ultisols and Oxisols
- Reconnaissance soil survey

Describe the procedure you would follow in conducting a detailed soil survey of an area where no aerial photographs are available.

## 7.0 REFERENCES/FURTHER READINGS

- Esu, I.E. (1999). *Fundamentals of Pedology*. Stirling-Horden Publishers (Nig.) Ltd, Benin-City.
- Edward, J.P. (1992). *Soil Science and Management*. New York: Delmar Publishers Inc.
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## **UNIT 5 PLANT GROWTH REQUIREMENTS**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
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  - 3.1 What is Growth?
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  - 3.5 Nutrient Uptake by Plant Roots
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### **1.0 INTRODUCTION**

The growth and general performance of any plant depends on adequate supply of environmental factors including the sixteen elements currently known to be essential.

### **2.0 OBJECTIVES**

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

- define what growth of plant is
- define what is meant by growth factor
- describe the functions of each growth factor
- explain the mechanisms by nutrients get to the root surface
- describe the three possible pathways by which nutrients get into the root cells for uptake.

### 3.0 MAIN CONTENT

#### 3.1 What is Growth?

**Growth** can be defined as the “progressive development of an organism”. It is expressed in terms of dry matter weight, length, height and diameter. There are two major factors affecting plant growth; namely, the genetic factor and the environmental factors.

#### 3.2 Factors Affecting Plant Growth and Development

**Genetic Factor** concerns primarily the inherent capability of a given crop to give high yield and desirable characteristics. Where such desirable characteristics are lacking, plant breeders could develop a given crop to give the desired character(s). Where this is successful, the ability of the “hybrid” to exhibit its characters depends majorly on the environmental factors.

**Environmental Factors** can be defined as the aggregates of all external conditions and influences that affects the growth, development and life of an organism. Unless both the genetic and the environmental factors are brought under control, the desired yield or characters of an organism may not manifest itself.

The major environmental factors affecting the growth development and life of plants are as follows:

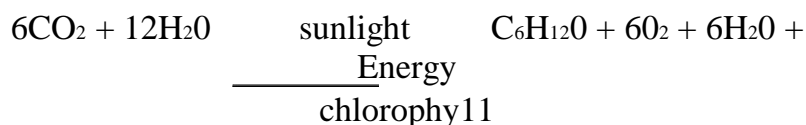
- Sunlight (radiant energy)
- Availability of oxygen/carbon dioxide
- Adequate supply of soil moisture
- Favourable temperature
- Favourable soil reaction (acidity and alkalinity)
- Absence of toxic substances
- Favourable root environment and
- Adequate supply of plant nutrients.

Among these factors, the one which is least optimum will determine the level of crop production. This is the **principle of limiting** factors which states that the level of crop production cannot be greater than that allowed by the most limiting of the essential plant growth factors.

#### **Sunlight**

Sunlight is very necessary for the supply of radiant energy needed for photosynthesis. Where there is inadequate sunlight the process of

photosynthesis will be disturbed and thus the overall growth and yield of the crop will be affected.



It has been estimated that less than 2% of the radiant energy is used for photosynthesis while about 45% is used for evapotranspiration while the rest is re-radiated into the space.

### **Availability of Oxygen and Carbon Dioxide**

Roots have openings called lenticels that permit gas exchange. Oxygen diffuses into the root cells and is used for respiration, whereas the carbon dioxide diffuses into the soil. Respiration releases energy that the plant needs for synthesis and translocation of organic compounds and the active accumulation of nutrient ions against a concentration gradient. Oxygen is usually inadequate in water logged soils. Differences exist between plants in their ability to tolerate low oxygen levels in standing water because they have morphological structures that permit internal diffusion of atmospheric oxygen down into the root tissue. Others like tomato may be wilted or killed by saturating the soil with water for just a day.

The wilting is believed to result from a decrease in permeability of the root cells to water, a result of a disturbance of metabolic processes due to an oxygen deficiency.

Aerobic micro-organisms, bacteria, actinomycetes, and fungi utilize oxygen from the soil atmosphere and are primarily responsible for the conversion of nutrients in organic matter into soluble forms (mineralisation) that plant can use. Under anaerobic condition many important processes will be hampered while the activities of important soil micro-organisms will be retarded greatly.

On the other hand, the carbon dioxide (CO<sub>2</sub>) concentration in soil environment is higher than the atmosphere because of respiration of plants and micro-organisms. CO<sub>2</sub> is not limiting under normal conditions.

### **Adequate Supply of Soil Moisture**

Water and oxygen are inversely related as regards utilization in soil. Roots need oxygen for their respiration process in order to obtain energy for the extraction of nutrients and water from the soil.

It has been estimated that about 500gm of water is needed to produce 1gm of dry plant material. About 5% of this water becomes integral part of this plant. The remainder is lost through the stomata's of leaves during absorption of CO<sub>2</sub>. Atmospheric conditions such as relative humidity and temperature determine how much of water is available for plant use. Since the growth of virtually all economic crop plants will be curtailed when shortage of water occurs, even though it may be temporary and the plants are in danger of dying, the ability of the soil to hold water against the force of gravity becomes very important unless rainfall or irrigation is frequent. It is equally important that optimum water be made available for plant as excess could cause a lot of damage to the plant system. As stated earlier, water and oxygen are inversely related. A good soil therefore is that which allows 50% pore space (macro and micro) and 50% solid particles. The macro-spaces hold air while the micro-spaces hold water. A good soil is that which has 25% micro-pores (H<sub>2</sub>O) and 25% macro-pores (O<sub>2</sub>). High level of water leads to low level of O<sub>2</sub> which affects plant respiration and its related benefits while O<sub>2</sub> signifies low amount of water and its attendant consequences.

Water is needed in plant for photosynthesis, turgidity, evapotranspiration, nutrient uptake in aqueous medium, translocation of food, chemical reactions in plants as well as leaching of anions and cations from the soil-plant system. Inadequate availability of water therefore leads to non-completion of vegetative and reproductive stages of crops. Moisture equally affects the activities of soil micro-organisms.

Absence of water leads to the development of resistant strains of micro-organisms or they may even enter a dormant stage. Most micro-organisms are less active at the wilting point for plants (i.e. less water for mobility). Optimum moisture level for higher plants (moisture potential of between – 0.1 to 1 bar) is usually considered best for micro-organisms. Anaerobes, which comprises only a small portion of soil microbes, are hindered by free oxygen gas and grows best at saturation conditions.

### **Favourable Temperature**

Temperature can be defined as the degree of coldness or hotness of an object. Usually there is an optimum temperature or otherwise known as “**comfort zone**” for most crops and micro-organisms. The optimum temperature for plant growth ranges from between 15<sup>0</sup> C to 40<sup>0</sup>C. Microbial activity in soil accelerates as temperature rises to a maximum of 40<sup>0</sup>C. This is the Q<sub>10</sub> theory. That is, as the temperature rises from 0 to 10 to 20 etc. the microbial activity increases twice up to a maximum by which their activities will be inhibited by high temperatures.

Soil temperature where it is far from optimum could be modified through: mulching, shading, and appropriate tillage operations. Temperature is considered important because it affects the process of photosynthesis, respiration, cell-wall permeability, absorption of water and nutrients, transpiration and enzyme activity.

### **Favourable Soil Reaction (Soil Acidity + Alkalinity)**

Majority of soil micro-organisms that influence organic matter decomposition and nutrient availability (fixation) grow best at pH 6.5 – 7, which is the pH of microbial cytoplasm (the cell material). Bacteria and actinomycetes are usually less tolerant of acid soil conditions than are fungi, and very few grow well at pH less than 5 except the sulphur oxidizing bacteria (the *Thiobacillus spp*) which produce sulphuric acid. Most crops do well at pH of 6.5 – 7.0. Extreme acidity and alkalinity affects nutrient availability uptake by plants. At low pH for instance, Mn, Al could be present in excess and thus become toxic for plant growth and development. At a very high pH, there may be preponderance of Ca<sup>++</sup> and Na<sup>+</sup> both which affect nutrient availability and maintenance of suitable soil structure. High and low pH therefore is detrimental to plant growth and development.

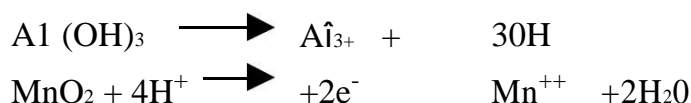
### **Favourable Root Environment**

The root environment or otherwise known as the **Rhizosphere** must be favourable for plant growth and development. A favourable root environment is that which has enough pore space in which roots can function. Oxygen must be available for root respiration. There must be absence of frangipans and it should provide enough anchorage to hold to plants. In addition, there must be absence of toxic substances which affects the normal growth of the plant.

### **Absence of Toxic Substances**

Toxic substances that affect plant growth and development are many and vary as follows:

Under reducing conditions and low pH, we have toxic levels of Al<sup>3+</sup>, Mn<sup>++</sup> and Fe<sup>2+</sup>, below pH of 5.2 there is preponderance of Al<sup>3+</sup> and Mn<sup>2+</sup> as shown below:

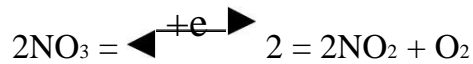


Plants differ in their tolerance to availability of Mn<sup>2+</sup> and Al<sup>3+</sup>. Most often it affects plant growth adversely.

Under reducing conditions

SO<sub>4</sub> = is converted to H<sub>2</sub> S

NO<sub>2</sub> = (Nitrite) build-up occurs at the expense of NO<sub>3</sub> = the form by which plants absorb nitrogen.



The decomposition of organic matter yield CH<sub>4</sub> gas instead of N, P and S. It is important to note that under reducing conditions there is less availability of O<sub>2</sub> mainly due to water-log conditions.

### Saline Soils

We have occasionally toxic levels of boron, selenium and sodium as well as high levels of salts namely calcium sulphate (CaSO<sub>4</sub>), Magnesium sulphate (MgSO<sub>4</sub>) and potassium chloride (KCL). Soils high in these elements and salts are usually characterized by high pH and high electrical conductivity that inhibit plant growth and development as well as structural stability of soils. Unless these elements/salts are drastically controlled it affects crop productivity.

Copper (cu) may be present at toxic levels owing to the application of fungicides such as **Bordeaux mixture**.

Herbicides could be toxic because of its specificity to certain crops e.g. atrazine applied to maize may adversely affect soyabean.

Soil pollution resulting from oil spillage, industrial wastes and sewage sludge can also affect plant growth adversely.

**Physical Condition of the Soil:** The soil must be loose enough to allow free root penetration. If the soil is compacted, it will be difficult for the root to penetrate; as such, even if other conditions are optimal, crop productivity will be retarded. High bulk density, frangipans (any hard layer), indurated or concretionary layer could prevent root penetration and thus root development.

### Availability of Plant Nutrients

At least there are about 18 elements currently considered necessary for growth of vascular plants. Carbon, Hydrogen, and oxygen obtained from air and water combine in photosynthetic reactions to produce carbohydrate needed for plant growth and development. These elements which make up to 93% of the dry matter are referred to as **structural**

**elements.** Carbon constitutes about 45% followed by oxygen (43%) and Hydrogen (6%).

The remaining nutrient elements (other than CHO) are obtained largely from the soil. Of these, we have primary or major nutrient elements followed by secondary elements then the micro-nutrients otherwise known as trace elements.

Nitrogen, phosphorus, and potassium are the elements referred to as **primary/major elements** because they are required in large quantities by plants. These elements (NPK) have to be supplied into the soil for plant growth because they are mostly deficient and because they are needed in relatively greater amounts. In plant, Nitrogen constitutes about 1 – 6%, phosphorus (0.1-0.5%) and potassium (1-4%).

Calcium, magnesium and sulfur are referred to as **secondary nutrients** which have to be supplied but not as much as the primary elements. In plant, Calcium ranges from 0.1 to 1%, Magnesium 0.1 – 0.5% and sulphur 0.1 – 0.5%. Then we have the micro-nutrients which are the nutrients required in considerably smaller quantities. The micro-nutrients include: Iron (Fe), Manganese (Mn), aluminium ( $Al_{3+}$ ), Copper (Cu), Zinc (Zn), Boron (B), Molybdenum (Mo) and chlorine (Cl). Other elements present in plants but not essential and which could be substituted with other nutrient elements include Cobalt (Co), sodium (Na) and silicon (Si).

Most of the nutrients exist in mineral and organic matter and as such are insoluble and unavailable to plants. They only become available through mineral weathering and organic matter decomposition. The nutrients are absorbed from the soil into the plant through diffusion, ion exchange and carrier hypothesis. They are either absorbed from the soil solution or from colloid surfaces as cations and anions. Cations are positively charged, anions are negatively charged. The Table below shows thirteen essential nutrient elements, their chemical symbols and the form in which they are commonly absorbed by plant roots.

**Table 5.1: Thirteen Essential Nutrient Element – Their Chemical Symbols, Forms commonly Absorbed by Plant and Percent of Dry Matters**

<b>Nutrient Element Absorbed by Plants</b>	<b>Chemical Symbol</b>	<b>Ionic Forms Commonly</b>	<b>% of dry Matters</b>
Nitrogen	N	NO <sub>3</sub> <sup>-</sup> , NH <sub>4</sub> <sup>+</sup>	1-6
Phosphorus	P	H <sub>2</sub> PO <sub>4</sub> , HP <sub>04</sub> <sup>=</sup>	0. ± - 0.5
Potassium	K	K <sup>+</sup>	1-4
Calcium	Ca	Ca <sup>2+</sup>	0.1 - 3.0
Magnesium	Mg	Mg <sub>2+</sub>	0.1 - 0.5
Sulphur	S	SO <sup>=</sup>	0.1 - 0.5
Manganese	Mn	Mn <sub>2+</sub>	20-50ppm
Iron	Fe	Fe <sup>2+</sup>	25-500ppm
Boron	B	Bo <sub>3</sub>	2-50 “
Zinc	Zn	Zn <sup>2+</sup>	5-25 “
Copper	Cu	Cu <sub>2+</sub>	2-50 “
Molybdenum	Mo	MoO <sub>4</sub> <sup>2-</sup>	0.01-2 “
Chlorine	Cl	Cl-	2.200

These nutrients are required by plants for their normal growth and development. Their deficiency in soil has to be supplied through fertilizer application. Given that the genetic and environmental factors are favorable, the plant can exhibit its qualities which are usually manifested in luxuriant growth and high yield from the crops. Effort has to be made to ensure that both factors are maintained so as to achieve optimum crop production.

### 3.3 Plant Nutrient Essentiality

A nutrient element such as nitrogen or zinc is referred to as an essential element if it satisfies the three conditions stated below:

The deficiency of the nutrient must make it impossible for the plant to complete both its vegetative and reproductive stages of growth.

The deficiency of the element cannot be corrected by substituting another element. For example, the deficiency of Sodium (Na) could be corrected by supplying potassium (K); therefore, Na is not an essential element in plant.

The deficiency symptoms of the element must be demonstrable for a wide variety of species and families. That is to say that the

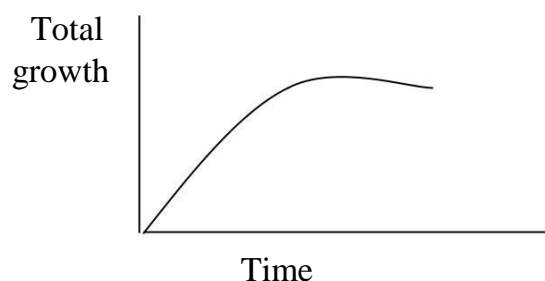


deficiency symptoms of the element must be the same in a number of plant species. As the symptom appears on maize, it should also show on rice and beans and so on.

### 3.4 Growth Expressions

Scientists have been using mathematical models to describe growth. Such mathematical models could be used in predicting the quantity of crop yields expected from the supply of an amount of an element or growth factor.

Growth is related to time whether measured in terms of height, dry weight etc. The general pattern is represented on a graph as a sigmoid shaped curve.



**Figure 5.1 Generalized curve illustrating growth pattern of an annual plant. Growth pattern – Initially, there are small increases in growth, then rapid growth followed by slow increases or non at all.**

Plant growth is also a function of various environmental or growth factors which are considered as variables. Symbolically it could be represented as:

$$= f (x_1, x_2, x_3, \dots \dots \dots x_n)$$

Where G = Some measure of growth

$x_1, x_2, x_3, \dots \dots \dots x_n$  = Various growth factors

If all but one factors are present in adequate amount, then

$$= f (x_1), x_2, x_3, \dots \dots \dots x_n$$

Thus addition of each successive increment of a growth factor results in an increase in growth.

#### 3.4.1 Mitscherlich's Equation

This equation was developed to relate growth to supply of plant nutrients. Mitscherlich's equation expresses that if all but one of the plant

nutrients are supplied in adequate amount to a plant, its growth is proportional to the amount of this one limiting element that was supplied to the soil.

Mathematically, it is expressed as:

$$dy/dx = (A - y)^C$$

where dy = increase in yield resulting from growth factor dx.  
dx = increment in growth factor x.  
=Maximum possible yield obtained by supplying optimum amount of all the growth factors.  
=Proportionality constant (depends on growth factor).

Value of C for N, P & K

N = 0.122, P<sub>205</sub> = 0.6, K<sub>20</sub> = 0.40. However C is in variance with different crops.

### 3.4.2 Spillman's Equation

This is expressed as  $y = M (I - R^x)$

Where y = amount of growth produced by a given quality of the growth factor, x.

=quantity of growth factor  
=Maximum growth (yield) when all growth factors are present at optimum levels.

R = Constant

Both Mitscherlich's and Spillman's equations could be reduced to

$$y = A (1 - 10)^{cx}$$

Where y = Yield produced by a given quantity of x  
=growth factor  
=maximum yield when all growth factors are supplied at optimum levels.  
=Constant which is dependent on the nature of growth factor. For convenience, the logarithm expression is used as follows:  
Log (A-y) = log A - 0.301 (x)  
0.301 = constant C. when A = 100 on a relative basis.

### Example 1

Assuming  $A = 100\%$ ,  $x_1 = 1$

$$\begin{aligned} \text{Then } \log(100-y) &= \log 100 - 0.301 \quad (1) \\ &= 2 - 0.301 \quad (1) \\ &= 1.699 \\ 100 - y &= 50 \\ y &= 50 \end{aligned}$$

For  $x = 2$

$$\begin{aligned} \text{Log}(100-y) &= 2 - 0.301 \quad (2) \\ &= 2 - 0.602 \\ &= 1.398 \\ 100 - y &= 25 \\ y &= 75 \end{aligned}$$

### Example 2

Using the above equation, calculate for  $x = 2, 3, \dots, 9, 10$ .

Draw a graph to represent % of maximum yield as well as increase in yield per growth factor,  $x$ .

Unit of Growth Factor, X	Y = yield, %	Increase in yield, X
0=	0	-
1	50	50
2	75	25
3	87.5	12.5
4	93.75	6.25
5	96.88	3.13
6	.	.
.	.	.
X	Y	x

## 3.5 Nutrient Uptake by Plant Roots

### 3.5.1 The Rhizosphere

Plant roots perform double functions of anchoring the plants firmly to the soil and as organs for nutrients and water absorption. (Fig 2.2). A nutrient element that is to be absorbed into the plant must be in a soluble form and must be located at **the root surface**, or within the area of the soil immediately surrounding the root hair. This portion of the soil which is usually about 2mm away from the root surface is termed the **rhizosphere**. Due to the activities of the root the **rhizospheric soil** has both biological and chemical properties different from the **bulk soil**. The soil in the rhizosphere differs from the rest of the soil in the following ways:

Soil acidity may be higher or lower in the rhizosphere than the bulk soil. when plants take up Cationic elements such as  $K^+$ ,  $Ca^{++}$ ,  $Mg^{++}$ , or  $HN^+_4$  from the soil solution, hydrogen ions,  $H^+$ , are released from the roots to balance the charge in the soil solution thus increasing the acidity. On the other hand, uptake of anions ( $NO_3$ ,  $NO_2$ ,  $SO_4^-$ ) makes the roots to exude bicarbonates ( $HCO_3^-$ ) in replacement thus lowering the acidity (increased PH level).

Due to uptake of dissolved nutrients by roots from this soil zone, nutrient concentration becomes low causing a form of **concentration gradient** between the rhizosphere and the other soil volume. Nutrients then move from bulk soil to the rhizosphere by **diffusion**.

There is higher concentration of energy-rich materials in the rhizosphere. These organic compounds include root exudates such as organic acids, sugars,

amino acids and phenolic compounds which are useful to the growth of micro-organisms.

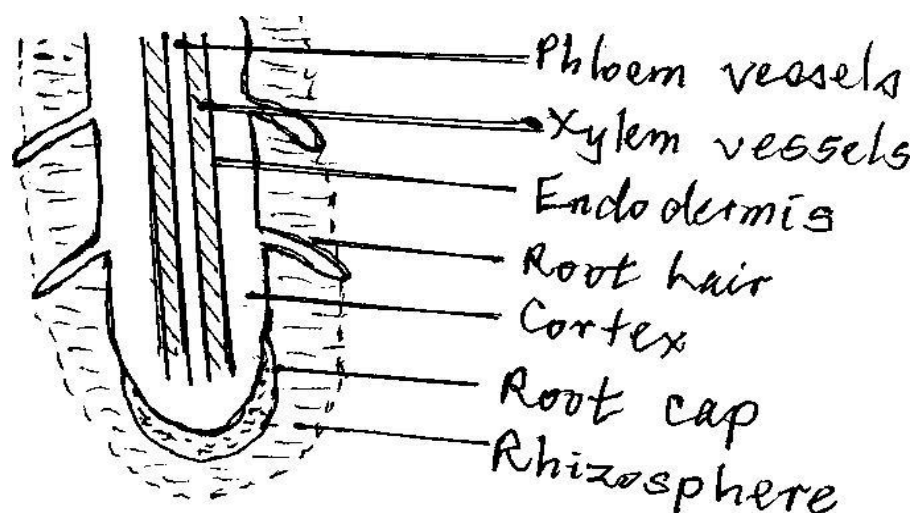
The high concentration of root exudates and other high-molecular mucilages secreted by root cap cells give rise to higher concentration of micro-organisms in the rhizosphere than the bulk soil.

The respiration of roots and microbes results in high concentration of carbon dioxide, ( $CO_2$ ).

The PH of the area surrounding the root is also lower owing to the formation of carbonic acid:



Fungi usually have beneficial association with plant roots to form **mycorrhizae**. These mycorrhizae accelerate the growth of certain trees spp such as *pinus resimosa* and *Pinus carribea* plant roots. The fungal hyphae grow out into the soil to about 15cm from the root surface to scavenge for nutrients thus increasing the **effective feeding zone** of the root. Fungi are also important because they excrete enzymes which dissolve nutrients in mineral soil.



**Figure 5.2** The root as plant organ of nutrient uptake. The xylem vessels conduct nutrients from root to the shoot.

### 3.5.2 How Nutrients Get to the Root Surface into Plant Cell

Nutrient elements in form of dissolved ions in soil solution have to come in contact with the plant roots for uptake to take place. This contact is effected mainly by three mechanisms: **mass flow**, **diffusion** and **root interception**. The three mechanisms may occur simultaneously, but one mechanism or another is usually favoured by a particular nutrient element. For example, in Table 4.2, calcium moves to the root surface mainly by mass flow and root interception, whereas diffusion accounts for phosphorus supply to plant roots because phosphorus is very low in soil solution.

**Mass-flow** is the movement of plant nutrients in flowing soil solution towards a root that is actively drawing water from the soil. There is some amount of nutrients transported to the root surface in the water used for transportation or by movement due to water potential gradients. For example, maize uses 500gm water per gram of dry matter accumulation. As the plant takes in this water, there are plant nutrients dissolved in the water for the plant to utilize. As the water moves pass a root from high water concentration gradient to a low water concentration, nutrients are carried along for the plant to utilize.

**Diffusion** is a continual process in the soil whereby plant nutrients move from area of higher concentration towards the areas of lower concentration around the root surface. The amount of an element moved to the root surface by diffusion depends on the path followed by the movement of water, on soil acidity, the amount of organic matter and the nature of the element itself. Other factors that have been found to affect rate of diffusion of an ion to the root surface are the nature of the

plant root system (tap or fibrous) which dictates the absorbing area of root surface, the soil type (clay, loam, sand, etc) and the difference between the concentration of the nutrient at root surface and in the bulk soil solution.

**Root Interception** is the contact made between the growing roots and nutrient ions in soil solution. The roots grow into new soil zone where there are pools of nutrients in solution. There is a direct contact of the root with the nutrient and results in a direct nutrient exchange between the root and the soil thus the term **contact feeding** used to describe this method of nutrient absorption.

**Table 5.2 Mechanisms by which nutrient elements move to the root surface. Mass-flow is major source of Ca & Mg, while diffusion is important for P and K.**

Nutrient	Total Uptake	Amount supplied by (Kg/ha)		
		Root Interception	Mass flow	Diffusion
Ca	230	66	175	-
Mg	280	16	105	-
K	135	4	35	96
P	39	1.0	2	36
Zn	0.23	0.1	0.53	-
B	0.07	0.02	0.70	-
Fe	0.80	0.10	0.53	0.17

### 3.5.3 Mechanisms of Nutrient Uptake into Plant Cell

The mechanisms of absorption of nutrient ions into the root cells continue to be a subject of research by plant nutritionists. Nutrients move into the cortex free space of the root by the **diffusion process**. But this cannot account for the high concentration of ions in plant cells compare to the very low quantity of the same ions in soil solution. For example the normal concentration of potassium in soil solution is about 5-10mg kg<sup>-1</sup>, plant content of this element is between 1-5%.

Plant roots have both positively and negatively charged surfaces. The ions attached to the root surface charges often could be exchanged for those in the soil solution depending on the requirement of the plant. This phenomenon is referred to as **ion Exchange**. For example, H<sup>+</sup> ion on the root surface may be exchanged for the K<sup>+</sup> ion in soil solution. However, the **carrier Hypothesis (active transport)** is the most acceptable mechanism by which nutrient ions are taken up by plants. Within the plants, there are **carriers**, organic compounds, which react with ions to form carrier-nutrient complexes which can pass through the membrane into the cell. By means of the organic carriers, plants can have selective

absorption of certain elements to the exclusion of others. The most probable theory is that all the three mechanisms – diffusion, ion exchange and carrier hypothesis – are employed in nutrient uptake but carrier hypothesis is used to explain absorption against nutrient concentration gradient.

#### 4.0 CONCLUSION

Several factors influence the growth and performance of field crops. Some of the growth factors are **genetic**, that is, inherent capability of the crop. There is no level of environmental factors that could make the crop perform beyond the level of genetic factors.

**Environmental factors**, on the other hand, could be controlled and made favourable to increase the performance of crops. Both genetic and environmental factors, such as water, temperature, or nutrient elements in the soil are referred to as limiting **factors**. This is because plant growth and yields are constrained (limited) by the deficiency of either one or a combination of the limiting factors.

#### 5.0 SUMMARY

Several factors influence the growth and performance of field crops. Some of the **growth factors** are **genetic**, that is, inherent capability of the crop beyond which there is no level of environmental factor that could make the crop perform better.

**Environmental factors**, on the other hand, could be controlled and made favourable to increase the performance of crops. Both genetic and environmental factors such as water, temperature, or nutrient elements in the soil are referred to as **limiting factors** because plant growth and yields are constrained (limited) by the deficiency of either one or combination of the limiting factors.

Thorough knowledge of the growth factors as they affect crop growth is a *sine qua non* for those who intend to make farming a profitable enterprise. Like human beings, crops must be supplied with balanced diets – the growth factors supplied in adequate quantity and quality at appropriate times during the growth period of the crops. The rhizosphere is defined as the immediate soil area surrounding the root. It is about 2mm from root surface. The rhizosphere has both biological and chemical properties such as  $p^H$ , nutrient concentration, microbial population and organic materials that are different from the bulk soil. Nutrient elements in the bulk soil move to the root surface through any one or combination of three mechanisms, namely, mass flow, diffusion and root interception. However, movement of nutrient ions from the

root surface or rhizospheric soil solution into the root cells is probably effected mainly by organic carriers in form of active transportation system.

## 6.0 TUTOR-MARKED ASSIGNMENT

Discuss the concept of the **limiting** factor and indicate its importance in enhancing or constraining plant growth.

What is an essential element? What determines whether an element is essential?

Discuss the individual effects of drought and high soil temperatures on crop performance.

Discuss the factors affecting the availability of nutrients to plants.

What is soil science and uses of soils in general?

Discuss the significance of soil pH in determining specific nutrient availabilities and toxicities, as well as species composition of natural vegetation in an area.

What are the environmental factors that most strongly hinder crop production in your area? What should be your role in combating those factors?

Discuss how soil acidity, soil temperature, soil moisture and sunlight could contribute to crop loss in a farming enterprise.

Discuss the term “rhizosphere” in relation to availability of nutrients to plants.

Describe the main mechanisms by which phosphorus, Calcium and Potassium are made available at the plant root surface.

## 7.0 REFERENCES/FURTHER READINGS

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## **MODULE 2      PROCESSES IN THE SOIL ENVIRONMENT**

Unit 1	Water in the Soil-Plant System
Unit 2	Soil Aeration and Temperature
Unit 3	Soil Organic Matter and Soil Organisms
Unit 4	Soil Reaction: Acidity and Alkalinity
Unit 5	Soil Colloids Ion Exchange in Soils

### **UNIT 1      WATER IN THE SOIL-PLANT SYSTEM**

#### **CONTENTS**

1.0	Introduction
2.0	Objectives
3.0	Main Content
3.1	Importance and Uses of Water to Plants
3.2	Availability of Water to the Soil Water
3.3	Forces that Influences Soil Water
3.4	Types of Soil Water
3.5	Water Retention and Movement
3.5.1	Measuring Soil Water
4.0	Conclusion
5.0	Summary
6.0	Tutor-Marked Assignment
7.0	References/Further Readings

#### **1.0INTRODUCTION**

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.

#### **2.0OBJECTIVES**

After studying 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.

### 3.0 MAIN CONTENT

#### 3.1 Importance and Uses of Water to Plants

On the average, crop plants use 220 to 320 of water to produce a single kilogram of dry plant matter. Water deficiency commonly limits plant growth; in several agricultural areas, water is one of the most important component in farming. Water is vital to growers because of the several functions it serves in plant growth:

Plant cells are largely made up of water. Plant tissue is 50% to 90% water, depending upon the type of tissue.

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.

Photosynthesis uses water as a building block in the manufacture of carbohydrates.

Transpiration, or evaporation of water from the leaf, helps cool the plant.

Plant nutrients are dissolved in soil water and move towards roots through the water. Water is thus important in making nutrients available to plants.

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 the plant becomes deficient in water guard cells begin to close the stomata thereby 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. At this stage, 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.

### **3.2 Availability of Water to the Soil-Plant System**

#### **3.3 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  $\text{SiO}_2$ , 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.

### 3.4 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 too 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.

### **3.5 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 separate.

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 (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.

<b>Texture</b>	<b>Field Capacity(in/ft)</b>	<b>Permanent Wilting Point(in./ft)</b>	<b>Available Water(in./ft)</b>
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

Table 6.1: Water retention of several soil textures. (*Adopted from Water: The Yearbook of Agriculture, USDA, 1955*).

### **3.3 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 material 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 because the passage of ions and molecules through the plant-root membrane.

### **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.

#### **3.5.1 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 pound when wet and 0.80 pound when dry, the moisture percentage would be

$$\% \text{ moisture} = \frac{1.0 \text{ pound} - 0.80 \text{ pound}}{0.80} \times 100 = \frac{0.20}{0.80} \times 100 = 25\%$$

### 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

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

If we are using U.S. Customary Units, then density can be expressed as pounds per cubic foot. Water has the density of 62.5 pounds per cubic foot, so the formula then would be

$$\% \text{ water by volume} = \% \text{ water by weight} \times \frac{\text{soil density}}{62.5}$$

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

$$\% \text{ water by volume} = 25\% \times \frac{90}{62.5} = 36\%$$

### Soil Depth Basis

A meteorologist states how much rain falls in inches of water, and irrigation is measured in inches of water as well. In saying that one inch 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 -inch depth. Inches 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 cubic foot of soil and squeeze all the water out of it into a one square foot cake pan. How many inches of water would be in the pan? If there were two inches of water, the soil had two inches of water per foot of soil. This can be calculated simply by the equation:

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

In above sample, then:

$$\text{inches water per foot} = 12 \text{ inches} \times 36\%/100 = 4.32$$

In the sample, each foot of soil depth contains 3.36 inches of water. If a soil profile were three feet deep, and each foot was the same, then the total of the entire profile would be 10.08 inches of total water.

Inches per foot is a common measurement used in irrigation. Irrigation also uses the *acre-inch*, which is the volume of water that would cover one acre of soil one inch deep. In the metric system, the measurement equivalent to an inch per foot is centimeter of water per centimeter of soil.

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 inches of water per foot of soil at field capacity and one inch per foot at the permanent wilting point, then the soil holds two inches per foot 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*, named 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.

## 4.0 CONCLUSION

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.

## **5.0SUMMARY**

In this unit, we have learnt that:

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.

## **6.0TUTOR-MARKED ASSIGNMENT**

Discuss the water levels that may be detrimental to crops.

## **7.0REFERENCES/FURTHER READINGS**

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## **UNIT 2 SOIL AERATION AND TEMPERATURE**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Status of Soil Air
  - 3.2 Definition of Oxidation-Reduction (Redox) Potential (Eh)
  - 3.3 Conditions that Affect Soil Air Composition
  - 3.4 Soil Aeration on Biological Activities and Plant Growth
    - 3.4.1 Effects of Redox Reactions in Aerated Soils, on Nutrient Availability Plant Growth
    - 3.4.2 Effect of Redox Reactions in Anaerobic Soils, on Nutrient Availability and Plant Growth.
    - 3.4.3 Effects of Reduction Reactions on Plant Growth
    - 3.4.4 Practical Application of Redox Reactions in Agriculture
  - 3.5 Soil Temperature and Plant Growth
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 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 oxygen is adequate nutrient elements exist in the forms that plant usually absorb; when oxygen is deficient in soil, toxic substances that adversely affect plant growth are formed. Plants also have optimum ranges of temperature for best performance.

### **2.0 OBJECTIVES**

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

- define soil aeration, oxidation-reduction potential (Redox Potential) and net radiation
- distinguish the conditions that affect soil air composition
- describe nutrient transformations in both aerated (aerobic) and anaerobic soils
- distinguish practical applications of redox potential reactions in agriculture

distinguish the effects of soil temperature on plant growth and those factors that help to moderate soil temperature.

### 3.0 MAIN CONTENT

#### 3.1 Status of Soil Air

There must be interchange of gases between plants root hairs 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-organisms. In these soil respiratory activities, oxygen, O<sub>2</sub>, is used up while carbon dioxide, CO<sub>2</sub>, is given off. **Soil aeration** is the process of 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<sub>2</sub>, thus ensuring 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 conditions; and (iii) Fine textured soils (clay, silt clay) which are easily water-logged but are good in areas with long drought periods.

S/n	Soil	Soil Types	Approx. Water	% Air	Content of Organic Matter	Mineral Matter
1.	Coarse Texture	Loamy sand Sand loam	30	15	1	54
2.	Medium textured	Loam, Silt Loam	25	25	5	45
3.	Fine Textured	Clay, Silt Clay	40	15	5	40

**Table 6.1: Composition of the air in soil (% by volume)**

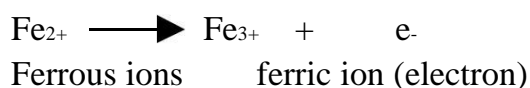
Soil Systems	Nitrogen	Oxygen	Carbon dioxide
Atmosphere (Average)	79.01	20.96	0.03
Soil (Average)	79.0	20.3	0.15-0.65
Arable land	80.1	19-20	0.9
Pasture land	80.5	18-20	0.5-1.5
Arable, uncropped	79.25	20.4	0.35
Sandy soil	79.10	20.5	0.40
Arable land, fallow	79.20	20.7	0.10
Grass land	80.0	18.4	1.60

Table 6.1 shows that the free atmosphere above the soil contains about 21% oxygen, 0.03% CO<sub>2</sub> and nearly 79% N<sub>2</sub>. In comparison, soil air may have about the same percent, or some what higher N<sub>2</sub> content, but is consistently lower in O<sub>2</sub> and higher in CO<sub>2</sub>. The upper soil layers contain more O<sub>2</sub> than soils at upper slopes after a heavy rainfall since water tends to accumulate at the low laying areas.

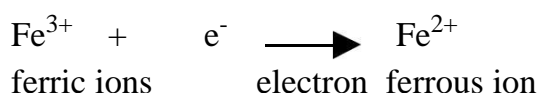
### 3.2 Oxidation – Reduction (Redox) Potentials (Eh)

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 (Fe<sup>3+</sup>), nitrate NO<sub>3</sub><sup>-</sup> and sulphate (SO<sub>4</sub><sup>-</sup>). 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 of chemical systems in soils. The redox provides a measure of the tendency of a system to reduce or oxidize chemicals and is measured in volts or millivolts. Positive and high values indicate strong oxidizing conditions while low and negative values indicates that element would exist in reduced forms

Oxidation is the loss of electrons in an atom or ion

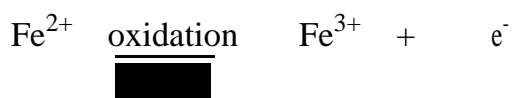
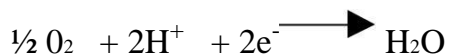


Reduction is the gain of electrons by an atom or ion





From the above reactions, oxidation can also be defined as gain or increase in positive valency while reduction is a decrease in positive valency. 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 a reducing agent easily donates electrons. Oxygen gas (O<sub>2</sub>) is a strong oxidizing agent while hydrogen (H<sub>2</sub>) is a strong reducing agent in the formation of water molecule.



The redox potential (Eh) is defined as

$$Eh = E_0 + 0.059 \log \frac{\text{Fe}^{3+}}{\text{Fe}^{2+}} - 0.058\text{pH}$$

Where E<sub>0</sub> 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 320mV at pH5.0.

**Table 6.2: Redox potentials, Eh, of some soil systems, compounds and elements at which change in forms commonly occur**

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

### 3.3 Conditions that Affect Soil Air Composition

#### Organic Matter and Biological Activity in Soil

In tropical soils, there is rapid evolution of carbon dioxide, CO<sub>2</sub>, by the highly active biological population especially soil micro-organisms which decompose organic matter at very fast rates. This trend affects the concentration of both oxygen (O<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>) in soil air. Microbial decomposition of organic **residues accounts** for the major portion of the carbon dioxide CO<sub>2</sub> evolved. During the process of respiration and decomposition, oxygen O<sub>2</sub> is used up while carbon dioxide CO<sub>2</sub> is evolved. 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.

#### Soil Type and Soil Depth

Carbon dioxide, CO<sub>2</sub>, increases with soil depth while oxygen O<sub>2</sub> decreases with depth with the heavier soils becoming more deficient than the lighter textured soils in the sub soil layers.

#### 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 oxygen O<sub>2</sub> and high Carbon dioxide CO<sub>2</sub> levels in the soil air. During the dry season, there is more circulation of air in the soil and O<sub>2</sub> levels are usually higher than Carbon dioxide CO<sub>2</sub>.

#### Application of Manure

The rate of Carbon dioxide CO<sub>2</sub> production could be increased through the application of farm yard manure (FYM) especially when the soil is wet and rate of diffusion of oxygen O<sub>2</sub> and Carbon dioxide CO<sub>2</sub> slows down. Green manuring (especially from fairly succulent crops such as *Leucaena* and *Gliricidia* spp.) could increase the Carbon dioxide CO<sub>2</sub> content of soil air. This can lead to poor germination of seeds sown too soon after a green manure crop has been ploughed in.

### 3.4 Soil Aeration on Biological Activities and Plant Growth

The composition of soil air affects the activities of soil micro-organisms, nutrient availability to plants, respiration and nutrient uptake of crops.

Aerobic soil microorganism absorbs free oxygen O<sub>2</sub> through the very efficient cytochrome oxidase enzyme system. This aerobic activity continues in the soil when the O<sub>2</sub> concentration is not less than between 3 to 6 x 10<sup>-6</sup>M. The concentration of oxygen O<sub>2</sub> in soil solution when in equilibrium with air at 20<sup>0</sup> to 25<sup>0</sup>C is 2.7 x 10<sup>-4</sup>M which is between 60 – 100 folds larger than that of the soil. Aerobic metabolism continues until oxygen O<sub>2</sub> concentration in the soil falls below the figure corresponding to a partial pressure of 1% of the pressure of Carbon dioxide CO<sub>2</sub> in free atmosphere.

### 3.4.1 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 0.8 volts.

Some biochemical transformations that proceed in well-aerated (aerobic conditions) soils are discussed below.

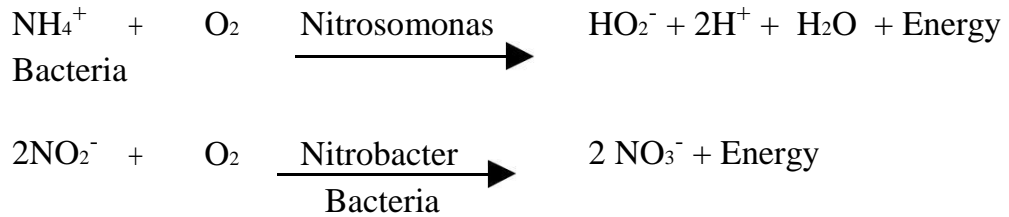
Generally, there is biological transformation of C, N, Mn, Fe, and S to CO<sub>2</sub>, NO<sub>3</sub><sup>-</sup>, Mn<sup>4+</sup>, Fe<sup>3+</sup> and SO<sub>4</sub><sup>2-</sup> respectively in well-aerated soils. These transformed species are the forms utilizable by plants. That is, under aerobic conditions most elements are available in forms that can be absorbed by plants even though nutrients such as ferric, Fe<sup>3+</sup> and magnate Mn<sup>4+</sup> 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 oxygen O<sub>2</sub> serves as electron acceptor.



Nutrient elements contained in organic matter are released during decomposition process. Nitrogen, in particular, is released in ammonium (NH<sub>4</sub><sup>+</sup>) form and the process is termed **mineralization**. It has been estimated that soil organic matter contains about 5 percent by weight of Nitrogen and 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 70kg/ha of nitrogen as ammonium, NH<sub>4</sub><sup>+</sup>.

Under continued conditions of aerobism, autotrophs (nitrifiers) now oxidize NH<sub>4</sub><sup>+</sup> which is released during decomposition of organic matter (and mineralization of organic nitrogen) in two coordinated steps to nitrite (NO<sub>2</sub><sup>-</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>).



The oxidation of ammonium cations ( $\text{NH}_4^+$ ) to nitrate anions ( $\text{NO}_3^-$ ) by the autotrophic nitrifying bacteria (*Nitrosomonas* and *Nitrobacter* spp.) is called **nitrification**.

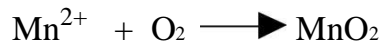
Another group of aerobic bacteria use reduced elemental sulphur,  $\text{S}^0$ , as source of energy thus oxidizing sulphur  $\text{S}^0$  to  $\text{SO}_4^{2-}$ .



There are some organisms which grow well in acid medium ( $\text{pH} < 4.0$ ) and usually not considered important in agricultural soils that are normally kept between  $\text{pH} 6.0 - 7.3$ . These microorganisms under aerobic conditions could oxidize  $\text{Fe}^{2+}$



Similarly manganese, Mn, is oxidized



The reactions above are carried out by aerobic autotrophs that utilize oxygen therefore, the reactions are subject to oxygen  $\text{O}_2$  tension and they occur in well aerated soils. In all these cases, energy for growth is released while the plant utilizable forms of the various nutrients elements are released, viz;  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Fe}^{3+}$ ,  $\text{Mn}^{4+}$  and  $\text{CO}_2$ . However, ferric ion ( $\text{Fe}^{3+}$ ) and  $\text{Mn}^{4+}$  are very highly insoluble and are therefore not found in high concentrations in agricultural soils.

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

#### Reduction Reactions

Set in under anaerobic conditions when oxygen diffusion within the soil is reduced mainly by excess water to a level below  $2$  to  $4 \times 10^{-6}\text{M}$  concentration. The anaerobic condition (low  $\text{O}_2$  concentration) gives rise to a series of microbial reactions that always take place in the same sequence. Although reduction reactions are associated mainly with

waterlogged or wet soils, they sometimes occur in all soils at some time during the year.

Immediately after flooding, the exchange of gases between the soil and the atmosphere is cut down as the diffusion of gases in water is approximately  $10^{-4}$  x 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 becomes 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**. As a result of metabolic activity of these organisms, many compounds with high oxidation states can be reduced, either directly 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 include:

- Accumulation of gases such as  $CO_2$ ,  $H_2$ , and  $CH_4$
- reduction (Denitrification) of nitrate,  $NO_2$  to e.g.  $N_2$
- Reduction of manganese and iron oxides to  $Mn^{2+}$  and  $Fe^{2+}$
- Reduction of sulphates to sulfides
- considerable increases in the concentrations of  $Ca^{2+}$ ,  $K^+$ ,  $Na^+$ ,  $H_2PO_4^-$  and  $CHO_3^-$  in the interstitial water.
- Production of ammonia and soluble organic compounds (fatty acids, amino acids and mercaptans) as a result of the anaerobic decomposition of fresh organic material.
- Stabilization of the pH between 0.5 and 7.0 and decrease of redox potential.

### 3.4.3 Effect of Reduction Reaction on Plant Growth

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 diseases 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 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 oxygen from outside into the plant root. Root growth in oxygen – deficient soils are stunted with reduced rate of water and 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.

#### 3.4.4 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:

**Surface drainage** which involves construction of ditches to convey water away.

**Ridging** to raise the seedbed above the surrounding topography.

**Moulding:** Also, farmers make big heaps (mould) whereby the top of the mould is kept above water all the year round.

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 oxygen diffuses down into the root, and out of the root into the soil immediately outside the root, thus permitting the actual uptake of ions by the root to take place as an 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, “tile drainage” is practiced so as to maintain an adequate rate of percolation of water. Green manuring and the use of

composts also help to maintain a good enough soil structure in the initial stages of flooding to allow adequate percolation.

Overdrainage of calcareous or alkaline soils can be undesirable; for by lowering the CO<sub>2</sub> 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 (NO<sub>3</sub><sup>-</sup> 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<sub>4</sub>, and urea, (NH<sub>2</sub>)<sub>2</sub> CO forms.

### 3.5 Soil 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 4-10°C, corn 10-29°C, potatoes 16-21°C sorghum and melons 27°C, cabbage and spinach 8-11°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 most favourable temperature limits of 27-32°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 reflected back into the atmosphere by clouds, atmospheric gases, or is scattered into the atmosphere before it reaches the earth. On the global average, about 50% of the solar radiation 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 3% 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 affected the temperature of a given soil are the amount of radiation it receives, its *albedo*, fraction of incident radiation that is reflected by the land surface, its moisture and air

contents and any factor that affects the rate of evaporation of water from the moist soil. These factors are elaborated upon below:

**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 act as insulators. In temperate regions the use of plastic mulches make 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.

**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, but during a sunny day the surface of a dry soil warms up much quicker, and during a clear night cools much quicker than a wet surface. A temperature difference 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.

**Soil Type:** Sandy soils warm up faster than clay soils thus sands 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.

**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. Soils under vegetation warm 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 at 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.

#### **4.0 CONCLUSION**

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.

#### **5.0 SUMMARY**

In this unit we have been made to understand that:

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 oxidation reactions are useful to plant while reduction causes the formation of methane (CH<sub>4</sub>) and the reduced forms of nutrient elements which may become 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<sup>o</sup> – 35<sup>o</sup>C. Soil temperatures are regulated by the use of mulch, regular water supply, soil tillage and establishment of vegetation cover.

#### **6.0 TUTOR-MARKED ASSIGNMENT**

Write short notes on the following:

oxidation potential

reducing agent

facultative anaerobic micro-organisms

mineralization

What species of nitrogen, sulphur, iron and manganese do you expect to find in aerated soils? In anaerobic soils?

## **7.0 REFERENCES/FURTHER READINGS**

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## **UNIT 3     SOIL ORGANIC MATTER AND SOIL ORGANISMS**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Soil Organic Matter versus Organic Materials
  - 3.2 Sources of Soil Organic Matter
  - 3.3 Composition of Soil Organic Matter
  - 3.4 Decomposition of Soil Organic Matter
  - 3.5 Mineralization of Organic Matter
  - 3.6 Roles of Microorganisms in the Transformation of O.M
    - 3.6.1 Factors affecting the Decomposition of Organic Matter in Soil
    - 3.6.2 General Importance of Organic Matter in Soils Especially in Nigerian Agriculture
    - 3.6.3 Constraints to the Maintenance of Organic Matter in Nigerian Soils
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Soil organic matter is the organic component of the soil. It consists all parts of living and dead plants and animals, micro-and macro-organisms 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.

## 2.0 OBJECTIVES

After completing this chapter, 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 Nigerian 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 Nigerian agriculture.

## 3.0 MAIN CONTENT

### 3.1 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 reverse 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 matter** 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.

### 3.2 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 faeces, animal feeds, and animal manures. The contribution of animal wastes in terms of nutrient supply depends primarily on the species of the animals (ruminant or non-ruminant), the type and part of plant consumed and the age of the animal as well as the plant.

### 3.3 Composition of Soil Organic Matter

About 75% 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 source of soil organic matter (plant tissue) is made of very complex substances such as carbohydrates (Sugar, starch, hemicellulose, cellulose, pectins, mucilages) 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 and it is resistant to decomposition. On the other hand, protein (which is readily decomposed) decreases 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 25cm 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.

### 3.4 Decomposition 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 lies primarily on its decomposition. That is, for an organic material to be useful it has to be decomposed. 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, phosphates 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 resistant product of decomposition.

### 3.5 Mineralization of Organic Matter

This 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:

**Aminization** which is the decomposition of organic matter by **heterotrophic bacteria** to release amino acids and amides.

Aminization is followed by **ammonification** which is the release of ammonium ion from amino acids and amides.

Amino acids + amides  $\xrightarrow{\text{heterotrophic bacteria}}$   $\text{NH}_4^+$ . The ammonium ion ( $\text{NH}_4^+$ ) further undergoes amino acids + amides  $\xrightarrow{\text{heterotrophic bacteria}}$   $\text{NH}_4^+$

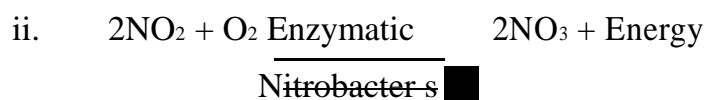
oxidation process as a result of participation of special purpose bacteria in another two-step process called **nitrification**

Enzymatic oxidation  $2\text{NO}_2 + 2\text{H}_2\text{O} + 4\text{H}^+ + \text{Energy}$   
Nitrosomonas spp

### 3.6 Roles of Microorganisms in Organic Matter Transformation

Conversion of ammonium to nitrate ( $\text{NO}_3^-$ ) nitrogen. Ammonium is first converted to nitrite as in equation:

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  $\text{NH}_4^+$ , Nitrite ( $\text{NO}_2^-$ ) is then rapidly converted to nitrate ( $\text{NO}_3^-$ ) through further oxidation by another group of obligate autotrophs, **Nitrobacter** bacteria, as in the following equation:



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 ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ) forms from the soil solution. In effect, the decomposition of organic matter results in:

The use of some of the carbon, nitrogen and some other elements by micro-organism.

The release of carbon dioxide, water and elements such as sulphur, nitrogen, phosphorus, potassium and micro-nutrients to the soil solution or atmosphere, and

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 ( $\text{H}_2\text{CO}_3$ ) in soil solution. The  $\text{H}_2\text{CO}_3$  dissociates to  $\text{H}^+ + \text{HCO}_3^-$  and further to  $\text{H}^+ + \text{CO}_3^{2-}$ . In the presence of calcium ( $\text{Ca}^{++}$ ), calcium carbonate ( $\text{CaCO}_3$ ) is formed in the soil.

### 3.6.1 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 maximize the use of organic fertilizer. The conditions favourable for organic matter decomposition include:

#### Composition and Particle Size of the Organic Material

The smaller or finer the organic matter particles, especially due to the composition of soil macro-organisms on organic matter, the greater the surface area exposed for decomposition, 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:

### **Carbon: Nitrogen Ration**

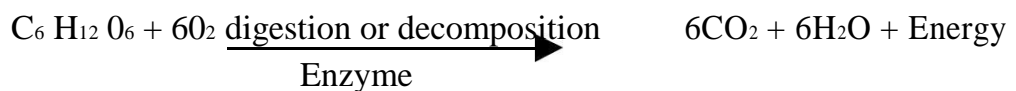
The carbon: nitrogen ratio of the organic matter affects rate of its decomposition. The micro-organisms require nitrogen for tissue or body building. The organic matter must contain reasonably high quantity of nitrogen for micro-organisms to obtain enough for rapid multiplication and accelerated activity.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

### **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 strive 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 effected by soil bacteria, it follows that decomposition is higher under neutral range than under acid and alkaline conditions. Liming acid soils will accelerate rate of organic matter decomposition. Most Nigeria soils are acidic especially in the middle belt and Southern Nigeria due to high rainfall and leaching losses of cationic nutrients from the topsoil.

### **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.



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.

### **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 Q<sub>10</sub> 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. In a dry season in northern Nigeria, Wild (1972) reported low numbers of autotrophic organisms because the temperature at a soil depth of 5cm reached a daily maximum which averaged between 38 and 40°C.

Not much information has been reported in the literature about the effect of temperature on decomposition in Nigeria 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 microorganisms 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 Nigeria, it does not meet the organic matter requirement of the soils. Therefore, the organic contents of Nigerian soils are relatively lower than soils in colder regions.

### **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.

### **Microorganisms involved**

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

## **3.6.2 General Importance of Soil Organic Matter**

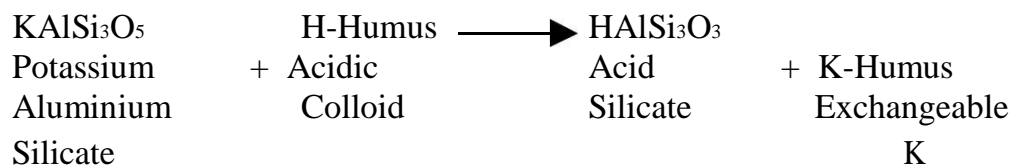
The politicization of the distribution of inorganic chemical fertilizers in Nigeria makes the role of organic matter as a source of plant nutrients

more desirable. Furthermore, increase in fertilizer prices coupled with its unreliable availability to farmers makes the assessment of the role of organic matter in Nigerian 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 Nigerian 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:

Decomposition of organic matter incorporated into soil results in the ~~release of plant utilizable forms of nutrient elements~~ such as  $\text{CO}_2$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{M}_n^{++}$ ,  $\text{SO}_4^{=}$ ,  $\text{H}_2\text{PO}_3^-$ ,  $\text{HPO}_4^{=}$  and so on.

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

Most Nigerian 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 Nigeria which usually result from the fact that most standard fertilizer formulations are devoid of micronutrients.

The practice of burning crop residue in traditional Nigerian 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 released into the soil which reduce nutrient losses through erosion of soil surface.

### **Organic Matter is a Major Source of Cation Exchange Capacity (CEC)**

Especially 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 Soil Organic Matter (SOM) are the carboxyl, aliphatic, phenolic and hydroxyl groups hence the CEC of SOM is pH – dependent. Owing to this property of SOM, the term  $\Sigma$ CEC is usually used; the  $\Sigma$ CEC 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 most used. Tropical soils have low  $\Sigma$ CEC and SOM is the major source of  $\Sigma$ CEC in such soils with higher values in the top soils than the sub-soils. The higher the  $\Sigma$ CEC, 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 bonds**. Thus we have zinc -chelate, copper-chelate and Fe-chelate depending on which metal ion is being complexed.

### **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.

### **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 amount 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.

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 are usually plastic and sticky. These forces make the soil difficult to work and 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.

### **Organic Matter Serves as Source of Energy for Microbes in Soil**

Decomposing 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.

Soil erosion by water or wind is common problem in Nigerian agriculture. **Coarse organic materials on the soil surface reduces the impact of raindrops and reduces 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) accumulates, 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 sub-humid ecologies of Nigeria.

**Applied as mulches, organic matter helps to regulate soil temperatures,** and reduces evapo-transpirational 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.

Increase microbial population 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.

### 3.6.3 Constraints to the Maintenance of Organic Matter in Nigerian Soils

#### **Competing Alternative Uses**

In addition to soil incorporation and as mulch, plant and animal 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.

#### **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 chopping) and application costs. Lack of tractive power to replace simple hand tools used by farmers in soil tillage is a great handicap for effective residue incorporation. Apart from problem of returning the crop residue into the soil, farmers often do not produce the quantity sufficient to maintain soil fertility and conserve the soil.

#### **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 of decompositions of freshly incorporated organic matter when enough time for equilibration is not allowed.

#### **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 prunings serve as shade, provide nitrogen-rich green manure for the companion crops and maintain 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.

### **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, soyabean, 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.

### **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.

#### **4.0 CONCLUSION**

Plant and animal remains such as crop residues, animal and green manures, compost, fallen leaves and forest litter make up soil organic matter. Its 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.

#### **5.0 SUMMARY**

In this unit, you have learnt that:

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 to the tremendous benefits of organic matter, efforts should be made to ensure 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 Nigeria, several constraints militate against the maintenance of soil organic matter. Their thorough understanding will help to map out strategies for amelioration.

#### **6.0 TUTOR-MARKED ASSIGNMENT**

What soil factors are conducive to the:

rapid decomposition of organic matter?

Accumulation of organic matter?

What steps could be taken to restore soil organic matter?

#### **7.0 REFERENCES/FURTHER READINGS**

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## **UNIT 4 SOIL REACTION: ACIDITY AND LIMING**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Meaning of Soil Reaction
  - 3.2 Active Acidity
  - 3.3 Buffer Systems
  - 3.4 Acidity Ranges in Soils
  - 3.5 Sources of Soil Acidity
    - 3.5.1 How Soils becomes Acidic
    - 3.5.2 Importance of Soil Acidity
    - 3.5.3 Measurement of Soil Acidity
    - 3.5.4 Liming Practices
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Soil reaction (pH) seems to be the single soil chemical condition that most strongly affects the environment of farm crops and soil micro-organisms. 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. Acknowledge of the conditions which cause different soil reactions is of tremendous value to the student of soil science.

The large presence of aluminium 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.

## 2.0 OBJECTIVES

After completing this unit, you should be able to:

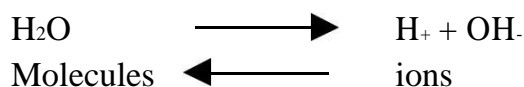
- define soil pH and describe how it is developed
- describe farm practices that tend to increase or decrease soil acidity
- describe how soil pH affect plant growth
- explain how to lime or acidify soil
- describe what is meant by buffering capacity in soils
- explain the various ways of determining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

## 3.0 MAIN CONTENT

### 3.1 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 dissociates 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:

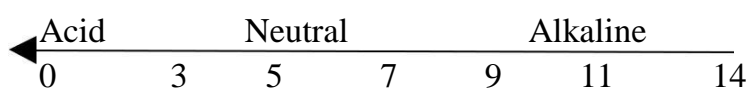


In pure water, the concentrations of hydrogen and hydroxyl ions are always equal and the solution is said to be neutral. Soil reaction is also the degree of acidity or alkalinity in the soil. Soil acidity is usually measured by determining the pH values which, according to Sorenson (1909), is defined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

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

where  $AH^+$  represents activity of hydrogen ion in moles/litre or molarity.

The acid (pH) scale grades from 0-14 as below:



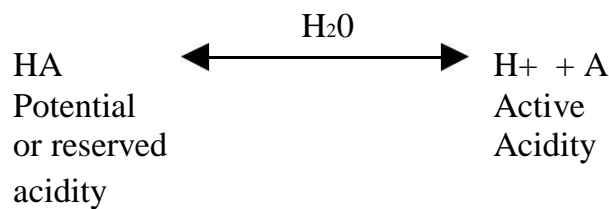
At neutral point  $AH^+ = 0.0000001M$   
 $= 10^{-7}M$

$$-\log_{10} 10^{-7} = + 7.0$$

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.

### 3.2 Active Acidity

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



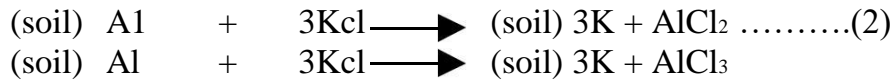
The **active acidity** is the sum total of all the hydrogen ions in the acid solution or in the soil solution. In the above equation the active acidity is represented by the  $\text{H}^+$  to the right; its strength dictates the strength of the acid solution. The HA on the left side of the equation is 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  $\text{H}^+$  in soil and it is always in dynamic equilibrium with active acidity.



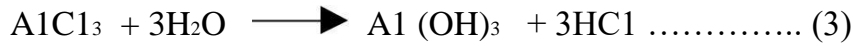
Although active acidity is only a small fraction of the total acidity, it is important because it is the one that actually affects the growing plant. **Total acidity** of a soil is the sum of the concentrations of active acidity which is represented by the  $\text{H}^+$  ion concentration in the soil 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 (Yagodin, 1984) and defined as the acidity due to carbonic acid ( $\text{H}_2\text{CO}_3$ ); 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  $\text{Al}^{3+}$  ions by cations of neutral salts into soil solution, as follows:





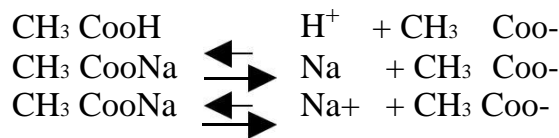
In soil solution, AlCl<sub>3</sub> is then hydrolysed to yield a weak base and strong acids



**Potential acidity** is very important in determining the strength of **active acidity** since portions of adsorbed H<sup>+</sup> and Al<sup>3+</sup> 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 less readily exchangeable with the soil solution cations.

### 3.3 Buffer Systems

These are compounds that maintain the pH of a solution within 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 soil solution.

### 3.4Acidity 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 0.01M CaCl<sub>2</sub> (1:2.5) or about 5.5 in water (1:1) 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 8.1: Soil acidity scale by Yagodin (1984)**

Reaction	pH	H <sup>+</sup> 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	$10^{-9} - 10^{-11}$

### 3.2 Sources of Soil Acidity

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

#### Organic Matter

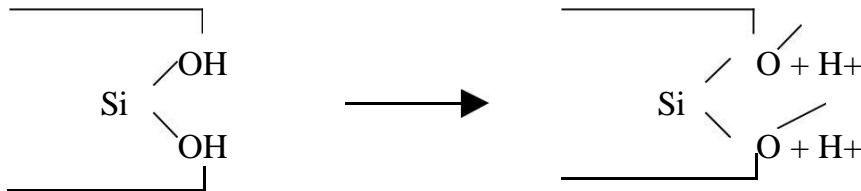
In organic matter or humus the carboxylic, phenolic, amino and sulphhydryl functional groups can undergo ionization to release their hydrogen ions, H<sup>+</sup>, into the soil solution thus increasing soil acidity. The functional groups constitute very significant source of reserved acidity in the soil.

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 explained earlier.

#### Aluminosilicate Clay Minerals

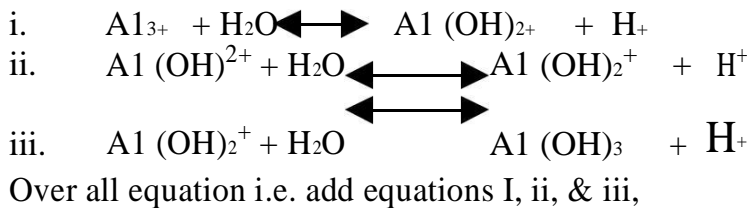
The 1:1 or 2:1 clay minerals typified by Kaolinite and montmorillonite usually carry negative charges on them as a result of isomorphous substitution in their crystal lattice. Additional charges on the clays also

arise from the dissociation of hydrogen ions from hydroxyl groups or from bound water of constitution, both of which are structural components of the crystal lattice. At the negative charged sites of these clays, hydrogen ions, H<sup>+</sup>, come in to 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<sup>+</sup>, on the edges of the layer silicates clay minerals could be released to the soil solution under certain conditions.



**Exchangeable Aluminium**

Present in the inorganic component of the soil are bonded Al<sub>3+</sub> which could be displaced from the clay minerals by other cations such as Fe<sup>3+</sup> Mg<sub>2+</sub>, or Ca<sub>2+</sub>. The displaced or exchangeable Al<sub>3+</sub> then undergoes hydrolysis in solution releasing H<sup>+</sup> 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<sup>+</sup> 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 Tropaquilt they studied.

Another source of H<sup>+</sup> 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<sup>+</sup> ions by hydrolysis.

**3.2.1 How Soil Becomes Acidic**

**Decomposition of Soil Organic Matter (SOM)**

Recent report of the effect of organic matter on soil acidity have 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  $(\text{NH}_4)_2\text{SO}_4$  fertilizer at 120 kg/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 were 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 Insch soil (light textured) decreased with glucose application; whereas, in Tillycorthie and Craden Bay soils (medium and heavy textured) added glucose tended to increase pH during the incubation period.

### Carbon Dioxide, $\text{CO}_2$

The release of carbon dioxide,  $\text{CO}_2$  to soil atmosphere by (a) respiration of plant root and (b) microbes could result in the production of weak acid.



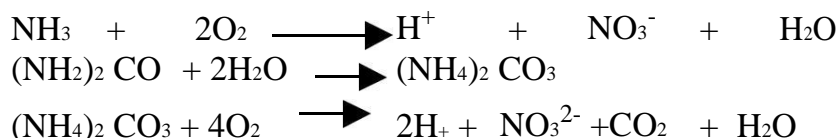
The production of acid from  $\text{CO}_2$  depends greatly on the solubility of  $\text{CO}_2$  in water, which in turn also depends on (a) partial pressure of  $\text{CO}_2$  in the soil and (b) soil temperature. The partial pressure of  $\text{CO}_2$  is related to the presence of  $\text{CO}_2$  and other gases in the soil.

In neutral or alkaline soils containing large quantities of carbonates or bicarbonates and in equilibrium with  $\text{CO}_2$  at the pressure of normal above ground air, the pH is 3.5. A decrease of  $\text{CO}_2$  partial pressure in such soil atmosphere to 0.02 atmosphere, gives a pH drop to about 7.5.

### Oxidation of Ammonium Compound

Oxidation of ammonium compound in the soil produces hydrogen ions,  $\text{H}^+$ , which lower soil pH. For example,  $\text{NH}_4^+$  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 —  $\text{NH}_2$ ,  $\text{NH}_4^+$ , or  $(\text{NH}_2)_2\text{CO}$  (Urea) — and they are all sources of soil acidity as shown by the following equations:





### **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:



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

### **Leaching of Cations**

Soil may become acidic through leaching of cationic elements in the soil most especially potassium ( $\text{K}^+$ ), Calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ) and sodium ( $\text{Na}^+$ ). 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  $\text{H}^+$  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).

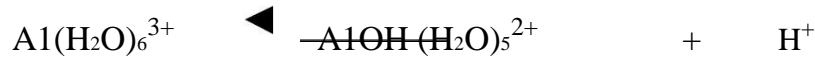
### **Removal of Cations by Harvest**

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 acidic. As the cation is removed, hydrogen ion,  $\text{H}^+$ , is released from exchange complex to balance the charge as explained for the leaching of cations.

### **Concentration of Aluminium in the Soil**

Each aluminium ion,  $\text{Al}^{3+}$ , released from exchange site gives three hydrogen ions,  $3\text{H}^+$ . There is the general belief that  $\text{H}^+$  and  $\text{Al}^{3+}$  exist 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  $H^+$ .



### 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

$$S + \frac{3}{2} O_2 + H_2O \longrightarrow H_2SO_4$$

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 are the obligate autotrophic aerobes such as *Thiobacillus thiooxidans*, *T. thioparus* and *T. Copraliticus*.

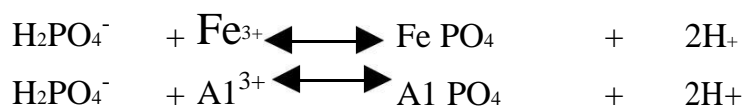
In areas with little or inadequate liming programme such as in humid tropical regions the continued use of acid-forming fertilizers leads to increase soils acidification. However, on alkaline soils, acid-forming mixed fertilizers like ammonium sulphate or the elemental sulphur may be used to depress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

### 3.5.2 Importance of Soil Acidity

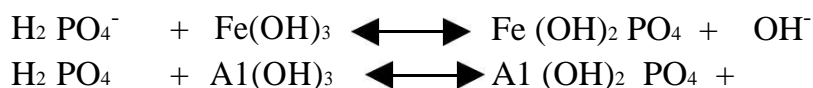
**Availability of Plant Nutrients:** Soil acidity affects availability of most soil nutrients especially phosphorus, nitrogen, sulphur, molybdenum and other micronutrients such as iron, aluminium and manganese. The pH of any soil could be a good guide in predicting which plant nutrients are likely to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

#### 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  $\text{OH}^-$  leads to formation of  $\text{Fe}(\text{OH})_3$  precipitate and increase in  $\text{H}_2\text{PO}_4^-$ .



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 increases 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.

$$6\text{Ca}^{2+} + 4\text{CaCO}_3 + 6\text{HPO}_4^{2-} \rightleftharpoons \text{Ca}_{10}\text{CO}_3(\text{PO}_4)_6 + 3\text{H}_2\text{CO}_3$$

(apatite) that is, the insoluble phosphates of iron and aluminium will be precipitated in acid soils and the insoluble phosphates of calcium and magnesium at pH values greater than 7.5. Several 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.

### 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  $\text{NO}_3^-$  under high pH and as  $\text{NH}_4^+$  under low pH in which it could also be fixed while  $\text{NO}_2^-$  could also easily be leached at high pH levels.

### Potassium

Potassium compounds are soluble at any pH but  $\text{K}^+$  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.

### Calcium and Magnesium

These are the most abundant bases in the soil. They are usually added in soil amendments but not so much as fertilizers.

### **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,  $\text{Fe}^{++}$ , 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  $\text{Mn}^{2+}$  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.

### **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. At high pH level, there is conversion of molybdenum oxide to soluble molybdate salts making the element available in alkaline soils. On the other hand, Mo is precipitated by Fe and Al as  $\text{Fe}_2 (\text{Mo}^{0}_4)_3$  and  $\text{Fe}_2 (\text{M.O}_4)_3$   $\text{Al}_2 (\text{Mo}^{0}_4)_3$  at low pH values, rendering Mo unavailable to plants.

### **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.

### **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.

### **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.

### **Effect of pH on Soil Physical Conditions**

Soil structure is most easily affected by soil pH. In soils with 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.

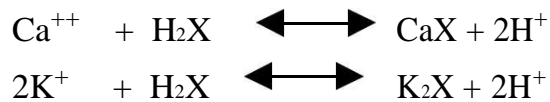
Saline soils could result from using salty water for irrigation.

### **3.5.3 Measurement of Soil Acidity**

The pH values of a soil are 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, 0.01M of either KCl or CaCl<sub>2</sub> solution is added to the soil and the pH is measured. The pH values of soil-salt solution suspension are 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 the displacement of extral hydrogen ions H<sup>+</sup>, from permanent exchange complex into soil solution by K<sup>+</sup> or Ca<sup>2+</sup> ions.



### 3.5.4 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 practised to increase the pH of acid soils and to eliminate all the deleterious effects of soil acidity as discussed in the preceeding sections. Work at Nsukka, Nigeria by Fori and Okigbo (1972) 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.
- increased 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 activity of nitrogen-fixing bacteria especially *Rhizobium* spp.
- Increase rate of nitrification by autotrophic nitrifying bacteria (*Nitrosomonas*) and (*Nitrobacter* spp.).
- precipitation of toxic substances – excess Al, Fe and Mn – from soil solution.
- retardation of certain plant diseases as well as plant pathogen.

Overliming may occur when lime is applied more than required to neutralize the excess Al<sup>3+</sup> or eliminate Mn toxicity. Overliming may manifest in yield reduction, soil structure deterioration and decreased availability of P, Bo, Zn and Mn. Friesen *et.al.* (1980) working on two

Nigerian 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 Paleudult from Benin (Alagba sandy loam) showed severe Mn deficiency on maize growth on the ustoxic Paleustult 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:

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

**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, Ca CO<sub>3</sub>. It is often expressed as a percentage of the neutralizing ability of an equal weight of pure Ca CO<sub>3</sub>. Therefore neutralizing value is usually called calcium carbonate (Ca CO<sub>3</sub>) equivalent. For example, let 100g of Ca CO<sub>3</sub> neutralize an amount, X, of acidity. If 100g of another liming material is able to neutralize 1/3 of what 100g Ca CO<sub>3</sub> can neutralize then the Ca CO<sub>3</sub> equivalent of that liming material is 33%. Furthermore, Ca CO<sub>3</sub> equivalent of

$$\text{Mg CO}_3 \text{ is } \frac{100}{84} \times 100 = * 119\%$$

$$\text{Ca CO}_3 \text{ equivalent of MgO} = \frac{100}{40} \times 100 = 179\%$$

$$\text{“ “ Ca(OH)}_2 = \frac{100}{74} \times 100 = 136\%$$

### **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:

### **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).

### **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 finess 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.

### **Particle Size of the Liming Material**

Certain liming materials such as  $\text{CaCO}_3$  are only slightly soluble and therefore their rate of reaction in soil depends on their particle size. Lime requirement of a lime decreases with decrease in finess of the particle. Upto a limit, the finer the particle, the greater the neutralizing value. It should be noted that too fine particle may not be desirable owing to cuddling.

Crop need can also dictate the lime requirement. Some crops such as groundnut and tobacco require more Ca for their nutrition.

### **Solubility of Lime Being Used**

For example,  $\text{Ca(OH)}_2$  is more soluble, and will therefore react faster, than  $\text{CaCO}_3$  as liming materials.

### **Liming Materials**

Calcic limestone,  $\text{CaCO}_3$

Dolomitic lime ( $\text{Ca Mg CO}_3$ )... most commonly used.

Hydrated lime  $\text{Ca(OH)}_2$

Air slaked lime ( $\text{Ca(OH)}_2 + \text{CaCO}_3$ )

Refuse paper mill ( $\text{CaCO}_3$  is the lime here)



Sugar beet refuse lime

Slage,  $\text{Ca SiO}_3$   $\text{Ca(OH)}_2$  +  $\text{CaO}$  +  $\text{Mg}$

8. Wood ashes,  $\text{Ca CO}_3$   $\text{Ca(OH)}_2$  +  $\text{K}_2 \text{CO}_3$ .

#### 4.0 CONCLUSION

Soil reaction (pH) could be acid, neutral or alkaline. Each of these reactions depends on the chemical condition of the soil. However, a particular reaction 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.

#### 5.0 SUMMARY

In this unit, we have learnt:

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

#### 6.0 TUTOR-MARKED ASSIGNMENT

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.

- a. What farm practices could lead to soil acidification?  
Enumerate the various sources of soil acidity.

#### 7.0 REFERENCES/FURTHER READINGS

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## **UNIT 5 SOIL COLLOIDS AND ION EXCHANGE IN SOILS**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Colloidal Materials of Soils
  - 3.2 Cation Exchange Reactions
  - 3.3 Cation Exchange Capacity
  - 3.4 Characteristics of Exchange Reactions
  - 3.5 Sources of Negative Charge in Soils
    - 3.5.1 Organic Sources of Cation Exchange Capacity
    - 3.5.2 Inorganic Fractions
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Soils colloids are soil particles (organic and inorganic) that carry charges on their surfaces. They are also referred to as surface-active materials in the soil. The soil colloids are therefore able to attract either cations or anions to themselves depending on whether they carry negative or positive charges.

Ion exchange between the solid and liquid phase of the soil is one of the important properties of soils. Cation exchange capacity of the soil measures the quantity of cations that a given amount of soil can hold or exchange which in turn depends on the type of colloidal materials that constitute the soil.

### **2.0 OBJECTIVES**

By the completion of this unit, you should be able to:

- describe colloidal material, ion exchange and cation exchange capacity of the soil
- outline the characteristics of cation exchange reactions
- calculate exchangeable cations in soils
- explain the laboratory determination of cation exchange capacity
- enumerate the significance of ion exchange in soil and crop management.

### 3.0 MAIN CONTENT

#### 3.1 Colloidal Material of Soils

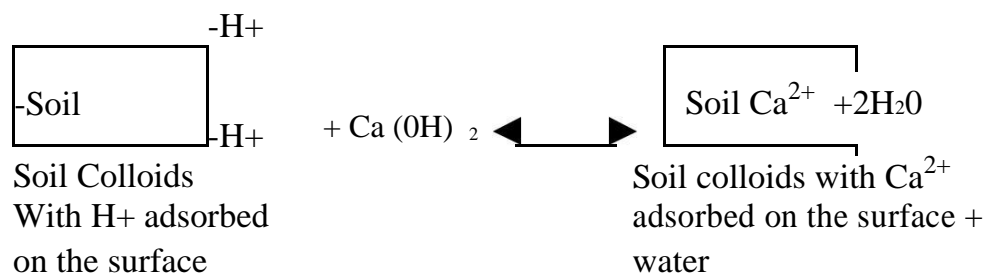
The most important and active portions of the soil are those in colloidal stems and they are the seats of ion exchange comprising of the organic and mineral fractions of the soil.

The organic fraction consists of the plant and animal residues in all stages of decomposition with humus as its stable phase. Both the primary and secondary minerals of the soil form the inorganic (mineral) fraction of soil colloids.

#### 3.2 Cation Exchange Reactions

The colloidal constituents of any soil are all the clay fractions, part of the silt and the humus. In all cases, they usually have effective diameter less than 2 micro meters (microns). By virtue of their large negative charge, the colloidal constituents are capable of attracting (adsorbing) positively charged ions (cations) such as  $K^+$ ,  $Ca^{2+}$ ,  $Na^+$ ,  $Mg^{2+}$  or  $NH_4^+$ . Cations are clustered around the surfaces of the clay and humus particles and are usually readily displaced by other cations added to soil or released into soil solution when they may be taken up by plant root. These displacement reactions are called **cation exchange reactions** which could also be defined as the interchange between a cation in the soil solution and another cation on the surface of any surface-active material (colloidal constituent). The most numerous cations on exchange sites (surface – active materials) in soils are calcium  $Ca^{2+}$ , Magnesium  $Mg^{2+}$ , hydrogen ion  $H^+$ , sodium  $Na^+$ , potassium  $K^+$  and aluminium  $Al^{3+}$ .

An example of cation exchange reaction is the mechanism involves in liming of acid soils. In acid soils, some hydrogen ion ( $H^+$ ) are present in solution but most of them are adsorbed on the surfaces of soils colloids. When calcium hydroxide (lime) is added to soil, much of the hydrogen ( $H^+$ ) and other cations (e.g.  $H^+$ ,  $Mg^{2+}$ ,  $Na^+$ ) are displaced by the calcium  $Ca^{2+}$  in lime. The hydrogen displaced is then neutralized with hydroxyl ions ( $OH^-$ ) in lime to form water. In this process, the concentration of hydrogen ions in soil is reduced and the soil becomes less acid (i.e. pH value rises) as lime is added. The process can be represented by the following equation:



Lime also neutralizes these H<sup>+</sup> ions in soil solution, but the quantity of ions in solution is very small compared to the quantity absorbed by the soil particles (Buffer effect).

### 3.3 Cation Exchange Capacity

In the soil cations are attracted to neutralize negative charges that develop on the surfaces of organic and mineral colloids. Cation exchange capacity (CEC) of any soil is the sum total of all the exchangeable cations that the soil can absorb or that could be attracted to the surfaces of the colloids in the soil, CEC is the amount of exchangeable cations per unit weight of dry soil. The quantity of the cations is expressed in **milliequivalent per 100g of oven dry soil**. Milliequivalent is the amount of an atom or an ion that will react with or combine with one milligram of hydrogen (1.0mg H<sup>+</sup>), or eight milligram of oxygen (8.0mg  $\frac{1}{2}$  O<sub>2</sub>).

The “equivalent” unit has been changed to the new metric system (Miller and Donahue, 1990) being represented by moles (+) or mole, which indicates a monovalent ion portion. For example, 6meq/100g is now written as either:

6 cmol (+) Kg<sup>-1</sup> of soil (= centimoles)  
 60 mmol (+) Kg<sup>-1</sup> “ (= millimoles)  
 60 mmol ( $\frac{1}{2}$  Ca<sub>2+</sub>) Kg<sup>-1</sup> of soil (if Ca is used).  
 60 mmole Kg<sup>-1</sup> of soil (where c = one charge).

### 3.4 Characteristic of Cation Exchange Reactions

#### Bond Strength

The bond strength attracting cations to the surfaces of negatively charged soil colloids is strong enough so that the cations are not easily leached by water of infiltration, and at the same time, the bond is not too strong for the plant to absorb the cations.

The cations are held on varying degrees of tenacity, depending on their charges and their hydrated and undehydrated radii. Generally, ions with 2

or 3 valence are held more tightly than monovalent cation; whereas the greater the degree to which the ions is hydrated, the less tight it will be held on the colloidal surface. The approximate adsorption order from strongest to the weakest is  $H^+ = Al^{3+} > Ca^{2+} = Mg^{2+} > K^+ = NH_4^+ > Na^+$ .

### Cation Exchange Reactions are completely reversible

Implying that they can proceed in either directions. For example the reaction describing the displacement of calcium by potassium from exchange site.



represents the negatively charged surface. The reaction can go the either direction depending on the relative concentration of  $Ca^{2+}$  or  $K^+$  ions in soil solution. Most ions adsorbed on colloidal surfaces are readily exchangeable with other cations depending on the bond strength and whether the quantities are large enough to cause displacement by mass actions.

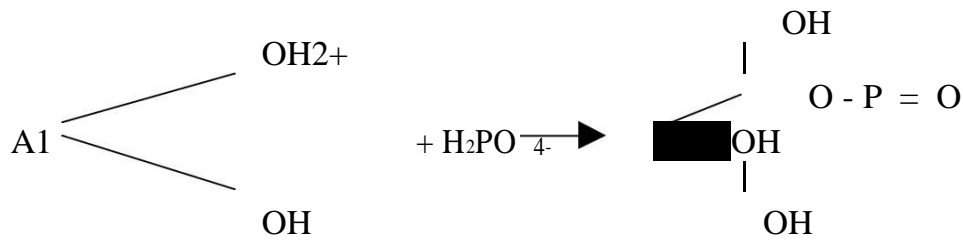
### Specificity

This means that not all exchange sites have equal capacity to attract all cations: some bonding sites are specific for certain cations. An example was the reaction of humic acid, montmorillonite, Kaolinite and muscovite with  $Ca^{2+}$  and  $NH_4^+$  ions: the result obtained was as follows:

#### % of Exchange Site occupied by

<u>Ca<sup>++</sup></u>	<u>NH<sub>4</sub><sup>+</sup></u>		
Humic Acid		92	8
Montmorillonite		63	37
Kaolinite		54	46
Muscovite		6	96

That is, humic acid has preference for  $Ca^{2+}$  ions as oppose to muscovite which prefers  $NH_4^+$  ions. Other examples of specific adsorption are known, and they are very important in agriculture. The most important are the fixations of  $K^+$  and  $NH_4^+$  by vermiculite: and the fixation of  $PO_4^{3-}$  by positively charged sites on kaolinite, or Fe and Al hydroxides. The fixation of  $K^+$  and  $NH_4^+$  occurs because of their hydration energies, and their ionic radii which is small enough to fit into the "hexagonal holes" in adjacent silica tetrahedral sheets. Fixation of  $PO_4^{3-}$  is believed to involve the replacement on hydroxide surfaces of  $-OH_2^+$  by phosphate anions (Evans *et al* 1982).



Exchange reactions are always *stoichiometric* meaning that they take place on equivalent weight basis. That is, one milliequivalent weight of a cation will displace or replace one milliequivalent weight of another cation.

**Example:** How many Kg Ca will be displaced by application of 100kg K per hectare?

**Solution:**

Equivalent weight of K = 39.1g  
 Equivalent weight of Ca = 20.0g  
 Number of equivalent weight of K in 100kg

$$= \frac{100 \times 1000}{39.1} = 2558 \text{ eq wt K.}$$

Therefore, same number of Ca, 2558 eq wt Ca will be displaced. 2558 eq wt Ca is then converted to Kg by multiplying by the equivalent weight of Ca (20g), viz: (2558 x 20)g

$$\frac{(2558 \times 20)}{1000} \text{ kg} = 51.16 \text{ kg Ca}$$

It is important to note that the number of negative sites in a given soil sample does not change but it is only the weights of adsorbed cations that are different.

### Calculating Exchangeable Cations in Soils

**Problem:** In laboratory analysis, the following values were obtained for exchangeable K<sup>+</sup>, calculate whether or not potassium fertilizer will be needed for a maize crop in each soil. If the critical value of K in maize is 400kg K<sup>+</sup>/ha – 30cm.

Description	Cmo1 of K/kg Soil
1. Well weathered paleudult sandy loam, pH4.9	0.22
2. Highly weathered sandy clay loam pH4.2	0.06
3. Semi-arid sandy loam pH 6.0	0.78

### Solution

Note that potassium fertilizer need depends on the crop, soil type, expected yield, soil test correlation for the area. The critical value has been given.

A hectare area 30cm deep has a volume of about  $100\text{m} \times 100\text{m} \times 0.30\text{m} = 3,000\text{m}^3$ . If the average bulk density is  $1400\text{kg}/\text{m}^3$ , then the weight of the soil would be  $3000\text{m}^3 \times 1400\text{kg}/\text{m}^3$  bulk density = 4,200,000kg of soil/ha – 30cm.

1 cmol  $\text{K}^+$  = (I) (atomic weight of  $\text{K}^+$ /100g

=  $\frac{39\text{g}_{\text{K}^+}}{100\text{g}} = 0.39\text{g}$

100g Soil

= 390mg of  $\text{K}^+$  per cmole of  $\text{K}^+$

The kilogram of  $\text{K}^+$  hectare – 30 centimeters is calculated using the 4 million Kg/ha – 30 cm approximation of soil weight.

i.e. 1 cmol of  $\text{K}^+$ /Kg soil = 390mg  $\text{K}^+$ /kg of soil

changing to mg unit = 390mg  $\text{K}^+$ /1,000mg of soil

multiplying by 4 = 1560mg $\text{K}^+$ /4,000,000mg of soil

converting to Kg units = 1560mg $\text{K}^+$ /4,000,000mg of soil

That is, 1 cmol of  $\text{K}^+$ /Kg of soil is equivalent to 1560 kg of  $\text{K}^+$  per hectare taken to depth of 30cm.

Therefore, for soil (1) above, amount of native soil  $\text{K}^+$  would

be  $\frac{(1560\text{Kg}\text{K}^+/\text{ha}-30\text{cm}) (0.22 \text{ cmol})}{\text{cmol}}$

cmol

94kg of  $\text{K}^+$ /ha – 30cm

Soil (3)  $\frac{(160 \text{ Kg } \text{K}^+/\text{ha} - 30\text{cm}) (0.78 \text{ cmol})}{1217\text{kg of } \text{K}^+/\text{ha} - 30\text{cm}}$

1217kg of  $\text{K}^+$ /ha – 30cm

### Conclusion

Soil 1 has a test value close to the critical value of 400Kg  $\text{K}^+$ /ha = 30cm and maize may have very little response to K fertilizers. It is marginal in need.



Soil 2 is low in potassium, response would be very high.  
Soil 3 would not respond to K fertilizer as typical of some arid and semi-arid soils.

### Laboratory Determination of Cation Exchange Capacity

Several methods of determining C.E.C of a given soil exist but the most widely used method in routine analysis is described here.

**Ammonium Saturation Method:** The soil is treated with  $N$   $NH_4$  OAC at pH7.0 in order to saturate the colloidal complex with  $NH_4^+$  ion. The excess salt is removed with ethanol, containing 5% water. Then the  $NH_4^+$  ion is displaced with  $K^+$  by treating it with 10% KCL at pH2.5. Finally,  $NH_4$  is measured in the displacing solution either by distillation and titration or other method. The amount of displacement is measured and expressed in term of meq per 100g oven-dry soil. However, the new unit (metric system) expressed weights of displaced cations in cmol (+) per kg of soil or mmol (+) per kg of soil.

Exchangeable Ca, Mg, K, Na,  $H^+$  and Al can be determined in the  $NH_4$  OAC extract and the sum of exchange cations and exchange acidity will give a good estimate of C.E.C. Other C.E.C methods are sodium saturation method (Na – Acetate at pH 8.2) and Barium saturation method (0.5N Barium Chloride pH 8.0).

**Exchangeable Cations:** The extracts prepared during the saturation process in CEC analysis, contain the exchangeable cations of the soil – Ca, Mg, K and Na. Sodium is in large amounts from saline soils while H and Al are high in acid soils. When Li and  $NH_4$  saturation is used, the extracts are suitable for determination of Ca, Mg, K and Na. Manganese (Mn) can be determined also in neutral  $NH_4$  OAC extracts.

**Exchange reactions are rapid:** they take place almost instantaneously and attain equilibrium rapidly.

**Cation exchange capacity is affected by surface area of soil colloids and are both related to colloidal structures:** Organic colloids have extremely complicated structures formed by the microbial decomposition of organic compounds. They have large surface areas and large cation exchange capacity that is pH dependent. Expandable clay minerals such as smectite or montmorillonite, have large surface areas; whereas non-expanding clay minerals, such as Kaolinite, have small. The ranges of cation exchange capacity and specific area of some soil colloids responsible for most soil Cation Exchange Capacity are outlined in Table 6.1.

**Table 9.1: CEC of some soil colloids**

Soil Colloid	CEC by N	Specific surface Area
	NH <sub>4</sub> AC, pH 7.0	
	<u>cmol kg<sup>-1</sup> of soil</u>	<u>M<sup>2</sup>/g</u>
Humus (organic-matter)	100 – 300	-
Kaolinite	3 – 15	3 – 30
Smectite (montmorillonite)	60 – 100	700 – 800
Vermiculite	80 – 150	300 – 500
Illite	10 – 40	100 – 200
Geotite	-	15 – 100
Hematite	-	15 – 200
Hydrous mica	25 – 40	-

### Effect of pH on Cation Exchange Capacity

Organic matter, hydroxides of Fe and Al, Kaolinite and chlorite clay minerals have CEC that are pH – dependent. This pH dependent cation emanates from the edge charges in Kaolinite and chlorite *protonation* of Fe and Al hydroxide surfaces, and the ionizable H in organic colloids. **Anion exchange capacity** may occur in acid solution and cation exchange capacities increase as the pH increases.

**Table 9.2 Effect of pH on soil CEC**

Soil type	Cation Exchange Capacity (cmol kg <sup>-1</sup> soil)			
	Soil pH	E.C.E.C.	N. NH <sub>4</sub>	Bac <sub>12</sub>
	<b>H<sub>2</sub>O</b>			
Alfisol rich in Kaolinite	5.0	2.67	3.20	4.64
Ultisol rich in hematite and gibbsite	4.7	2.14	4.13	25.64
Oxisol rich in hematite and goethite	5.1	4.00	15.65	16.99
Volcanic ash soil	5.1	13.08	20.80	30.52
Acid peat soil	4.8	99.00	-	184.0
				0

### 3.5 Source of Negative Charge in the Soil

As mentioned above, two main sources of negative charge in soil are the organic and inorganic (mineral) fractions:

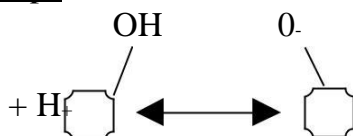
### 3.5.1 Organic Sources of Cation Exchange Capacity

This is the most important source in tropical soils. The negative charge from organic colloids emanates from the dissociation of hydrogen ion,  $H^+$ , from functional groups such as:

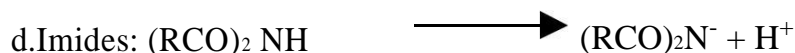
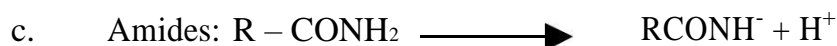
#### Carboxyl group



#### Phenolic – OH groups



These two groups ( $-COOH$  and  $-OH$ ) contribute about 90% of the CEC from organic sources in the soil. Other sources are the:



Consequently, the negative charges of soil organic fractions depend on soil pH and are highest in alkali soils. Other charges that are pH-dependent are those associated with 1:1 – type clays, the oxides of iron and aluminum and allophane.

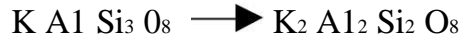
### 3.5.2 Inorganic Fractions

The negative charge on the inorganic fraction (mainly clay fraction) of soil originates from two sources namely, Isomorphous substitution and edge charge.

#### **Isomorphous Substitution**

By definition, **isomorphous substitution** is the replacement of one atom by another atom of similar size in a crystal lattice without disrupting the crystal structure of the mineral. Usually the substituting cation has a lower valence than the substituted cation thus resulting in a net negative charge on the clay mineral. The net negative charge is called *lattice charge* which occurs at the edge of clay crystal plates. In clay lattice structure aluminium ( $Al^{3+}$ ) substitutes for silicon ( $Si^{4+}$ ) in the *Silicon tetrahedral layers*, while  $Mg^{2+}$  substitutes for  $Al^{3+}$  in the *octahedral layer*.

Cations are attracted to the surfaces of the clay crystal plates to balance the negative charge which results from the isomorphous substitution. The type of cation attracted to the clay surface depends on what elements are present in the medium of the crystal. It may be potassium as in the case of feldspar:



The net negative charge (lattice charge) on the edge of the crystal of the mineral particle gives rise to cation exchange capacity (C.E.C). The charge on the 2:1 mineral clays in soils arises principally from isomorphous substitution and it is greater than the charge on the 1:1 clays. Examples of 2:1 clays are montmorillonite and vermiculite while Kaolinite is a 1:1 clay. The charge that comes from isomorphous substitution in the clay lattice is described as **permanent charge** whereas the charge that comes from the carboxyl and phenolic groups on soil organic matter and from the ionization of hydrogen from OH groups which occur at the broken edges of the crystal lattice of clays is referred to a **pH- dependent charge** or **variable charge**.

**Edge Charges:** Edge charge is the charge at the edge of clay mineral particles due to **unsatisfied oxygen bonds**. The edge charge arises from the ionization of hydrogen from OH groups at the broken edges of the crystal lattice of clays. The oxygen at the crystal has preference for hydrogen; that is, increases with increase in soil pH. For example, the CEC of clay particle could be calculated from the relationship:

$$CEC_{clay} = 30 + 4.4 (pH) \dots\dots\dots (i)$$

That is, at pH 7.0

$$CEC_{clay} = 30 + 4.4 (7.0)$$

$$= 60.8 \text{ me}/100\text{g of clay}$$

at pH 4.0,  $CEC_{clay} = 30 + 4.4 (4.0)$

$$= 47.6\text{me}/100\text{g of clay.}$$

For organic matter (Humus)

$$CEC (O.m) = 34 + 30 pH \dots\dots\dots(ii)$$

At pH 7.0  $CECo.m = 34 + 30 (7.0)$

$$= 186\text{me}/100\text{g of o.m.}$$

at pH 4.0,  $CEC = -34 + 120$

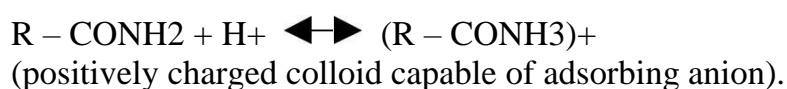
$$= 86\text{ME}/100\text{g of o.m.}$$

These two equations reveal that at the same soil pH, the CEC of organic matter is higher than that of clay materials.

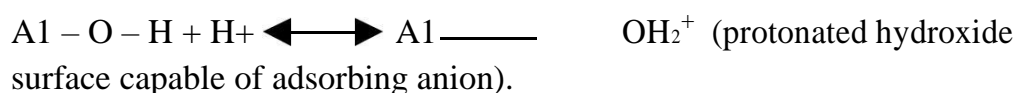
In some soil types high in 1:1 clay minerals (such as Kaolinite) and hydrous oxides of iron and aluminium, phosphate and sulphate anions are highly retained especially under acid conditions.

Using equation (ii) above and at pH 1.0  $CEC = -34 + 30 (pH) = -4 \text{ me}/100\text{g}$  gives negative CEC which is referred to as **anion exchange capacity** (AEC) which is very much pH – dependent. The more acid the soil, the greater the extent of anion adsorption. AEC is greater in soils high in 1:1 clays (e.g Kaolinite) and hence those containing hydrous oxides of Fe and Al.

Under very acid condition it is possible to have a AEC situation:



The hydroxides of Fe and Al and the OH groups at the edges of Kaolinite, will readily accept a hydrogen ion in acid solutions. When this situation occurs they become positively charged and capable of adsorbing anions.



In practical terms, AEC conditions are not found in most agricultural soils which normally have pH values at which anion adsorption does not occur.

#### 4.0 CONCLUSION

Owing to the surface-active sites of soil colloids, ions are exchanged between the solid and liquid phases of the soil. The cation exchange capacity of the soil is the sum total of all cations that can be held or exchanged by a given amount of soil. The cation exchange capacity is related to the soil buffering capacity. The knowledge of the soil CEC could be used to estimate the fertilizer needs of a crop thereby ensuring economic use of fertilizers

#### 5.0 SUMMARY

Ion (either cation or anion) exchange is one of the important properties of soils. Cation exchange capacity of the soil measures the quantity of cations that a given amount of soil can hold or exchange whereas anion exchange is a measure of total anions the soil can adsorb or exchange. The cation or anion exchange capacity of a named soil is a function of the type of colloidal materials – 2:1 layer silicate clays, 1:1 silicate

clays, organic colloids (humus), oxides of iron and aluminum and allopane – that constitute the soil.

Owing to the surface – active sites on soil colloids, ions are held by bond strength enough to hold the ions against leaching forces but still enables the plants to exchange  $H^+$  ions for nutrient ions such as  $Ca^{2+}$ ,  $K^+$  and  $OH^-$  for  $SO_4^{2-}$  and  $NO_3^-$ .

The buffering capacity of a soil (ability of the soil to resist change in pH and ions) is also a function of the cation exchange capacity. The higher the CEC the higher the buffering capacity and vice versa. The knowledge of CEC of a soil could be used to estimate the fertilizer needs of a crop thereby ensuring economic use of fertilizers.

## 6.0 TUTOR-MARKED ASSIGNMENT

Enumerate five most predominant cations commonly occupying the soil's cation exchange sites? Which two become dominant in strongly acid soils.

Describe four characteristics of cation exchange reactions in soils. Which one is most useful in purification of ground water? How?

What is the relationship between cation exchange capacity and buffering capacity?

Describe the importance of ion exchange property of the soil in plant nutrition.

Where in Nigeria would you find a soil fairly high in humus, 2:1 clays and 1:1 clays?

A soil contains 4% humus, 10% 2:1 clays and 10% Fe, Al oxides. What is the soil's cation exchange capacity?

Calculate the number of grams of  $Al^{3+}$  ions needed to replace 10 cmole of  $Ca^{2+}$  ions from the exchange complex of 1 kg of soil.

How many Kg  $K^+$  will be displaced by application of 100kg Mg per hectare?

What are the agricultural practices that could lead to an increase in the CEC of a soil?

Where in Nigeria could you find soils with high anion exchange capacity why?

## 7.0 REFERENCES/FURTHER READINGS

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## **MODULE 3      SOIL-PLANT NUTRIENTS INTERACTION**

Unit 1	Fertilizers as Agricultural Input
Unit 2	Nitrogen as Plant Nutrient Element
Unit 3	Phosphorus Nutrition in Plants
Unit 4	Potassium Nutrition in Plants
Unit 5	Sulphur, Calcium and Magnesium

### **UNIT 1      FERTILIZERS AS AN AGRICULTURAL INPUT**

#### **CONTENTS**

1.0	Introduction
2.0	Objectives
3.0	Main Content
3.1	Importance Fertilizer Terminologies
3.2	General Principles of Fertilizer Mixtures
3.3	Efficient Fertilizer use
3.4	Fertilizer Placement Methods
3.5	Fertilizer Efficiency
3.6	Fertilizer Application and the Environment
3.7	Chemical Composition of Fertilizers
3.7.1	Fertilizer calculations
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5.0	Summary
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7.0	References/Further Readings

#### **1.0      INTRODUCTION**

The importance of fertilizers as an agricultural input cannot be over emphasized, particularly in Nigeria where the nutrient levels of the soils in most areas are low. Crops require fertilizers in sufficient amount to give the maximum economic return. This of course depends on the cost of the fertilizers, the yield increase obtained and the local selling price of crops.

The use of fertilizers has increased very rapidly (3 times) in Nigeria in the last two decades. The most obvious effect of fertilizer is that it averts crop failures especially in areas of low soil fertility. Although, other techniques, such as breeding, crop protection, use of herbicides, could result in increased crop yields, fertilizer usage plays a major role in the universal need to increase food production to meet the demands of the growing world population.



A good grasp of the technical terms in common use in fertilizer management is essential for interpreting recommendations and for implementing the recommendations. Some of the terms in use are explained in this chapter.

## 2.0 OBJECTIVES

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

- explain the general principles involved in fertilizer use
- list the different types of fertilizers
- enumerate the different methods of fertilizer application
- explain important fertilizer calculations
- identify fertilizer sources and compounds for each nutrient element.

## 3.0 MAIN CONTENT

### 3.1 Important Fertilizer Terminologies

A **fertilizer** is an artificially prepared manure with a variable concentration of plant food. Fertilizers are mostly inorganic preparations although some like urea are organic compounds.

Fertilizers are available in the form of **single fertilizers, incomplete fertilizers** and **complete fertilizers**. Single element fertilizers contain only one fertilizer element. Examples are ammonium sulphate ( $\text{N}_2$ ), Urea (N), super phosphate ( $\text{P}_2\text{O}_5$ ), Mariate of potash ( $\text{K}_2\text{O}$ ).

**Incomplete fertilizers** contain two fertilizer elements, a typical example is Ammonium Phosphate ( $\text{N} + \text{P}_2\text{O}_5$ ). **Compound fertilizers** containing three elements are designated **complete fertilizers**. Ammonium phosphate which has an analysis of 11-45-0 is also called a compound two element fertilizer while an example of a complete fertilizer is compound 15-15-15.

All the above named fertilizers are called **inorganic fertilizers**. Similarly organic fertilizers are available in large quantities all over the world. In Nigeria, some of the organic waste considered to be possible sources of organic fertilizers could be classified as Industrial Organic Fertilizers and Non-Industrial Organic Fertilizers.

### **Industrial Organic Fertilizer**

The Industrial Organic materials include waste from brewery factories like molasses; waste from tobacco companies like tobacco leaf; waste from the canning industries such as orange or fruit peelings; bones, hooves, bones and blood from meat canning factories; sawdust from saw-mills and other by-products such as hey from milk factories. Industrial wastes in Nigeria depend upon the industrialization and sophistication of the town or state.

### **Non-Industrial Organic Fertilizers**

These are many and vary from town to town and state to state depending on their type of farming system or litter disposal. Non-Industrial Organic materials include cocoa pods, rice brans, bean pod, sorted town refuse, sewage and city waste; poultry droppings, animal dung, human faeces and urine. It also includes yam peelings, cassava peelings, straws of rices, maize, millet, sorghum and sugar-cane leaves.

### **Fertiliser Elements**

Fertiliser elements are those nutrient elements the demand for which is particularly critical in plant nutrition to the extent that they are focus of attention in fertilizer formulation. Nitrogen, Phosphorus and Potassium (NPK) are the primary elements, followed by the secondary elements calcium, magnesium and sulphur. Micro-nutrient elements like zinc, boron and molybdenum are in more recent years being increasingly included in fertilizer formulation to take care of micro-nutrient deficiencies where they occur.

### **Carrier**

A carrier is any material that contains (i.e carries) one or more of the fertilizer elements; ammonium sulphate (or sulphate of ammonia) is a carrier supplying nitrogen. The superphosphates supply phosphorus. Muriate of potash carries potassium. Ammonium phosphate contains both nitrogen and phosphorus.

### **Straight/Single/Simple Fertilizer**

Straight, single or simple fertilizers are those that supply only one primary element.

## **Mixed or Compound Fertilizer**

Mixed or compound fertilizers are those that contain more than one primary element. Those that contain only 2 of these elements are described as incomplete, while those that contain all 3 are referred to as complete fertilizers. A mixed or compound fertilizer can be a home mixture of 2 or more straight carriers, or a directed formulation from the factory.

## **Fillers**

Fillers are materials, which may or may not possess manorial value, added to compound fertilizers to make up the weight required to get them conform to a predetermined specification in terms of percentages of the active ingredient. Inert materials like fine river sand, powdered charcoal and kaolin were used in the past for this purpose.

More recently, materials like gypsum, dolomite and dried poultry manure have been used, to act as fillers at the same time that they serve other additive functions.

**Active Ingredient** refers to the primary nutrient nitrogen (N) and the oxidized forms of phosphorus (Phosphorus pentoxide,  $P_2O_5$ ) and potassium (potassium oxide  $K_2O$ ) in the straight carriers or mixtures supplying them. Active ingredients also refer to the oxidized forms of such secondary elements as magnesium ( $MgO$ ).

## **Fertilizer ratio**

This is a term which shows the percentages of the active ingredient N,  $P_2O_5$  and  $K_2O$  in this order, in a compound fertilizer. A 5:10:12 NPK mixture, for example, contains 5% N, 10%  $P_2O_5$  and 12%  $K_2O$ . A 10:10:10 mixture contains 10% nitrogen, 10%  $P_2O_5$  and 15%  $K_2O$ .

## **Fertilizer Analysis (or Fertilizer Guarantee)**

This is a statement of the proportion of plant food a fertilizer contains. The analysis for a straight carrier is the percentage of the active ingredient it supplies. When applied to a compound fertilizer, analysis refers to the sum of the percentage of the various ingredients it supplies. Fertilizer analysis is graded. Fertilizers guaranteed to supply less than 15% total active ingredients are described as low in analysis.

15-25% is medium analysis

25 – 30% in high analysis

over 30% is concentrated.

## Fertiliser Rate

Fertilizer rate is the quantity (weight) of fertilizer that should be applied per unit area of farm land for a given crop. Rate can be expressed as weight of straight carrier (or mixture of a given ratio) per hectare. Consider the following hypothetical examples: 300kg of a 15:15:15 NPK mixture per hectare, 150kg of ammonium sulphate per hectare. It is gradually becoming more conventional to express rate of fertilizer application in terms of weight of active ingredients per unit area of land, in which case the quantities by weight, of straight carriers that will supply them have to be proportionately calculated, so long as the analysis of the constituent is true. Exercises 1 to 2 contain examples of fertilizer rates expressed in terms of active ingredients per hectare.

### 3.2 General Principles of Fertilizer Mixtures

A mixed fertilizer is a combination of 2 or more straight carriers blended together so that the nutrients they carry are distributed in the field in a single operation.

#### Advantages of Mixtures

Lesser labour is involved in applying mixtures than in applying each of the components separately.

Mixtures lend themselves more easily to **granulation**

**Granules** are comparatively free from small dust-like particles.

Granules are less easily carried by the wind.

Granules retard the action of the fertilizer with the soil so that nutrients are not released faster than necessary.

There is room for correcting residual acidity in mixtures through addition of conditioners such as dolomitic limestone.

Small quantities of trace elements can be incorporated in mixtures so that the former become more evenly distributed in the field. Home made mixtures in particular have (a) definite educational and research value, (b) economic advantage—they may be cheaper than factory mixtures.

#### Limitations of Fertilizer Mixtures

No room to apply individual nutrients in type or amount at specific times they may be most seriously needed.

No room to pre-judge the quality of the individual plant nutrients in relation to the farmer, crop and soil.

Concentration of plant nutrient in a mixture may be less than that in the component, perhaps due to losses during manufacture.

Unit cost of nutrients is generally higher in mixtures.

### 3.3 Efficient Fertilizer Use

In the recent past, fertilizer recommendations have been made on regional basis (blanket recommendation) inspite of differences in parent materials, soil types, micro-climatic conditions, cropping history, land use pattern and other agro-ecological differences. Ideally, recommendations on fertilizer use on crops should be crop and soil, specific. Recommendations must emanate from well-researched soil testing programmes and not only from soil analysis. Amount of fertilizer to add to each crop is based on the inherent fertility of the soil which is usually classified as:

Low – the value below the critical level of the element.

Medium – the range above critical level but at which response can (Moderate) still be obtained.

High – the range where response is not likely to occur and fertilizer application is not economical.

Using the above criteria, fertilizers are added to crops in such quantities that will reduce wastages, and minimize or guide against soil and water pollution through the addition of excessive fertilizers.

### 3.4 Fertilizer Placement Methods

The method to use depends on the crop, cropping system, nature of fertilizer materials, labour cost among others.

**Broadcast:** The fertilizer is spread uniformly over the surface of the land before or after planting. It may or may not be worked into the soil. The slowly dissolving fertilizers, such as P, should be worked into the soil. Urea should be worked into the soil because it is volatile especially if soil is dry and temperature is high. Others such as  $(\text{HN}_4)\text{SO}_4$  and KCl may be applied on the surfaces but run-off may occur on sloppy surfaces where intensity of rainfall may be greater than infiltration rate. This method is suitable for those crops whose seeds are usually broadcast.

**Ring Application:** For plants that are far placed apart such as tree crops-oil palm, cocoa, rubber, plantain, etc.

**Row, Band, or Side-Dressing:** Usually applied to the side(s) in a band and usually 5 to 10cm to the side and about 5cm deep. Machines are designed to achieve this. Row application is used for crops grown in rows at close spacing such as maize, cowpea,

soyabeans, tomato, cotton and potato. Band placement minimizes fertilizer-soil contact and reduces P-and K-fixation.

**Spot Application:** Similar to ring application, but in addition, holes are made in a ring form round the crop so as to make the fertilizer go down deep into the soil. It is used to apply fertilizer to deep-rooted permanent crops such as orange and palms.

**Top-Dressing:** The fertilizer is applied to the crop after emergence. Top-dressing usually refers to broadcast application on crops such as small grain or forage as a second dose on the soil surface close to the plants when they are 3-4 weeks old. Nitrogen fertilizers are usually applied with this method.

**Foliar Application:** Particularly used for micro-nutrients such as Fe, Mn, Cu, Zn, Mo, Bo and Cl; leaves are able to take up directly the small amounts needed by plants when applied in liquid form. Concentration of nutrient in solution is less than 1% to avoid leaf burn. This method is used for deep rooted trees whose roots grow into sub-soil beyond fertilizer zone. Foliar spraying avoids problem of nutrient fixation when applied to the soil.

### 3.5 Fertilizer Efficiency

The amount of fertilizer nutrient absorbed by the plant compared to the quantity of the fertilizer nutrient added to the soil gives the efficiency (Fe). It is expressed in percentages.

$$\text{Fe} = \frac{\text{Nutrient in plant}}{\text{Nutrient added}} \times \frac{100}{1}$$

It is assumed that plants do not absorb excess nutrient, but this is not so, since plants will continue to absorb nutrients for as much as it is available; this is known as **Luxury consumption** by plants. The second assumption is that all nutrients absorbed are necessary for increased yield. Nitrogen, phosphorus and potassium have about 30-70%, 5-30% and 50-80% of their added nutrient utilized by plants respectively. Since maximum efficiency is difficult to achieve for reasons of management changes, profitability and environmental factors, the goal of any farmer is to achieve optimum fertilizer efficiency, which gives best results for the expenditures of money, time and equipment.

### 3.6 Fertilizer Application and the Environment

Use of fertilizers has two major global effects on the environment.

**Pollution of Drinking Water:** The highly mobile nutrients such as nitrogen easily finds its way to underground water and streams when added in large doses and repeated applications. It was found that the amount absorbed by crops is about 50%, amount fixed in organic form by microbes is approximately 30%, amount lost through denitrification is 15% while the amount usually lost by leaching is 5%. Nitrogen is lost by leaching in form of nitrate ( $\text{NO}_3^-$ ) which in sub-soil could be reduced to nitrogen dioxide,  $\text{NO}_2$ , which in turn induces methaemoglobinemia in infants. There is also a risk of production of carcinogenic nitrosamines from nitrates and nitrites. World Health Organization (WHO) does not allow to exceed 10ppm  $\text{NO}_3^- - \text{N}$  so as to avoid nitrate poisoning.

**Eutrophication and Fertilizers:** Excess fertilizer – nutrients especially phosphates and nitrogen that find their ways to lakes and rivers promote the growth of plants, animals and microbes in those lakes and rivers. The result is usually oxygen deficiency, preponderance of anaerobic organisms, accumulation of methane-ethylene, hydrogen sulphide ( $\text{H}_2\text{S}$ ) which are toxic to aerobic organisms.

### 3.7 Chemical Composition of Fertilizers

The composition of a fertilizer element in a fertilizer formulation is expressed in percents. If ammonium sulphate has an analysis of 21% N, it means that in every 100kg of ammonium sulphate there is 21kg of available nitrogen. The analysis of most fertilizer materials available commercially is expressed by a numbering system showing the percentage of composition of each element in the order N-P-K. These numbers are printed on the label of each fertilizer container. Though the label is P and K in reality the percentage is expressed in terms of  $\text{P}_2\text{O}_5$  and  $\text{K}_2\text{O}$ .

The chemical composition of the common fertilizers is given below:

- |    |                                |              |
|----|--------------------------------|--------------|
| 1. | Sulphate of Ammonia (S/A)      | - 20 – 21% N |
|    | $(\text{NH}_4)_2\text{SO}_4$   | - 24% S      |
|    | Urea                           |              |
|    | $\text{CO}(\text{NH}_2)_2$     | - 45 – 46% N |
| 3. | calcium Ammonium Nitrate (CAN) | - 25% N      |
| 4. | Diammonium Phosphate           | - 21% N      |

	Single Super Phosphate	
	Ca (H <sub>2</sub> PO <sub>4</sub> ) <sub>2</sub> H <sub>2</sub> O	- 18.0, 21% Ca
	CaSO <sub>4</sub>	- 12% S
6.	Super Phosphate double or triple	- 45-50% P <sub>2</sub> O <sub>5</sub>
	Ca (H <sub>2</sub> PO <sub>4</sub> ) <sub>2</sub> ·H <sub>2</sub> O	- 12 - 14% Ca
		- 12% S
7.	Boronaced super phosphate (BSP)	- 18.5% P <sub>2</sub> O <sub>5</sub> - 2% Boron
8.	Muriate of potash (MOP)	- 60% K <sub>2</sub> O
	NPK 26-12-0 – 26% N/+ 12% P <sub>2</sub> O <sub>5</sub>	
	NPK 20-20-0 - 20%N+20% P <sub>2</sub> O <sub>5</sub>	
	NPK 15-15-15 - 15%N+15%P <sub>2</sub> O <sub>5</sub> +15% K <sub>2</sub> O	
	NPK 27-13-13 – 2MgO – 27% N + 13% P <sub>2</sub> O <sub>5</sub> + 13% K <sub>2</sub> O.	

### 3.7.1 Fertilizer Calculations

Like the numbering system for expressing an analysis of fertilizers, fertilizer recommendations are given in kilogrammes of nutrient elements/ha in the order N.P.K. If only N is needed, the rate is given in kilogrammes of N Ha. When the recommended rate of fertilizer is given, one must be able to weigh the exact amount of the appropriate fertilizer material to be applied to each individual plot, bucket or pot. The following procedures are adopted in calculating the various amounts of fertilizer material required.

#### Example 1a

How much of sulphate of ammonia is required for a top dressing of a gross experimental area of 500m<sup>2</sup>. If the dose is 30kg/ha N?

#### Solution

Recommendation is 30kg ha N. the % of N in sulphate of ammonia =

Quantity of ammonium sulphate required for a hectare at the above recommendation is:

$$\frac{100}{20} \times \frac{30}{1} = 150\text{kg of ammonium sulphate/ha}$$

Quantity required for 500m<sup>2</sup> is:

$$\frac{100}{20} \times \frac{30}{1} \times \frac{500}{10,000} = 7.5 \text{ kg}$$



**Example 1b**

How much of this fertilizer is required for a plot of 50m<sup>2</sup>?

**Solution**

Quantity required for 50m<sup>2</sup> is  $\frac{100}{20} \times \frac{30}{1} \times \frac{50}{10,000} = 0.75\text{kg}$  or 750g.

**Example 1c**

How much of this fertilizer is required for a pot containing 10kg of soil?  
Note 2,000,000kg of soil is equivalent to one hectare of land.

**Solution**

Quantity required for 10kg of soil

$$\frac{100}{20} \times \frac{30}{1} \times \frac{10}{2,000,000} \times \frac{1000}{1} = 0.75\text{g}$$

**Example 2**

A recommendation of 20kg/ha N, 60kg/ha P and 30kg/ha K is made for basal application of a varietal trial. The fertilizers to be used are urea, triple super phosphate and muriate of potash. What are the quantities of fertilizer required for a single trial plot 50m<sup>2</sup>.

**Solution**

Recommendation is 20kg/ha N

60kg/ha P<sub>2</sub>O<sub>5</sub>

30kg/ha K<sub>2</sub>O

% N in Urea = 45

% P<sub>2</sub>O<sub>5</sub> in triple super phosphate = 50

% K<sub>2</sub>O in muriate of potash = 60

Quantity required/ha =

$$\frac{100}{45} \times \frac{20}{1} \text{ kg urea/ha} \quad \frac{100}{1} \times \frac{60}{1} \text{ kg triphos/ha}$$

$$\frac{100}{60} \times \frac{30}{1} \text{ kg muriate of potash/ha}$$

Quantity required/plot of 50m<sup>2</sup> is

$$\frac{100}{50} \times \frac{20}{1} \times \frac{50}{10,000} \text{kg. Triphos Urea}$$

$$\frac{100}{50} \times \frac{60}{1} \times \frac{50}{10,000} \text{kg. Triphos}$$

$$\frac{100}{60} \times \frac{30}{1} \times \frac{50}{10,000} \text{kg muriate of potash.}$$

#### 4.0 CONCLUSION

Both organic and inorganic fertilizers constitute an indispensable farm input worldwide. Fertilizer use management in crop production, is very essential to achieve profitable and maximum crop yields, especially in tropical soils which have low reserves of plant nutrients. For successful fertilizer use it is essential to be knowledgeable about the formulation, rates, chemical compositions and appropriate application methods for the various fertilizer nutrients.

#### 5.0 SUMMARY

In this unit, you have learnt:

- the definitions of important terms in fertilizer usage.
- general principles in fertilizer mixtures
- the benefits and limitations of the various methods of fertilizer application
- calculations involved in fertilizer use.

#### 6.0 TUTOR-MARKED ASSIGNMENT

Describe the following methods of fertilizer application with specific examples:

- Broadcast
- Band
- Ring
- Foliar

Find how much of Urea (46%N), triple super phosphate (45% P<sub>2</sub>O<sub>5</sub>) and Muriate of potash (60% K<sub>2</sub>O) is needed to prepare 2000kg of a fertilizer with a grade of 20-10-10.

## 7.0 REFERENCES/FURTHER READINGS

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## **UNIT 2     NITROGEN AS PLANT NUTRIENT ELEMENT**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Forms and Function of Nitrogen in Plants
  - 3.2 Forms of Nitrogen in Soil
  - 3.3 Nitrogen Gains and Losses in Soil-Plant System
    - 3.3.1 Means by which Nitrogen is added to Soil-Plant System
    - 3.3.2 Factors Affecting Mineralization and Nitrification Processes
    - 3.3.3 Losses of Nitrogen from Soil-Plant System
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Of all the 16 essential plant nutrient elements needed for plant growth, development and reproduction, nitrogen is the most important and most easily limiting or deficient throughout the world particularly in the tropics. Animals and man depend on the protein manufactured by plants from nitrogen which could be regarded as the key nutrient in plant growth. This unit examines the forms and functions of nitrogen in plant, the gains and losses in soil-plant system and those factors that govern nitrogen transformations in soil.

### **2.0 OBJECTIVES**

By the time you complete this unit, you should be able to:

- describe the specific functions of nitrogen as a plant nutrient element
- describe the several forms of nitrogen compounds in soil
- list the various ways by which nitrogen is added to and lost from the soil-plant system
- describe how nitrogen transformation processes in the soil are affected by other factors
- describe the nitrogen cycle.

### **3.0 MAIN CONTENT**

### 3.1 Forms and Functions of Nitrogen in Plants

Nitrogen gas,  $N_2$ ; which accounts for about 78% of atmospheric gas has to be converted into two forms utilizable by plants before it can be regarded as useful to the plants. These two forms are the cation form, ammonium ions ( $NH_4^+$ ) and the anion form, nitrate ( $NO_3^-$ ). It is not clear yet which of the two forms is preferred by plants. If the nitrate form,  $NO_3^-$  is absorbed by plants, it has to be reduced in plant tissue to amino form ( $-NH_2$ ) which is utilized directly to form organic nitrogen compounds such as glutamic acid (an amino acid). More metabolic energy (ATP) is expended by plants fed with nitrate than those supplied with ammonium. Plants can also take up nitrogen in form of amino acids. Plants can utilize  $NO_3^-$  because they possess a special enzyme system (not found in animals) for reduction of  $NO_3^-$  to ( $NH_4^+$ ) a process often referred to as **assimilatory nitrate reduction**. The overall reaction is depicted by the equation below:



Although, nitrate appears to be more available than ammonium,  $NO_3^-$  uptake is a wasteful way of taking up nitrogen. It has been found that urea as well as amino-acids could be taken up just as the uptake of  $NH_4^+$  and  $NO_3^-$ .

Most normal agricultural plants contain 1 to 6% nitrogen which is an important structural component of many compounds necessary for plant growth and development. Nitrogen is a major constituent of chlorophyll (for example, chlorophyll a with molecular formula  $C_{55}H_{72}O_5N_4Mg$ ), protein and related amino acids, various enzymes, nucleic acids and many other compounds in the cell of plants. Other functions of nitrogen in plants include carbohydrate utilization, root growth and development, above ground vegetative growth and stimulation of uptake and utilization of other nutrient elements such as potassium, phosphorus and sulphur.

#### Deficiency Symptoms

Nitrogen is a **mobile element** and therefore deficiency symptom shows up first in the older parts (leaves or stem) of the plants and later extends to younger portions of the plants. When nitrogen becomes insufficient in supply, the nitrogen already absorbed into the plant moves and translocates to the younger leaves and stem parts from the older leaves hence nitrogen is described as being **mobile**.

Nitrogen insufficiency results in the yellowing of lower (older) leaves beginning at tips extending backwards along inner margin (midrib) as deficiency becomes more severe. The yellowing is due to lack of chlorophyll since nitrogen is a component of chlorophyll. The whole plant may be stunted in growth and develop restricted yield if any.

A peculiarity of nitrogen is that deficiency symptom disappears within few days if N-fertilizer is restored.

**Excess Nitrogen:** Over-supply of nitrogen to crops may make them develop excessive vegetative growth at the expense of reproductive development. The crop has dark green luxuriant lanky growth and abnormal cells due to insufficiency of other elements such as K, Ca and Mg. Lack of Ca results in thin cell wall rendering the plant susceptible to lodging and attack by pests and diseases.

### 3.2 Forms of Nitrogen in Soil

Soil nitrogen exists in three main forms namely:

Mineral and gaseous forms.

Ammonium nitrogen fixed in 2:1 layer silicate clay

Organic nitrogen associated with soil organic matter. The first two forms constitute inorganic nitrogen pool in the soil.

Similarly, nitrogen exists in many oxidation states as presented in Table 11.1 or in valence states from  $-3$  to  $+5$  mainly in important gaseous forms ( $N_2$ ,  $NH_3$ , nitrogen oxides).

**Table 11.1: Nitrogen in Valence states**

Nitrogen compound	Molecular formular	Oxidation State of Nitrogen	% of Total N
Nitrate	$NO_3^-$	+ 5	1%
Nitrite	$NO_2^-$	+3	Few ppm
Nitrous oxide	$N_2O$	+1	Trace
Nitric oxide	NO	+2	Trace
Ammonia	$NH_3$ , $NH_4^+$	-3	0 – 2%
Nitrogen gas	$N_2$	0	Gas
% of total N in Soil		=	1 – 5%

#### In-Organic Nitrogen in Soil

Only a small amount of nitrogen in the soil is in available forms being useful to plants ( $NH_4^+$  and  $NO_3^-$ ) and accounts for about 1-5% of total N

while the remainder of the total N is in the organic form (about 98.6%). Non-exchangeable N is  $\text{NH}_4^+$  combined in the interlayer spaces of clay minerals such as vermiculites and some smectites. Similarly, N is present in the form of  $\text{NH}_4^+$  fixed in mineral lattices of sedimentary rocks. The amount is small and makes little contribution to soil available N. In layer silicates, such as vermiculite clay mineral, the excess negative charge which arises from **isomorphous substitution** is usually satisfied by  $\text{K}^+$  and  $\text{NH}_4^+$  which fit in perfectly well between the spaces of the clay minerals. The available  $\text{NH}_4^+$  and  $\text{NO}_3^-$  are supplied from aerobic decomposition of soil organic matter or added to the soil as chemical nitrogen fertilizers.

### Organic Nitrogen

Organic N in soil constitutes about 95 to 99% of total N and it is distributed as follows:

- Combine amino acids (protein, peptides): 30-45%
- Combined Hexosamines (aminopolysaccharides) : 5 – 10%
- Cellulose, lignin, nucleotides etc : 1-2%
- Unidentified : 40-60%

Soil organic matter (SOM) contains, on the average, about 5% N by weight but varies between 3-7%. Only about 1-3% of the total N contained in SOM is released yearly by decomposition. The amount of N in the soil could be estimated from organic matter content. For example, if organic matter is 2% and assuming weight of 1 hectare land area 15cm depth is  $2 \times 10^6 \text{kg}$

Then weight of O.M, is  $5\% \times 2 \times 10^6 \text{kg}$ .

weight of N is  $5\% \times 2\% \times 2 \times 10^6 \text{kg}$ .

$0.05 \times 0.02 \times 2 \times 10^6 \text{kg}$ .

2000kg/ha.

It is estimated that about 1- 3% of total N in soil becomes available during the growing season. If we take 2% as average of 1- 3%, therefore, amount of N available or released from organic matter is  $2\% \times 2000 \text{kg}$  or  $0.02 \times 2000 = 40 \text{kg N}$ . Assuming that maize yield of 2 tonnes/ha needs about 120kg N during the growing season; therefore, the 80kg N deficiency has to be supplied as N-fertilizer.

### 3.3 Nitrogen Gains and Losses in Soil-Plant System

The **nitrogen cycle** (fig 1) shows soil nitrogen changes, inputs and losses, during the growth period of the plants as describe below.

### 3.3.1 Means by which Nitrogen is added to Soil-Plant System

#### Rainwater

There are atmospheric nitrogen compounds such as ammonia, nitrates, compounds released from the soil and plants, compounds from the soil and plants, and compounds from coal and petroleum industrial areas which are usually added to the soil through rain. Nitrogen inputs through rainfall are location-and season-dependent, usually greater around industrial cities, near large animal feed lots and areas with high annual precipitation such as the tropics. The supply of N through rain fall may be up to 5 to 25kg/ha/year nitrogen, in a readily available form, thus assisting in the maintenance of soil fertility.

#### Nitrogen Fixation

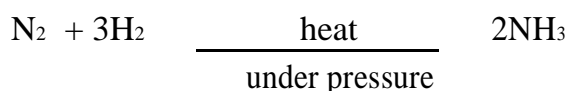
The amount of dimolecular nitrogen in the air is about 2500 times larger than the global amount of combined nitrogen. This dinitrogen (N<sub>2</sub>) has to be converted into forms useable by plants. This change of N<sub>2</sub> gas to plant utilizable forms is known as **Nitrogen fixation** and it is carried out mainly by microorganisms in the soil in which case it is known as **Biological N- fixation** or through electric discharges (during lightning and thunder-storm) in which case the process is **electric fixation**. **Chemical fixation** occurs in the laboratory.

#### Electric Fixation

Nitrogen compounds such as nitrous oxide (N<sub>2</sub>O) and nitric acid (NO, NO<sub>x</sub>) come mainly through electric discharge during lightening or thunderstorm. The distribution of lightening over the globe is not equal being higher in the tropics than elsewhere. The principal form of NO<sub>x</sub> being from lightening is NO which has low solubility in water. The nitrogen oxides have to be either in form of nitric acid or nitrogen dioxide (NO<sub>2</sub>) to be easily removed from the atmosphere by precipitation. There could be a small transformation rate from nitric oxide to form nitric acid (HNO<sub>3</sub>) but that thunderstorm could be a substantial source of NO<sub>x</sub> and that the total quantity of nitrogen added to the soil is not insignificant.

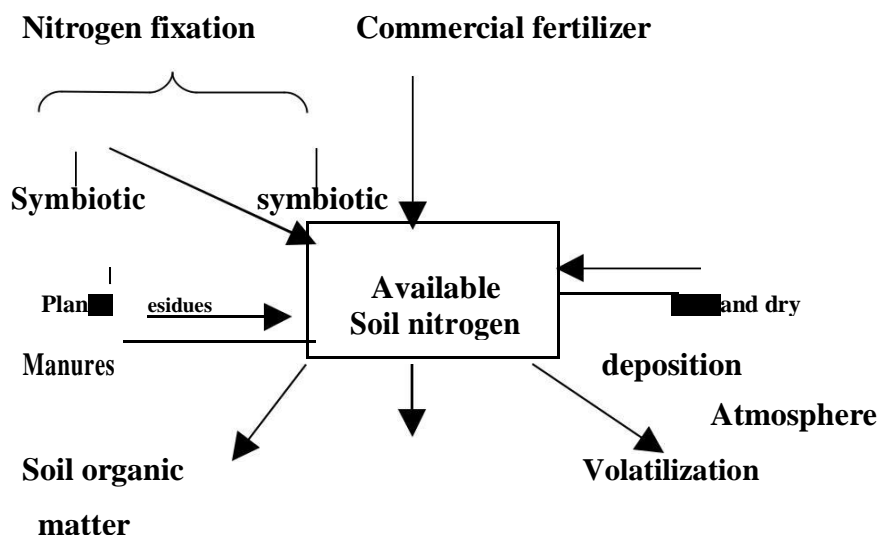
#### Chemical Fixation

This process occurs in the laboratory whereby ammonia gas is formed from the elements hydrogen and nitrogen.





The process requires high temperature and pressures while it consumes large quantities of energy. Natural gas is the source of hydrogen and the  $N_2$  comes from the atmosphere. Several nitrogen compounds and fertilizer materials are then derived synthetically from ammonia. Some of these materials are nitrogen solutions, urea, ammonium nitrate, ammonium sulphates and ammonium phosphates.



Plant removal Leaching losses Erosion losses

Figure 11.3: Major gains and losses of available soil nitrogen

The widths of the arrows roughly indicate the magnitude of the losses and the additions often encountered. It should be emphasized that the diagram represents average conditions only and that much variability is to be expected in the actual and relative quantities of nitrogen involved. [from Brady and Weil (1999)].

### Biological Nitrogen Fixation

Biological nitrogen fixation is the conversion of dinitrogen ( $N_2$ ) in soil air into combined forms useable by the plants and effected by microorganisms. Some groups of microbes live freely in the soil where they are able to convert  $N_2$  into body tissue nitrogen form and when they die and decompose, the combined nitrogen is released for plant use. These groups of free living N-fixers are known as **Non-symbiotic nitrogen fixing microorganisms**. In the tropics *Azotobacter* and *Bjeirinckia* species are known to be free-living microbes that fix  $N_2$  under aerobic well aerated soils of pH 6.0. *Clostridium spp.* Are free-living bacteria that fix  $N_2$  under anaerobic conditions in soil. Other-living soil micro-organisms that fix nitrogen are blue -green algae and *Azospiriullum* in the rhizosphere of certain plants. The range of fixed N by these group of non-symbiotic microbes is between 2-25 kg/ha/year.

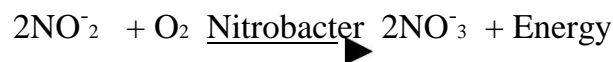
In **symbiotic fixation**, bacterial and *actinomycetes* effect the formation of **root nodules** (abnormal root growth) in both legume and non legume plants and then inhabit those nodules where they fix nitrogen. The host plant supplies the bacteria with carbohydrate as source of energy, and the bacteria supplies the plant with fixed nitrogen compounds. In effect, both the plant and the microorganism have a mutually beneficial association known as *symbiosis*. There are various species of Rhizobium bacteria that inhabit different plant species such as *R. trifolic* which inhabit clovers, *R. japonicum* for *Glycine max* (soyabeans) and *R. Phaseoli* which associates with *Phaseolus vulgaris* (dry beans). Appropriate Rhizobia cultures are used to inoculate the soil for a particular crop to nodulate for the fixation of nitrogen.

### Organic Matter Decomposition and Mineralization of Nitrogen

The release of ammonium-nitrogen from soil organic matter decomposition by heterotropic soil organisms through series of enzymatic digestion of complex protein compounds is known as **mineralization** of nitrogen. That is, organic – N is converted to usable mineral – N. This is a major source of nitrogen in non-fertilized soils.

### Nitrification of Ammonium

The mineralized ammonium ions have very short lifetime because it is rapidly oxidized to nitrate anions by bacteria in a two-step process called **nitrification**. First the ammonium is transformed to nitrite by **Nitrosomonas** bacteria and then to nitrate by **Nitrobacter** as shown below:



That is,  $2\text{H}^+$  is released when  $\text{NH}_4^+$  is oxidized to  $\text{NO}_3^-$  during nitrification which thus contributes to soil acidity.

**Fertilizer-N addition:** Nitrogen fertilizers applied to crops supplement the quantity of nitrogen already present in the soil.

### 3.3.2 Factors Affecting Mineralization and Nitrification Processes

Mineralization and nitrification being microbial processes are affected by conditions that affect the activities of bacteria in soils. The conditions are temperature, soil water, oxygen supply, soil pH, presence of other nutrients, inhibitors, and carbon nitrogen ratio of the decomposing material. The effect of these conditions on soil microorganisms have been mentioned in earlier units of this course.

### 3.3.3 Losses of Nitrogen from Soil-Plant System

Apart from nitrate ( $\text{NO}_3^- - \text{N}$ ) and ammonium ( $\text{NH}_4^+ - \text{N}$ ) which are plant utilizable forms of nitrogen in the soil, other forms of inorganic N such as nitrogen dioxide ( $\text{NO}_2$ ), nitric oxide ( $\text{NO}$ ) ammonia ( $\text{NH}_3$ ), nitrous oxide  $\text{N}_2\text{O}$  and nitrogen gas ( $\text{N}_2$ ) do exist having been transformed from organic fractions. However, these other forms usually escape to the atmosphere in gaseous forms completely away from the soil-plant system. They are regarded as nitrogen losses and are usually the products of **denitrification** and **volatilization**.

Other losses are through **crop removal** or by harvest, **erosional losses** and **liquid leaching losses**. Certain portions of nitrogen ( $\text{NH}_4 - \text{N}$  and simple amino compounds) are held on negatively charged sites in the soil in the interlayer spaces of 2:1 clay minerals and are also unavailable to crops but cannot be regarded as losses since they can still be released for plant use under certain soil conditions.

## 4.0 CONCLUSION

Nitrogen is the main nutrient in plant growth and the most limiting throughout the world particularly in the tropics. The nitrogen cycle emphasizes the various ways by which plant utilizable forms of nitrogen ( $\text{NH}_4^+$  and  $\text{NO}_3^-$ ) are added to the soil and the several means by which same nitrogen forms are lost from the reach of the plants.

## 5.0 SUMMARY

In this unit we have learnt:

- about the functions of nitrogen as the most limiting nutrient element in plants.
- that nitrogen exists in various forms and oxidation states in soils
- the various ways by which plant utilizable forms of nitrogen are added to the soil
- several means by which nitrogen is lost from the reach of the plant.

## 6.0 TUTOR-MARKED ASSIGNMENT

Discuss the benefits and problems of nitrogen added to soils by man and by natural processes each year  
Describe the following terms:

Mineralization  
Luxury consumption  
N-fixation  
Denitrification  
Mobile element.

## 7.0 REFERENCES/FURTHER READINGS

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## UNIT 3 PHOSPHORUS NUTRITION IN PLANTS

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### 1.0 INTRODUCTION

Phosphorus, P, is the second most critical element influencing plant growth and production throughout the world. Phosphorus is taken up by plants from soil solution as primary and secondary orthophosphates anions ( $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$ ) depending on the pH of the soil. We refer to these two forms of phosphorus as **phosphates** which are equal in quantity when soil pH is about 7.2.

### 2.0 OBJECTIVES

After completing this unit, you should be able to:

- list the functions of phosphorus in plants
- describe various forms of phosphorus in soil
- define p-fixation/solubility and identify the factors that affect these P-reactions in soils
- explain some P-availability indices or chemical extraction methods

### 3.0 MAIN CONTENT

#### 3.1 Forms and Functions of Phosphorus in Plants

#### 3.2 Amount of in Plant Tissue

Amount of P in plant tissue is about 0.1 to 1.0% and it is present as an essential part of nucleoproteins in the cell nuclei, which control cell division and growth, and a portion of **deoxyribonucleic acid (DNA) molecules**, which carry the inheritance characteristics of living organisms. Phosphorus is also essential component of several organic compounds in plants and animals especially the two compounds involved in energy transformation in plants, adenosine diphosphate (ADP) and adenosine triphosphate (ATP) which supplies energy for all the numerous metabolic processes. Phosphorus is also a component of ribonucleic acid (RNA) essential for protein synthesis. Other compounds containing P are phospho-lipids, phitin, phosphorylated sugars, nucleoprotein, nucleic acids, pyridine nucleotides (TPN, DPN) and flavin nucleotides (riboflavin – B<sub>2</sub>).

#### 3.3 Functions of Phosphorus in Plants

In its many compounds phosphorus has many significant role in plants among which are:

- Energy transfer reactions (TPN) in various metabolic processes in plants.
- Cell division and multiplication.
- Formation of fat and albumin.
- Involvement in the conversion of starch to sugar during cell respiration.
- Flowering and fruiting, including seed formation.
- Crop maturity in which phosphorus counteracts the effects of excess nitrogen application.
- Strengthening of cereal straws, therefore preventing lodging.
- Root development particularly fibrous and lateral roots.
- Improvement of crop quality in forages and palatability of vegetables.
- Increased resistance to diseases.

Plants containing adequate quantities of P are beneficial to animals and humans for growth of bones and teeth which are mainly calcium phosphates.

### 3.4 Phosphorus Deficiency and Toxicity

Since P is a mobile element, deficiency symptoms first show up in older leaves of plants. The deficiency symptoms may appear as:

Stunted overall growth of whole plant compared to normal plants.

Dark green colour, dark red to purple discolouration of stems, and at times dull green. Protein synthesis is impaired, vegetative growth is depressed. P-deficient plants have limited root system and thin stems. In cereals, tillering is affected.

There is a deposition of starch in roots. Stems of annual plants have reddish green colour because of formation of anthocyanins. Leaves are tinged with brownish colour and fall off prematurely. Phosphorus contents of P-deficient plants are usually low (0.1% P).

When cereal and herbage are supplied with P, their P-content may go up to about 0.3 to 0.4%. Phosphorus toxicity is not common, but when it occurs it leads to reduced growth due to retardation of up-take and translocation of micro-nutrients including zinc, iron and copper.

### 3.5 Forms of Phosphorus in Soil

The major sources of phosphorus in soil are parent material (the apatite group of primary minerals), plant and animal residues and inorganic fertilizers.

Total soil P contents vary considerably over a wide range and depends on the organic matter content, parent material and degree of weathering. A value of 120 to 1880g g<sup>-1</sup> (or 268.8 to 4211.2kg per hectare) had been quoted for Nigerian soils.

#### 3.5.1 Inorganic Phosphorus in Soils

Inorganic phosphorus constitutes 20 – 80% of total phosphorus in most soils and is usually associated with calcium and magnesium or with the oxides and hydroxides of aluminum, iron, and manganese. The various forms of inorganic phosphorus in soil are explained as follows:

##### **Solution-Phosphorus**

This form is also called available phosphorus because it is the form taken up by plants. These P-forms are  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$ , the combined concentration of which is very low in soils with a range of about 1-3 mg

P per ml. A value of 0.01 to 0.02mg P per litre were found in saturated extracts of three Northern Nigerian ferruginous soils by Bache and Rogers (1970).

Phosphate in solution represents the **intensity factor** while the other phosphorus forms constitute the **quantity or capacity factor**. The ratio of  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$  in soil solution is pH dependent. That is, high  $\text{H}^+$  concentrations shift the equilibrium to the more protonated form according to the equation.

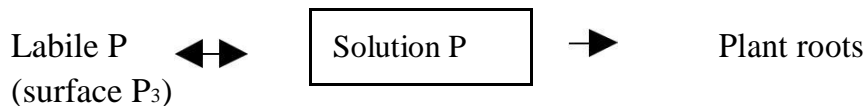


At pH5,  $\text{HPO}_4$  is almost absent whereas at pH 7.0 both phosphate species are present in almost equal proportions.

Usually, the amount of phosphorus in solution is much less than plant need. The soil must therefore contribute to P-nutrition of plants from other sources such as the labile-P form.

### Labile-P or Surface-P

Labile – P is the phosphorus adsorbed onto the surfaces of soil mineral particles and it is usually exchangeable with solution –P. Surface-P replenishes the P being depleted from the solution of rapid equilibrium reaction.



How is surface P formed? Surface P is formed by the attraction of phosphate anion,  $\text{H}_2\text{PO}_4^-$ , onto the surfaces of aluminum, iron and manganese oxides and hydroxides in acid soils or adsorption to calcium in alkaline calcareous soils, thus making phosphorus unavailable.

Thus in acid soils, phosphate is locked up as Al and Fe- hydroxyl phosphate.

### Non-Labile or Sub-Surface P

As phosphate is added to the soil solution, some  $\text{OH}^-$  is replaced on the mineral surfaces, this process continues until some of the  $\text{H}_2\text{PO}_4^-$  ions begin to migrate into the soil mineral particles to form part of the sub-surface P. The migration is detected by a slow equilibrium reaction unlike the surface-P reaction which is in rapid equilibrium with solution P.





- 1, rapid
- 2. slow or sub-surface

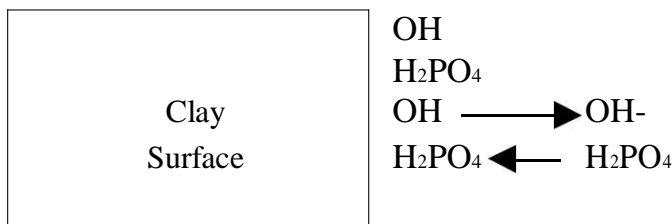
That is, the sub-surface P is slow equilibrium with surface P while the surface P is in rapid equilibrium with solution P. The sub-surface P is available with difficulty unlike surface P which is exchangeable and moderately available.

**Occluded Phosphorus**

The migration of surface P to sub-surface may be at such magnitude that some of the migrating P may lose contact and be completely blocked out of reach of some of the surface P and form occluded P. The occluded P is in very slow equilibrium with the sub-surface P because the occluded P has migrated further into the Al (OH)<sub>3</sub> or Fe (OH)<sub>3</sub> crystals. The P becomes unavailable. This process could happen when time is too long after P fertilization before cropping.

**Clay Lattice Locked-Up Phosphorus**

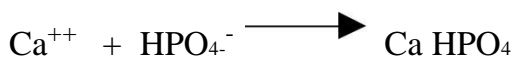
At the edge of silicate clay minerals, there are hydroxyl ions, OH<sup>-</sup> which could be replaced by H<sub>2</sub>PO<sub>4</sub><sup>-</sup> ions. This is called exchange reaction between OH<sup>-</sup> and H<sub>2</sub>PO<sub>4</sub><sup>-</sup> whereby P is made less available than the amorphous form.



The highly weathered tropical soils (laterites) usually contain high contents of aluminum, iron and kaolinite clays which usually mop up phosphate ions either applied as fertilizer or released from mineralized process.

**Reactions of Phosphorus with calcium**

In calcareous soils, pH range is usually around 7-8.5. In these alkaline soils, calcium precipitates phosphorus; that is, low soluble calcium phosphate is formed, soluble phosphate ions (H<sub>2</sub>PO<sub>4</sub><sup>-</sup>, HPO<sub>4</sub><sup>2-</sup>) can also be adsorbed to surfaces of solid calcium carbonate.



This monohydrogen orthophosphate has solubility of 0.29g per 100ml.

Calcite ( $\text{CaCO}_3$ ),  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  and  $\text{CaHP}_4$  are the three forms of phosphorus present in calcareous soils and are in equilibrium which is mainly disturbed by the concentration of  $\text{CO}_2$ .

As  $\text{CO}_2$  increases solubility of P increases, for example in the rhizosphere soil,  $\text{CO}_2$  is given off by the microbial and root population and P becomes more soluble.

However, in alkaline soils but non-calcareous there is no problem of P-fixation because  $\text{KH}_2\text{PO}_4$ ,  $\text{K}_3\text{PO}_4$ ,  $\text{NaHPO}_4$  or  $\text{Na}_3\text{PO}_4$  which are formed in alkaline soils are usually soluble.

In the presence of  $\text{CaCO}_3$ , rock phosphate (apatite) is formed. Powdered rock phosphate can be used directly as fertilizers but with low solubility.

From the forgoing information on the behaviour of phosphate in both acid and alkaline soils, it could be concluded that maximum phosphorus availability is at pH of 6.5 for mineral soils and about 5.5 for organic soils and oxisols. Liming practices which increase soil pH from 5.5 to 6.5 improve phosphorus availability to crops.

### 3.5.2 Organic Phosphorus in Soils

This fraction of phosphorus in soils varies considerable ranging between 20 and 80% of the total P in the surface layer of soils. In Nigeria, organic P constitutes about 17 to 72% of the total P and a range of 46 – 70% for Ghana soils.

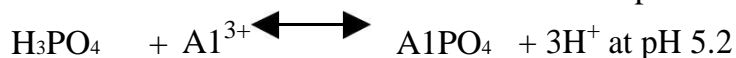
There are three major groups of organic phosphorus compounds identified in soils; namely, inositol phosphates, phospholipids and nucleic acids out of which inositol phosphate predominates.

The mineralization of soil organic P is brought about by the activities of soil microorganisms.

## 3.6 Factors Affecting Solubility and Fixation of Phosphorus in Soils

### Soil pH

Phosphate retention or fixation in acid soils is due to reaction of orthophosphate ions,  $\text{H}_2\text{PO}_4^-$ , which is favoured in acid media having high contents of iron, aluminum, manganese and possibly silicate clays. The phosphate ions react with soluble iron, manganese and aluminum ions ( $\text{Fe}^{2+}$ ,  $\text{Al}^{3+}$ ) to form insoluble phosphates. This fixation or chemical immobilization of phosphate ions by Al, Fe and their hydrous oxides becomes more pronounced at pH below 5.5.



The more acid the soil the greater the amount of phosphate fixed. Aluminum phosphate is generally more soluble than iron phosphate. These phosphate compounds when poured into the soil are either (i) precipitated as small particles or crystals, or (ii) adsorbed on the surfaces of iron and aluminum oxides or of the clay particles.

When the soil is alkaline, at pH above 7.0, phosphate fixation occurs in different ways. Most of the phosphate ions are probably precipitated as calcium phosphates and magnesium phosphates. If the soil contains free calcium carbonate such as black clays around Zaria area or Biu, Plateau in Northern Nigeria, then the phosphate may be precipitated as dicalcium phosphate  $\text{CaHPO}_4$  or apatite.

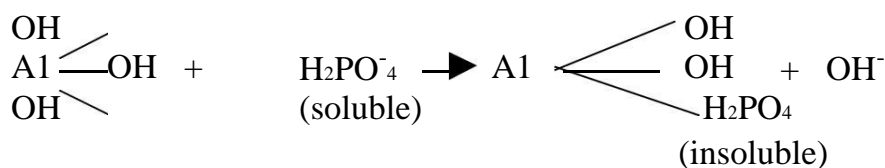
Therefore, the intermediate pH range of between 5.5 – 7.0 represents the soil reaction in which phosphate is most readily available to plants.

### Mineralogy

The type and amount of clay in the soil constitute an important factor in the fixation of applied or mineralized phosphorus. As pointed out above, the 1:1 lattice clays such as kaolinite retain or fix more phosphate ions than an equal amount of 2:1 lattice clays such as montmorillonites. The quantity of clay the soil contains is also important since the more heavily textured soils are likely to fix more phosphate than loams or sand. Banded placement minimizes contact between soil and fertilizer phosphorus before being taken up by roots.

### The Presence of Hydrous Oxides of Aluminum and Iron

Apart from the reaction of phosphate ions with soluble Fe, Al and Mn,  $\text{H}_2\text{PO}_4^-$  also forms complexes with the insoluble hydrous oxides of these elements such as gibbsite ( $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ) and goethite ( $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ). These oxides are more prevalent in humid tropical soils where large amounts of  $\text{H}_2\text{PO}_4^-$  are usually fixed as exemplified below:



### **Presence of Organic Matter**

Decomposition of organic matter liberates phosphorus which participates in the equilibrium reactions between free and adsorbed P ions. The presence of organic matter may also reduce P fixation by forming coatings around sesquioxides and hydrous oxides of aluminum and iron thus preventing them from complexing with phosphate ions.

### **Carbon Dioxides, CO<sub>2</sub>**

The decomposition of organic matter by soil microbes is associated with increase in CO<sub>2</sub> production. The CO<sub>2</sub> forms weak carbonic acid with water and increases the solubility of P.

### **Redox Potential**

In flooded soils (rice soils), redox potential could drop below 0.2V (anaerobic condition). Under this low oxygen or anaerobic conditions, the low soluble ferric ion (Fe<sup>3+</sup>) is reduced to the very active and highly soluble ferrous form (Fe<sup>2+</sup>). This affects the Fe containing skin of occluded P and can thus result in P release. Under reducing conditions, surface adsorbed P is also released.



### **Root Exudates and Organic Materials**

In the rhizosphere soil organic materials usually enhance proliferation of soil microorganisms which in turn increase mineralization of organic matter and the release of inorganic phosphorus.

### **Phosphorus status of the Soil**

The degree of phosphorus saturation of the soil or amount previously fixed by the soil also affects subsequent fixation of added phosphorus fertilizer. Repeated application of high doses of phosphorus fertilizer could satisfy the P-fixation capacity of P-fixing soils. Further application of phosphorus will then go directly into solution where plants can take up almost all the applied phosphorus.

## **3.7 Phosphorus Availability Index**

Availability index refers to the amount of nutrient that is available to the crops or the amount of nutrient uptake. It is an indication of how much of the nutrient is available to the crop. The objective is to find suitable extractants that could give suitable indices of the readily available (soluble) phosphorus that correlate with plant uptake. Those extractants in use include water or carbonated water, dilute organic and inorganic acid, dilute alkaline, highly buffered and salt solutions.

The surface P is usually measured since the amount released by organic matter will eventually go to adsorbed surface – P. A combination of surface P and organic P gives better P availability index especially in Western Nigeria if the soil has just been recovered from fallow.

#### **4.0 CONCLUSION**

The total phosphorus content of tropical soils is generally low with a range between 24-1087  $\mu\text{g g}^{-1}$ . However, only a small percentage of these levels is present in available forms. This low availability is more pronounced in tropical red soils which contain hydrous oxides and kaolinitic clays which usually lockup native phosphorus and also fix added fertilizer phosphorus.

In acid soils ( $\text{pH} < 5.5$ ), inorganic phosphate is fixed by iron and aluminum ions while phosphate is precipitated as calcium phosphates in calcareous soils. Maximum phosphorus availability is usually achieved at pH 6.5 for mineral soils and about 5.5 for organic soils and oxisols. Liming practices which increase soil pH from 5.5 to 6.5 improve organic matter mineralization, control the amounts of soluble iron and aluminum and consequently increase availability of phosphorus to plants.

#### **5.0 SUMMARY**

In this unit, we have learnt that:

- phosphorus performs very important role in the growth and development of plants

- phosphorus exists in many forms both in plants and soils

- several factors in soils could increase or reduce the availability of phosphates to plants

- there are several methods of determining, in the laboratory, the amount of phosphorus that may be available to crops in a given soil.

#### **6.0 TUTOR-MARKED ASSIGNMENT**

What reactions are expected when single super phosphate fertilizer is applied to: (a) an acid soil (b) an alkaline soil?  
What are the practical measures that could reduce P-fixation in soils?

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## **UNIT 4 POTASSIUM NUTRITION IN PLANT**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Forms and Functions of Potassium in Plants
  - 3.2 Amount in Plant Tissue
  - 3.3 Functions of Potassium in Plants
  - 3.4 Potassium Deficiency and Toxicity
  - 3.5 Soils Potassium
  - 3.6 Factors Affecting Availability and Fixation of Potassium in Plants
  - 3.7 Potassium Fertilizers
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

After nitrogen and phosphorus, potassium is the third most important fertilizer nutrient, especially in the more humid climatic areas of southern Nigeria where leaching of soluble potassium is most prevalent. The three elements (nitrogen, phosphorus and potassium) called primary nutrients, are generally added to crops as N:P:K compound fertilizer to correct deficiencies.

### **2.0 OBJECTIVES**

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

- describe the amount and functions of potassium in plants
- discuss the symptoms of potassium deficiency and toxicity in plants
- describe the various forms of potassium in the soil
- understand potassium availability and fixation and factors that affect these chemical processes in soil
- have good knowledge about K-fertilizer carriers.

### 3.0 MAIN CONTENT

#### 3.1 Forms and Functions of Potassium in Plants

#### 3.2 Amount in Plant Tissue

Potassium accounts for 1 and 3% of plant tissue (dry weight) on the average but could reach up to 12% in young tissues. Potassium occurs in plants only as a mobile soluble ion,  $K^+$ , but does not form integral part of any specific compound in plant cell. Due to its extreme mobility, potassium is easily translocated across plant membranes and its high concentration helps in ionic balance and regulation in plant cells.

#### 3.3 Functions of Potassium in Plant

Among the multi of various functions of potassium in plants are cell division, formation and translocation of carbohydrates (sugar and starch), activator of several enzymatic systems (over 60 enzymes are known to requires potassium for activation), regulation of osmosis or control of water in the plant, cell permeability, the resistance of some plants to certain diseases and insects attack, increased strength of stem to prevent lodging such as maize, conversion of sugar to organic acids in roots, the regulation of N-uptake by roots thus preventing excessive elongation and many other functions.

Potassium is known to increase grain formation in cereal crops and also for tuber development in roots and tuber crops which respond highly to generous application of potassium fertilizers.

Most plants have **luxury consumption** for potassium. That is, if excess quantities of potassium fertilizers are applied to a soil, the plants will absorb potassium in excess of that required for optimum yields (critical level). In most cases the uptake curve is linear implying direct relationship between soil quantities of potassium and plant tissue potassium.

Potassium does not enter into organic structure in plant tissue as do calcium and magnesium in calcium pectate of middle lamella and chlorophyll, respectively.

#### 3.4 Potassium Deficiency and Toxicity Symptoms



On an annual basis, agricultural crops remove between 100-300kg K ha<sup>-1</sup>. The amount taken up annually by a good cereal crop yielding 5 to 10t ha<sup>-1</sup> grain is between 200-300kg K ha<sup>-1</sup> while a good crop of potato could also be upto 300kg K ha<sup>-1</sup>. Potassium uptake by grass could be very much higher than the figures quoted for common arable crops.

Although the total amount of potassium in soil may be several times larger than uptake, the potassium may not be present in the soil in the available form to meet crop requirement. This is because amount available for crop uptake depends on the concentration at the root surface and its replenishment. Potassium in its form taken up by plant, that is K<sup>+</sup>, is a mobile element easily translocated to the younger parts of the plants whenever there is a short fall in the amount taken up by the crop. Therefore, deficiency symptoms first manifest on the older plant parts. There is yellowing along the margin from leaf tips or apex of older leaves. Necrotic areas along leaf margins is characteristic of K-deficiency symptom in dicotyledon plants. There is also browning of tips of leaves down to the base. Acute shortfall in K-supply leads to stunted growth, poor root development and reduction in the production of fruits and grains.

Fertilizer K is normally added to correct K deficiencies. Deficiencies occur in soils that are low in micas, soils that are low in clay (few exchange sites) and acid soils of pH 4.0 – 6.0 due to leaching by high rainfall.

Excess potassium has been found to induce the deficiency of magnesium (Mg) and cobalt (Co). Excess application of K-fertilizer generally leads to deficiency of other cations such as Mg- deficiency in oil palm referred to as **orange frond**. This condition is called **ion antagonism** in plants.

At the end of the growing season, some K is passed back to the soil through the roots. Potassium moves up the plant as salt by passive means in water solution through the xylem vessels and moves down as organic K through the phloem.

### 3.5 Soil Potassium

Although potassium is the third most important and most used element in fertilizers, it is one of the elements whose usual chemical compounds are most soluble, yet its soil mineral forms (micas and orthoclase feldspar (KA1si<sub>3</sub>O<sub>8</sub>)) are only very slowly soluble and occur in relatively unavailable forms.

Soil total potassium is between 1-3%, while 90-98% of soil total K is found in primary minerals –K- feldspar (Orthoclase and micas, muscovite and Biotite). These minerals are resistant to weathering and supply relatively very small quantities of K during a given breakdown of these primary minerals due to the presence of acid clay and the action of other solvents such as carbonated water.

Large portion of plant  $K^+$  comes from exchangeable and solution  $K^+$  especially in neutral and basic soils. In acid soils, exchangeable  $K^+$  is the major source. Potassium accumulates as the mica and feldspars weather and as  $K^+$  in plant residues is released into the soil solution.

Potassium can be lost in leaching waters and or entrapped between layers of hydrous mica (illite), sinectite and vermiculite. The inter layers of these 2:1 expanding clay mineral accommodates  $K^+$  and  $NH_4^+$  ions to becomes “fixed” into non-exchangeable potassium and ammonium ions.

### **3.6 Factors Affecting Availability and Fixation of Potassium Soils**

#### **Nature of Soil Colloids**

The dominant clay species in a soil determines the extent to which added fertilizer K could be fixed. Soils in which 1:1-type clays, such as Kaolinite, are dominant fix very little K. On the other hand, soils in which 2:1-type clays, such as vermiculite, montmorillonite and fine grained mica (illite), are dominant readily fix K in large amounts. The 2:1 clays have larger negative charge from isomorphous substitution of  $Al^{3+}$  for  $Si^{4+}$  in their silical tetrahedral layer thereby strongly binding the  $K^+$  ions.

#### **Alternate Wetting and Drying**

Alternate wetting and drying and freezing and thawing has been reported to contribute to fixation of K into non exchangeable form as well as its ultimate release to the soil solution. During wetting, the 2:1 expanding clay minerals increase their interlayer spaces and  $K^+$  ions could easily move into the spaces. On drying, the expanded layers collapse to entrap the  $K^+$  ions between the interlayer spaces, thereby preventing the release of the potassium. The same mechanism is believed to occur during freezing and thawing.

#### **Influence of Lime**

Application of lime usually results in an increase in K-fixation and thus conserved against leaching losses. Nevertheless, in soils where the

negative charge is pH-dependent, liming can greatly reduce the level of K in the soil solution. High calcium levels in the soil solution also reduce potassium uptake by the plant.

### **Frequency of Application**

Frequent light applications of K are found to be superior to heavier ones. Frequent light applications are recommended to avoid luxury consumption, leaching losses and fixation of excess potassium.

### **Crop Removal**

Crop removal of K is higher than all other nutrient elements except nitrogen. Annual losses by crop removal could be as high as 200kg ha<sup>-1</sup> of K especially in leguminous crops such as soyabean and cowpea.

The percent recovery of K from fertilizer – K by crops on most soils is about 70% but if the clay content is upto 27%, especially illite clay, recovery is only about 30%.

### **Presence of other Nutrient Elements**

Potassium is supplied as cation K<sup>+</sup> and it is readily available to crops. However, there is competition between NH<sub>4</sub><sup>+</sup> and K<sup>+</sup> uptake and between Ca<sup>2+</sup> and K<sup>+</sup> as in calcareous soils where uptake of K may be suppressed.

## **3.7 Potassium Fertilizers**

The principal K-fertilizer is KCl (potassium chloride) called muriate of potash which is 60% K<sub>2</sub>O.

Second in importance is sulphate of potash (potassium sulphate, K<sub>2</sub>SO<sub>4</sub>) which is about 50% K<sub>2</sub>O. These two K-fertilizers are very soluble and are sold in crystal forms.

Potassium Nitrate (KNO<sub>3</sub>) which is 40% K<sub>2</sub>O potassium-magnesium sulphate (20% K<sub>2</sub>O) are other K-fertilizer materials.

Frequent light applications of potassium has advantages over heavy application in preventing luxury consumption by certain plants, reducing leaching losses and minimizing fixation into unavailable forms. Potassium fertilizer use is yet to reach the optimum in developing agriculture compared to developed agriculture of the world.

Soil incorporation of residues of leguminous crops such as the haulm of groundnut and soyabean is an important practice for conserving soil potassium especially in savanna areas.

#### **4.0 CONCLUSION**

The primary (Feldspars and micas) and secondary (clay) minerals are the main sources of soil potassium. Despite its abundance in soils, potassium mostly occurs in unavailable form for plant uptake. Hence potassium could easily become deficient where crop demands outweigh available amounts in soil solution.

Losses of potassium are mainly through leaching especially in regions of heavy rainfall, through crop removal where whole plant is harvested and removed away from the farmland and by fixation into non-exchangeable forms which, however, is often released to the exchangeable form.

Management of soil potassium should emphasise small split applications so as to avoid luxury consumption, leaching losses and chloride toxicity. Soil pH should be maintained at optimum (pH 6-6.5) while crop residue and manures should be returned by incorporation during cultivation.

#### **5.0 SUMMARY**

In this unit, we have learnt that:

- potassium plays critical roles in plant growth and production
- absence or deficiency of potassium element result in deficiency symptoms and even total crop failure.
- soil potassium may be high but it is not always available for plant uptake
- a number of factors affect availability and fixation of potassium.
- it is desirable to apply K-fertilizers in small doses rather than heavy applications

#### **6.0 TUTOR -MARKED ASSIGNMENT**

What are the effects of soil pH, alternate wetting and drying and the presence of other nutrient elements on the availability of potassium to crops?

Compare the processes of nitrogen, phosphorus and potassium fixation and enumerate the benefits and constraints they each provide.

## 7.0 REFERENCES/FURTHER READINGS

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## UNIT 5    **SULPHUR, CALCIUM AND MAGNESIUM**

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### 1.0 INTRODUCTION

Another group of essential nutrient elements are the secondary nutrients; that is sulphur (S), calcium (Ca) and magnesium (Mg). These elements must be supplied to crops for their growth and production. However, the secondary nutrients are not easily deficient in soils and their need by crops not as high as the primary nutrients.

As soil science students, you should understand the specific functions and deficiency symptoms on plants of each of the nutrients.

### 2.0 OBJECTIVES

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

- discuss the forms and functions of sulphur, calcium and magnesium in plants
- explain the forms and reactions of sulphur, calcium and magnesium in soils
- identify the deficiency symptoms of sulphur, calcium and magnesium as secondary nutrient elements in plants
- describe the analytical methods for available potassium, magnesium and calcium
- enumerate the major fertilizer materials supplying sulphur, calcium and magnesium to crops.

### 3.0 MAIN CONTENT

#### 3.1 Forms and Functions of Sulphur

##### 3.1.1 Amount and Functions of Sulphur in Plants

Like phosphate, sulphur is taken up by plants as the sulphate form,  $\text{SO}_4^-$ . Sulphur concentration in plant tissue is about 0.05% forming the  $-\text{SH}$  and the  $-\text{S}-\text{S}$  groups in plant cells. There is high requirement for S by such crops as soyabean, cotton, tobacco, legume (for manufacture of protein), cabbage family mustard, onion and pepper which has hot taste due to S-containing compounds such as glucosides.

The major functions of sulphur in plant could be summarized as follows:

Sulphur forms structural components of plants through three amino acids containing sulphur – cysteine, methionine and cystine-by the disulphide bonds. There is serious human malnutrition whenever these amino acids are deficient.

Sulphur is important in the metabolic processes.

It is involved in fatty acid synthesis, forms constituents of vitamins biotin, thianine and glucosides whose characteristic taste is found in onion and pepper. The mustard produced from sulphur in plants contains allylthio-cyanate  $\text{CH}_2 = \text{CH} \text{CH}_2\text{CNS}$  which has high flavour as in onion and mustard oil.

Sulphur is required for nomenclature of leguminous plant by Rhizobium, the nitrogen fixing bacteria.

Sulphur also increases oil content of oil producing plants such as groundnut, oil palm and soyabean.

Sulphur functions in proteins: in coenzymes for carbohydrates and lipid metabolisms.

**Deficiency Symptom** of S occurs as a general yellowing of entire plants; and this characteristic yellowing may be difficult to distinguish from severe nitrogen deficiency. Plants are usually small and spindly. Nodulation of the roots of legumes is reduced. Absence of S may also delay maturity of fruits and seeds and reduce the quality of protein in plants.

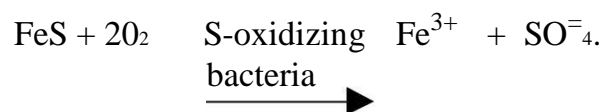
Sulphur-deficiency is prevalent in the tropics compared to the temperate regions due to parent materials, high leaching rates and low level of atmospheric sulphur-bearing air.

Excess S has been found to lead to accumulation of  $\text{NO}_3^-$  in plants and also the reduction in the absorption and utilization of molybdenum, Mo, by plants.

### 3.1.2 Soil Sulphur

Soil sulphur occurs in both organic and inorganic forms. About 50 – 70% of the total S in top soil is in organic matter implying high S in soils with high organic matter content. Total S content in soils is about 0.005 to 0.1% depending on the soil type. Organic S occurs as organic sulphates and carbon sulphides.

It could occur in absorbable sulphates –  $\text{SO}_4^{2-}$  and as elemental sulphur, S, in some soils. Most S in soils comes from parent materials, the S-containing minerals such as FeS, CuS, NiS which could be oxidized by microorganisms to form water soluble sulphates:

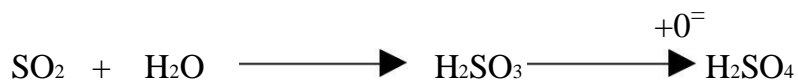


Some small amount of sulphate is held on positively charged sites of soil colloids. FeS and CuS are referred to as primary minerals which have not been weathered. Sulphur is also found in secondary minerals. Often found along with  $\text{CaCO}_3$  and  $\text{CaSO}_4$  in arid or semi-arid soils.

There are few S-deficient soils in the world. In normal agricultural soils, S is added in many ways.

Weathering of minerals as mentioned above.

Rainfall dissolves the sulphur oxides  $\text{SO}_2$  evolved during the burning of wood, coal, fuel oil or from range and forest fires. Rainwater combines with sulphur oxide to form sulphuric acid making the soil to be acidic. Natural gas has high level of  $\text{SO}_2$  which is usually dissolved in rain water as follows:



This is referred to as **Acid Rainfall** which is produced in large amounts especially in oil-prospecting areas causing acidification of lakes and rivers. During the dry seasons, dry deposition of  $\text{SO}_2$  may occur on leaves and soil surfaces. Soils generally are becoming S-deficient due to reduced use of S-containing agricultural inputs but are also still receiving their S from atmosphere.



## 3.2 Forms and Functions of Calcium

### 3.2.1 Amounts and Functions of Calcium in Plants

Calcium is taken up as divalent cation,  $\text{Ca}^{2+}$ , by plants. Plant Ca varies between 0.1 and 0.5% whilst the critical concentration level of Ca in plants is around 0.20%. **Critical concentration** level is the concentration of an element in plant below which yield is reduced. Critical level of an element depends on plant species.

Generally, dicotyledonous plants, especially legumes, require more Ca than monocotyledons. Potatoes and cereals do not require high amounts of Ca. Groundnut responds easily to Ca especially in the Northern part of Nigeria; other crops may not easily show response to Ca application. Specific functions of Ca in plants are enumerated as follows:

Calcium together with other cations (Magnesium, sodium, potassium) is important in maintaining ionic balance in plant cells.

Calcium is carried in xylem vessels to growing points and to the cell walls where it is immobilized in the formation of middle lamella. Calcium is present as calcium pectate in cell wall and for this reason it tends to accumulate in the leaf. Just a small fraction of plant Ca is used to maintain ionic balance.

Calcium is involved in the structure and permeability properties of membranes thus influencing the selectivity of cell membranes in allowing nutrients to pass through. Ca oxalate crystals may be formed in the cells of plants probably to get rid of oxalate which may be toxic to the plant. The blossom-end rot of tomatoes might be caused by Ca- deficiency as a result of break-down in the cell wall; but this is still very controversial. The disease has been described as a physiological disease of tomato plant.

Calcium is known to favour the formation of mitochondria by increasing its protein content. Also by its enhancement of  $\text{NO}_3^-$  – N uptake, Ca is related to protein synthesis and the activity of certain enzyme systems.

Calcium is also involved in cell elongation and the development of meristematic tissue.

Calcium is an immobile element that does not easily translocate from one part of the plant to another because it forms the structural part of the middle lamella of cell wall; and when formed, Ca remains there. Most

deficiency symptoms of Ca therefore appear on new vegetative growth such as die-back from growing tips. The meristematic tissue such as hair roots fail to develop as a result of Ca- deficiency. General stunting of whole plant may occur. In maize, new leaves fail to unroll.

It is usually very difficult to differentiate between Ca-deficiency and acidity. However, Ca, deficiency symptom, is common in acid soils, soils with low inorganic matter and sandy soils.

Excess Ca could occur in calcareous soils where it is found to depress uptake of other nutrient elements especially magnesium, manganese and boron when taken up as anion borate.

### 3.2.2 Soil Calcium

Calcium is predominant cation at exchange sites because, as a divalent cation, it is held more tightly than monovalent cations. Compared with other divalent cations such as  $Mg^{2+}$ ,  $Ca^{2+}$  has low charge and small water of hydration surrounding it. It therefore has higher strength with which the cation is adsorbed to exchange sites than magnesium. Exchangeable  $Ca^{+}$  is between 125-200mg  $g^{-1}$  with highest values in clayey soils and lowest in acid sandy soils. Major sources of Ca in soils are listed below:

Primary minerals such as apatite ( $Ca_{10}(PO_4)_6X_2$ ), amphiboles, pyroxene, dolomite, calcium-feldspar and calcite all form primary source of Ca in most soils.

Secondary minerals such as  $CaCO_3$ ,  $CaSO_4$  and Ca- phosphate. The peculiarity of Ca is that it can be the dominant element in some soils, for example,  $CaCO_3$  can be up to 20-30% in certain soils.

Seawater also contains Ca, Na, K and Mg. The effect of sea spray decreases as one moves inland.

Rainwater supplies little Ca.

Farm yard manure and organic manure contains a lot of Ca.

Lime is the most important source of Ca and it is added to acid soils which is larger than alkaline soils worldwide. Lime contains  $CaCO_3$  (calcite),  $Ca(OH)_2$  and CaO but the most important is  $CaCO_3$  and CaO. In burning, K<sup>-</sup>, Na<sup>-</sup>, Mg<sup>-</sup> and  $CaCO_3$  are formed to make the soil slightly alkaline.

The important role of Ca in maintaining soil pH implies that loss of Ca automatically leads to low pH. Calcium could be lost from the soil through leaching and application of acidifying fertilizers such as ammonium.

Rainfall can lead to loss of Ca in the soil in the sense that carbon dioxide, CO<sub>2</sub>, in rain forms Ca (HCO<sub>3</sub>)<sub>2</sub> in soil which can be leached leading to decreased pH.

### 3.3 Forms and Functions of Magnesium in Plants

#### 3.3.1 Amount and Functions of Magnesium in Plants

Magnesium is absorbed by plant roots as divalent cation, Mg<sup>2+</sup>; and the concentration in tissue is between 0.1 to 0.4% similar to the range of phosphorus, calcium, and sulphur in plant tissues. The functions of magnesium in plants could be listed as follows:

Magnesium is a constituent of chlorophyll accounting for about 2.7% of chlorophyll molecule.

Mg is a co-factor, an enzyme activator, in reactions associated with ATP formation (Phosphorus metabolism), phosphorylation reaction and subsequent transfer of phosphate.

It is required to activate a number of other enzymatic systems in plant tissue such as carbohydrate metabolism, citric acid cycle in cell respiration, oil synthesis in oil palm, groundnut, sunflower and soyabean.

Mg performs structural role in plants linking together the subunits of ribosomes.

Due to its structural role in cell wall, Mg is immobile in the cell wall but mobile in other parts of the plant such as its presence in cell vacuoles where it controls the ionic strength of the cell.

Due to its moderate mobility in plants, symptoms of Mg deficiency appear on lower older leaves as interveinal chlorosis whereby only the leaf veins remain green. There are deep-green veins against a yellow background in a leaf.

There is a reddish pigmentation necrotic condition of older leaves of maize and oat due to chlorophyll deficiency.

Plant levels of nutrients generally have implications on human and animal feeding. Plants and grasses low in magnesium can cause **grass stager** called **hyper magnesium** disease in animals that are fed on those grasses. Mg- Deficiency in Nigeria occurs in acid sandy soils and sedimentary zones. Soils low in cation exchange capacity and organic matter are likely low in Mg. Mg-deficiency in oil palm is called **orange frond**. Uptake of Mg is inhibited by high rates of K<sup>+</sup> and NH<sup>4+</sup>. This is called **ion antagonism** which can occur in oil palm, tree orchard, tomato and tobacco on sandy soils.

### 3.3.2 Soil Magnesium and Fertilizer Materials

Exchangeable magnesium which is available for the immediate use of the crop is between 50-500kg ha<sup>-1</sup> in soils. The primary sources of unavailable Mg in soils are biotite, Olivine (Mg Fe Si<sub>3</sub>O<sub>4</sub>) which is dominant in serpentine soils, amphiboles, pyroxene and dolomite (CaCO<sub>3</sub> Mg CO<sub>3</sub>) used for liming acid soils.

Vermiculite is the most important secondary mineral supplying Magnesium in soils. Magnesium behaves like Ca; it can move into interlayer spaces of clay minerals to become non-exchangeable. Leaching of Mg<sup>2+</sup> follows same pattern like Ca<sup>2+</sup>.

In serpentine soils, Mg. is dominant. Generally in most soils 40-80% of exchange sites is utilized by Ca<sup>2+</sup> while 10-15% is utilized by Mg<sup>2+</sup>. Materials containing Mg are:

Dolomite (Ca, Mg) <sub>2</sub> (CO <sub>3</sub> ) <sub>2</sub> contains	13% Mg
Sulpo mag K <sub>2</sub> SO <sub>4</sub> . 2Mg SO <sub>4</sub>	12% Mg

En Mag (+K) or M NH<sub>4</sub> phosphate can also be applied as spray.  
Epsom salt (magnesium sulphate) MgSO<sub>4</sub>. 7H<sub>2</sub>O  
MgO (not sufficiently soluble)..... 55% Mg

The En Mag (+K) also supplies N, P and K. It is a slow-release fertilizer produced in Aberdeen, Scotland. In the early SO's, this fertilizer was used extensively for flowers and shrubs at the Seaton Park near Hillhead Students Hostels, University of Aberdeen.

### 3.3.3 Analytical Methods for Available Potassium, Magnesium and Calcium

In routine analysis for advisory purposes, attention is paid mainly to available -P,-K-Mg, pH, lime requirement.

#### Potassium and Magnesium

Exchangeable Potassium K<sup>+</sup> is measured with:

1M NH<sub>4</sub> NO<sub>3</sub> extraction method. This method is popularly used in England and Wales.  
Extraction with 0.5M CH<sub>3</sub> COOH (Acetic acid) recommended for acid soils as for Scotland soils which are more acid than soils of England and Wales.

## Calcium

Interest is not on available Ca, but on the indirect availability of Ca through pH. pH is measured:

In water (pH H<sub>2</sub>O)

In 0.01M CaCl<sub>2</sub> or KCL (pH CaCl<sub>2</sub>) whereby pH CaCl<sub>2</sub> < pH H<sub>2</sub>O by about 0.5 – 1.0 unit. When pH measured is low, liming desirable to a final pH of 6.2 – 6.5.

## 4.0 CONCLUSION

The behaviour of sulphur in plants and soil is very much related to that of nitrogen in that they both form essential parts of proteins and other organic compounds in soil organic matter. The release of sulphur in the inorganic forms is mainly through the mineralization of soil organic matter mediated by soil microorganisms. Sulphur also causes acid rain or acid deposition as an environmental problem in soils. The deficiency of sulphur easily shows on legumes such as groundnuts, soyabeans and cowpea especially in savanna zones with coarse – textured soils subjected to repeat annual burning.

The sufficiency or deficiency of calcium in soils is associated with soil acidity. Calcium is usually low in acid soils, soils low in organic matter and in sandy soils where leaching of calcium minerals is usually pronounced. The use of Ca CO<sub>3</sub> to correct soil acid level simultaneously adds calcium (Ca<sup>++</sup>) element to the soil. Calcium (Ca<sup>++</sup>) and magnesium (Mg<sup>++</sup>) dominate the exchange complex of most salt-affected soils. Minerals such as serpentine rocks and dolomite are sources of both magnesium and calcium.

## 5.0 SUMMARY

In this unit, we have learnt:

- the major roles of secondary elements (sulphur, calcium and magnesium) in plants
- the major sources of S, Ca and Mg in soils
- the fertilizer materials that could supply S, Ca and Mg to crops
- that S, Ca and Mg levels in plants and soils could be determined in the laboratory.

## 6.0 TUTOR-MARKED ASSIGNMENT

What are the main distinguishing features of calcium and magnesium deficiencies on crops?

Explain why most soils in the southern parts of Nigeria are more acidic than soils in the North?

## 7.0 REFERENCES/FURTHER READINGS

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## **MODULE 4      SOIL FERTILIZER EVALUATION AND MANAGEMENT**

Unit 1	Micronutrient Elements
Unit 2	Soil Analysis and Soil Testing
Unit 3	Principles and Practice of Plant Analysis
Unit 4	Soil Salinity and Alkalinity
Unit 5	Soil and Water Conservation

### **UNIT 1      MICRONUTRIENT ELEMENTS**

#### **CONTENTS**

1.0	Introduction
2.0	Objectives
3.0	Main Content
3.1	General Characteristics of Micronutrients
3.2	Forms and Functions of Micronutrients
3.2.1	Iron, Fe
3.2.2	Manganese, Mn
3.2.3	Cooper, Cu
3.2.4	Zinc, Zn
3.2.5	Boron, B
3.2.6	Molybdenum, Mo
3.2.7	Chloride, Cl
4.0	Conclusion
5.0	Summary
6.0	Tutor-Marked Assignment
7.0	References/Further Readings

#### **1.0      INTRODUCTION**

The micronutrient elements are iron Fe, manganese Mn, copper Cu, Zinc Zn, Boron B, molybdenum Mo and chloride Cl (Cobalt Co is required in animal feed). They are usually called trace elements especially when referred to requirements of animals. They are required by plants in small quantities, in contrast to macronutrients, which constitute relatively larger percentage of plant weight. Fe, Mn, Cu and Zn are cations, while Mo, B and Cl are anions.

## 2.0 OBJECTIVES

After completing this unit, you should be able to:

- describe some characteristics that are common to all micronutrient elements
- enumerate those soil factors that affect the availability, deficiency and toxicity of micronutrients
- describe the specific functions of each micronutrient element in plants
- explain the amount in plant and soil of each micronutrient element.

## 3.0 MAIN CONTENT

### 3.1 General Characteristics of Micronutrients

The micronutrients have common characteristics as follows:

They are present in small amounts in the earth's crust and surface soils. The range is about 20 to 1000ppm except iron that occurs to about 5% of earth's crust.

They all originate from weathering of primary minerals where they occur as impurities mixed with macronutrient cations.

Clay soil are good sources of micronutrients where they may be ten times as high as in sand soils. Calcareous soils generally are low in micronutrients except boron as  $\text{CaBo}_3$ .

They have ability to undergo *chelation reaction* by:

Forming either *covalent bond* with other elements whereby there is sharing of one or two of their outermost electrons with another element as in  $\text{H}_2$ .

Forming coordinate-covalent bond between molecules which have incomplete shell orbitals or covalent orbitals such as in Boron tetrafluoride,  $\text{BF}_4$ : where a rovalent orbital is provided by  $\text{BF}_3$  to accommodate two electrons supplied by HF.

A popular example of chelation or coordination bond formation is Ca – EDTA i.e. calcium-ethylenediaminetetra acetate. Ca is the element that is chelated to EDTA. The formation of a coordination complex completely changes the solubility of the elements being chelated. For example, Fe is soluble at pH2.5, but Fe-chelate is only soluble at pH



9-10. Therefore, chelates are used widely to supply micronutrients in fertilisers.

The metal chelate is soluble when the organic chelating compound (ligand) is soluble; the reverse is true, the metal chelate is insoluble when the ligand is insoluble. Both soluble and insoluble chelates occur in soils. As organic matter in soil decomposes, there is formation of chelating agents, organic compounds which are capable of complexing with certain metallic cations by means of multiple chemical bonds. The metallic cations are protected from leaching losses in the soil and at the same time made absorbable by plants. Chelate complexes are formed by Fe, Zn, Cu and Mn. *One common iron chelate is Ferric ethylene-diaminetetracetate (Fe EDTA).*

Micronutrients are only added when it is certain that there is deficiency of the nutrient. The soil contents of micronutrients are generally regarded as sufficient. When deficiency occurs, micronutrients are applied as sprays to the crop.

*Deficiency or toxicity of micronutrients are affected by soil factors such as follows:*

The micronutrients may be deficient in soils formed from parent materials in which they are absent.

The micronutrients rarely act independently; the presence of one affects the uptake of the other. For example, excess Mn suppresses the uptake of Fe. In other words, they have negative relationships.

**pH:** Metallic micronutrients (Fe, Cu, Zn, and Mn) are soluble under acid conditions or solutions; but Mo is more soluble at high pH. The word “soluble” here means that they are so soluble that they may be washed of the soil. Their toxicity can be cured by just liming to bring the pH up and therefore make them less soluble.

**Redox state:** The soil oxidation-reduction state affects the availability of micronutrient elements. They are less soluble at oxidized Ferrous  $Fe_{2+}$ .

They have common peculiarity in that their deficiency appears during rapid plant growth, then the deficiency disappears again. Ultimately, there may be no noticeable decrease in yield as the end of the growing season.

Intensive cultivation tends to increase the demand for micronutrients. If soil cannot supply demand by crop, deficiency may occur.

Microorganisms have requirement for micronutrients e.g. Cobalt. In the rhizosphere, microorganisms and plant roots tend to make micronutrients more available. As the carbon dioxide concentration of the rhizosphere increases due to the .....

### **3.2 Forms and Functions of Micronutrients**

#### **3.2.1 Iron, Fe**

The concentration of iron in plant tissue is between 5-200ug g<sup>-1</sup> (ppm). Iron is taken up by plants in its ferric (Fe<sup>3+</sup>) or ferrous (Fe<sup>2+</sup>) forms as well as soluble chelates, considering the massive amounts of irons (4-5% of soil) in the soil, the small tissue content implies that most iron in soil, is not available to plants or that plants have selective uptake for iron.

**Functions:** Iron is mainly involved in oxidation-reduction reactions being a constituent of ferredoxin, the electron carrier in the cytochrome system. It therefore, participates in NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> reduction, N-fixation and the activation of enzymes of electron transfer chain. Iron is important for the formation of chlorophyll. Iron is a constituent of haemoprotein in the root modules of leguminous plants. Iron and manganese may have to be present together for the functioning of certain coenzymes.

#### **Deficiency Symptoms**

Since its deficiency lead to failure of chlorophyll synthesis, the same “chlorosis” is used to describe Fe – deficiency symptom. A deficiency of iron causes chlorosis (whitening) of new leaves since it is immobile. The whitening is bleached condition is preceded by interveinal chlorosis especially in citrus. Iron deficiency is cured by foliar spraying ferrous sulphate (FeSO<sub>4</sub>) 0.5% solution.

#### **3.2.2 Manganese, Mn**

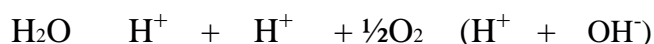
Manganese is taken up by plants as the manganous ion Mn<sup>2+</sup> and Mn-chelate through the leaves as at is usually applied as foliar spray to correct deficiency. Plant Mn ranges between 5-100ug g<sup>-1</sup> but may be higher in arable crops (15-300ug g<sup>-1</sup>), some crops have high tolerance for Mn such as citrus, rice, pine-apple and corniferous trees. Plants with less than 10ug g<sup>-1</sup> Mn tends to be deficient.

## Functions

Manganese functions in plants in the following ways:

Activation of enzyme systems especially in carbohydrate metabolism, citric acid cycle and phosphorylation reactions where Mn is a co-factor for various enzymes.

Mn is required in the splitting of water molecule, H<sub>2</sub>O in photosynthesis whereby leading to the formation of oxygen, O<sub>2</sub>.



Mn is also involved in the assimilation of CO<sub>2</sub> during photosynthesis.

Manganese participates in oxidation-reduction reaction. Mn is required in the reduction of nitrate, since the enzyme nitrate reductase requires Mn to function.

Mn is involved in the formation of riboflavin, ascorbic acid and carotene.

In general, Mn deficiency has been found to be prevalent in sands, organic soils, high pH calcareous soils and soils used for continuous cultivation of fruits and vegetables. Mn toxicity occurs in acid soils which could be ameliorated by liming.

Manganese deficiency is common in Scotland because of high pH and high organic matter.

In soil with high organic matter, Mn deficiency is easily induced by raising pH to 6.5 – 7.0. Advisory services in Scotland therefore recommends liming up to pH6.2 where as in England and Wales, it is pH6.5.

### 3.2.3 Cooper, Cu

Cooper is taken up by plants as the cupric (Cu<sup>2+</sup>) and less as cuprous (Cu<sup>+</sup>) ions. Like iron and manganese, normal Cu level in plant is also 10ug g<sup>-1</sup> with a range of 1 to 75ug g<sup>-1</sup>. Deficiency level in plant is less than 3.0ug g<sup>-1</sup>.

## Functions

In plants, Cu serves as enzyme activator as it is associated with oxidation-reduction system oxidases found active during the last stage of cytochrome system of respiration and in photosynthesis by activating ribulose diphosphate carboxylase.

## Deficiency of Cu

There is always problem in estimating deficiency level due to low values. As an immobile element, symptoms of Copper deficiency are seen in growing points and deficiency generally leads to death of plant parts. There is die-back of terminal growing points. The auxillary buds will develop into “bushy” growth part of the plant. There may be some dead spots, yellowing of younger leaves and leaf curl. In maize Copper deficiency leads to accumulation of iron because iron is not utilized in the plant when Copper is deficient. There may be twist on the needle of trees which itself may take unusual shape. In effect, tree form may be affected. In effect.

*Toxicity of Cu:* May occur in fields sprayed with Cu- containing pesticidies such as Bordeamx mixture which is an insecticide containing  $\text{CuSO}_4 + \text{Ca}(\text{OH})_2$ . Correcting Cu deficiency is done by spraying with  $\text{CuSO}_4$  (0.1% solution) or with copper exychloride (0.1%).

### 3.2.4 Zinc, Zn

Zinc is absorbed by plants as the divalent cation,  $\text{Zn}^{2+}$  only, since it is not affected by oxidation-reduction reaction in the soil-plant system.

## Functions

The growth regulator, indoleacetic acid (IAA), produced in the absence of Zn; is reduced.

Similarly, zinc enzyme is involved in auxin production which encourages stem elongation. Zinc is associated with the enzyme which participates in carbonic enhydrase and several dehydro-genases of respiration and nitrogen metabolism.

## Deficiency Symptoms

Zinc deficiency leads to low production of auxin which in turn results in shortened internodes and bushy leaves at the end of branches often referred to as *rosette* type of growth. Leaves become small stiff and brittle and fall prematurely. Zinc is slightly mobile in plants. The

deficiency symptom (interveinal chlorosis) appears on both younger and older leaves.

Zinc deficiency is corrected by using small amounts of Zn chelates or Zn SO<sub>4</sub> as foliar sprays especially on trees and ornamentals at rates of 0.5 – 2kg Zn ha<sup>-1</sup> for foliar sprays and 10-20kg Zn ha<sup>-1</sup> for soil amendments. Crops most susceptible to zinc deficiency are beans, citrus, corn, grapes, onion, rice and soyabean.

### Soil Zinc

Zinc is similar to copper in its chemistry. Zinc appears as a positive ion, Zn<sup>2+</sup>, which is immobile in soil. It is less soluble in anaerobic than aerobic soil in contrast to iron and manganese. Other forms of Zn in soils are Zn (OH)<sup>+</sup> at pH7-8 and Zn (OH)<sub>2</sub> precipitate at pH 9.0. It could also form Zn S in paddy soils where sulphides are produced from decomposing organic matter under anaerobic conditions.

### 3.2.5 Boron, B

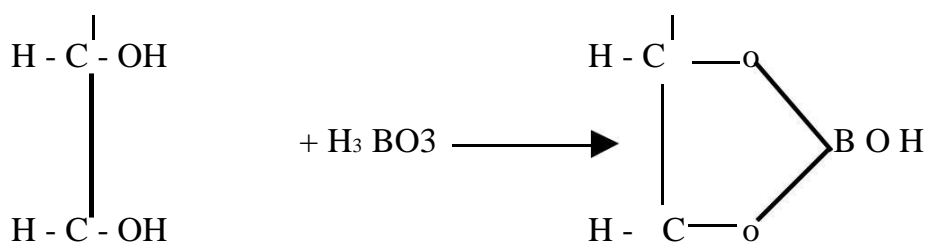
Boron is required in small amounts similar to manganese but with wide differences among plants. Amount in tissue is about 2-75ug g<sup>-1</sup>. Boron is taken up as boric acid, H<sub>3</sub> BO<sub>3</sub> or as simple organic compounds. Boron does not form chelates but complexes.

#### Functions of Boron

In plants, Bo is associated with the:

transport of sugar which may be due to reaction of BO<sub>3</sub><sup>-</sup> which reacts with dehydroxyl groups.

2)



Boron is possibly involved in cellwall formation in meristematic tissues of plants alongside calcium.

Boron is involved in carbohydrate metabolism. Low boron level leads to accumulation of carbohydrates in the leaves and low carbohydrates in the roots and meristematic tissues. This is because

the sugars and starch manufactured in the leaves are not transported to roots in the absence of boron.

Boron affects flowering, fruiting and pollen germination.

Boron is required for cell division, N-metabolism, active salt absorption, hormone movement and water metabolism.

Crops with high boron requirement are tomatoes, sunflower, cabbage family, sugarbeet and alfalfa, while maize, cowpea, soyabean and most grasses have low boron requirement.

### **Boron Deficiency Symptoms**

Boron deficiency may easily result from excessive leaching in sandy soils and high rainfall areas. It is not easily mobile in plants, therefore, boron deficiency affects, first, the growing points. Cellwalls fail to develop at growing points. There is thin cell-walled cells of growing tissues thus giving opportunity for secondary infection such as heart rot of sugar beet, whereby growing points rot and turn black and plant may die off.

Names are used for B-deficiency e.g. canker of beets, hollow stem of cauliflower, cracked stem of celery, water core of rutabagas and stem-and russet of tomatoes.

There may be shortening of internode leading to a bumpy appearance like bunch top virus disease. In Western States of Nigeria, boron deficiency has been observed on oilpalm and cocoa plant.

The range between deficiency and toxicity of boron is small. Toxicity may occur in acid soils where boron accumulates and also in irrigated water if it is above  $1.0\text{ug g}^{-1}$ .

In most boron amendment, borax fertilizer (sodium tetraborate  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$ ), which is about 14 percent boron, is used. In Britain, sodium borate is mixed with other fertilizers and it is called boronated fertilizer. Solubor  $\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$  is about 20% boron and completely water soluble; it is used as liquid fertilizer or as powder spray.

### **8.2.6 Molybdenum, Mo**

Molybdenum (Mo) is most difficult to work with because it is present in the soil in minute quantities. It is absorbed by plants as molybdate ion  $\text{MoO}_4^{2-}$  in the soil solution. Deficiency symptoms in plants begin to set in at concentration less than  $2.0\text{ug g}^{-1}$ . Molybdenum is usually deficient

in acid soils while other micronutrients are usually deficient in alkaline soils. Soils high in metal oxides (sesquioxides) have low molybdenum availability.

### **Functions of Molybdenum in Plants**

Molybdenum main function is its association with *nitrate-reductase*, usually with manganese, for the assimilatory reduction of nitrate  $\text{NO}_3$  in plants.

Molybdenum is also associated with enzyme nitrogenase in root nodules of legumes for nitrogen-fixation. If  $\text{NH}_4^+$  is applied to crops, then Mo may not be needed.

### **Mo Deficiency**

There is malformation of the plant referred to as “whiptail” of cauliflower, whereby the leaves are thin, brittle and stunted. There is also “yellow leaf sport” of cashew associated with Mo deficiencies. Usually, Mo affects form and growth of leaves.

Deficiency is cured by spraying with sodium molybdate  $\text{Na}_2 \text{MoO}_4 \cdot 2\text{H}_2\text{O}$  which is about 40 percent Mo at a rate of only 40 – 400 grams per hectare (0.04 – 0.4kg). Ammonium molybdate  $(\text{NH}_4)_6 \text{Mo}_7 \text{O}_{24} \cdot 2\text{H}_2\text{O}$  is also an effective fertilizer to correct Mo deficiency.

### **Importance of Molybdenum to Animals**

Molybdenum is in association with Mo – Cu – S compounds in animals. The three elements have to occur in appropriate balance in plants on which the animals feed. Toxic concentrations of molybdenum in soils affect grazing animals more than plants. In alkaline soils, high in organic matter. Mo can become toxic causing an imbalance between copper and molybdenum. Animal feeding on grasses grown on such soils have stunted growth and bone deformation called *molybdenosis* or *teart pasture disease*. Animals could be treated with dose of  $\text{CuSO}_4$  or copper fertilizer could be added to the grazing area.

### **8.2.7 Chloride, Cl**

Chlorine is present in all soils in adequate amount. It is absorbed as the chloride ion, Cl. Plants responding to chlorine deficiency include tobacco, tomatoes, maize and cotton. To prove that chlorine is an essential element, boyer *et. al* in 1954 performed experiment to show that chlorine was an essential element.

Amount required by plant is not well known but amount present in plant tissue is about 100 to 500 $\mu\text{g g}^{-1}$  (as for Fe and Mn).

### **Functions of Chlorine in Plants**

Exact functions of chlorine are not yet well documented but it is found as inorganic ion in cell sap. In plants, chlorine participates in osmotic and in balancing cell cationic charges.

It is a universal contaminant because it comes from ocean water. Chlorine deficiency makes plants to wilt, plants become chlorotic and necrotic in some areas and may exhibit “leaf bronzing.”

With excess chlorine, leaves of tobacco and potatoes become thickened and tend to roll. Storage quality of potato tubers and smoking quality of tobacco are lowered.

## **4.0 CONCLUSION**

In contrast to macronutrients, micronutrient elements are required by plants in small quantities. Micronutrients in general have several characteristics in common and their behaviours, both in soils and plants, take similar patterns though each has distinct effect on the performance of crops.

## **5.0 SUMMARY**

In this unit, we have learn that:

Micronutrient elements are governed by certain soil conditions which make them either to be deficient or toxic to plants.

The main function of micronutrients is to serve as enzymes in bio-chemical processes in plants.

They easily form chelates with organic compounds released during organic matter mineralization.

Their deficiency is mainly corrected through foliar sprays and not soil application.

## **6.0 TUTOR-MARKED ASSIGNMENT**

- 1.a. Under what conditions could micronutrients become deficient in soils?  
Define *chelate*; *synergism* and *antagonism*.



## 7.0 REFERENCES/FURTHER READINGS

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## **UNIT 2 SOIL ANALYSIS AND SOIL TESTING**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 General Principles of Soil Analysis and Soil Testing
    - 3.1.1 Purpose of Soil Analysis
    - 3.1.2 Characteristics of Soil Analytical Methods
    - 3.1.3 Interpretation of Soil Test Data
    - 3.1.4 Soil Sampling Procedures
    - 3.1.5 Soil Test Correlation
    - 3.1.6 Soil Test Calibration
  - 3.2 Fertilizer Recommendation
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Fertilizer nutrient use efficiency by field crops depends on very reliable and economic fertilizer recommendations. The knowledge of the quantity of soil reserves of plants nutrients ensures that adequate amounts of the nutrients are added to the soil for maximum crop yields. Recommendations are based on experimental work which includes soil analysis, plant analysis and soil testing programmes. Blanket fertilizer recommendations must be avoided.

### **2.0 OBJECTIVES**

By the time you complete this unit you should be able to:

- explain the purpose of soil analysis and soil testing
- describe soil sampling techniques for laboratory analysis
- outline the procedures involved in soil correlation and calibration
- explain how to interpret soil test data followed by fertilizer recommendation.

### 3.0 MAIN CONTENT

#### 3.1 General Principles of Soil Analysis and Testing

##### 3.1.1 Purpose of Soil Analysis

Generally done to predict the behaviour of the soil when put into various uses – cropping, road construction, and so on. That is, evaluation of soil productivity is achieved.

The analysis may be to discover its origin, its composition (constituents), or effect of changing environment.

Routine soil analysis is useful for advisory purposes. Prediction of probability of getting profitable response to fertilizer application.

Analysis may be for the purpose of research, whereby the analysis is specific.

In soil survey, the analysis may be to classify soils i.e. grouping of soils into classes for the purpose of fertilizer and lime recommendation. Data provide guides for plant nutrient recommendations.

Chemical soil analysis investigates the capacity of the soil as a medium for plant growth. However, other factors such as climate, microbiological conditions, structure and other physical properties affect plant growth.

The determination of specific soil conditions that may be improved by the addition of amendments or cultural practices.

To develop appropriate methods for estimating the availability of a particular nutrient. Detecting plant nutrient uptake and responses to various cultural treatments.

##### 3.1.2 Characteristics of Soil Analytical Methods for Practical Advisory Work

The methods must be precise, reliable, simple, and cheap. Accuracy refers to the correctness of the method while **precision** refers to the reproducibility of an analytical result.

Methods for the determination of available nutrients take into recognition that the available fraction of the total amount of nutrients in soil is not uniformly available, viz:

Method for the determination of available nutrient is designed to estimate either the total available fraction or only part of it. The different forms are interrelated.

Plants take up nutrients from the soil solution (water soluble form or **intensity factor**).

The maintenance of a high intensity factor depends (via the exchangeable form) on a high content of easily mobilizable reserves (**capacity factor**) and on the rate of transfer from one fraction to the other.

Choice of method depends on the special behaviour of the nutrient in soil and the production level, e.g.

- a. Cationic nutrient have high exchangeable fraction which should therefore give a fair estimate of the available fraction, specially if the reserves are relatively low.

At low production and fertilization level, plants are forced to use largely mobilizable soil nutrients and the methods must place emphasis on the reserves.

High yielding plants at high production level should have a good supply of easily available nutrients in the soil, since these crops are selected for high production and not for high utilization of nutrient reserves.

For several micro nutrients (Fe, Mn, Zn, Cu.) the chelating reagent DTPA (Diethylene Triamine Pentaacetic Acid) seems to be quite useful and it is applied in several countries.

Chemical soil analysis can be done at any time of the year unlike field test which must be done during the growing season.

Evaluation (Calibration) of soil Methods. **Calibration:** is necessary in order to select the best analytical method for a **given soil** and **production condition**.

The main standards, for calibration are the relative yield and the plant nutrient uptake, of (as a substitute) the nutrient contents.

The **Relative Yield** is obtained from fertilizer experiments where the nutrient tested is the main factor and solely responsible for the yield obtained.

The **Nutrient Uptake of Contents** of plants can be used if fertilizer experiments are difficult to carry out (there is not uniform field of deficiency especially for trace elements). In the range of **latent deficiency** and optimum supply, the contents of nutrients in plants reflect the contents available nutrients in soil and can therefore be used as an index of calibration.

The **Final Evaluation** i.e the comparison of soil extraction as  $r^2$ - value (%). The  $r$ -value often used is much less adequate and less intelligible, soil methods should have  $x^2$ -value of at least 50-70% in order to be useful e.g. for manganese Mn.

**Table 16.1: Calibration of Soil Tests for available Manganese in Egypt (Correlation with Mn content of Soybeans) (Metwally *et al*, 1973)**

Method	$r^2$ – value(%)
0.1 A1 phosphoric acid	28
0.05m Mn- EDTA	34
0.5% hydroquinone in $MH_4^-$ acetate	69
0.025% hydroquinone in $NH_4^-$ acetate	63

The method with the highest  $r$  – value is the best method (especially if the regression is rather steep).

Correlation could be improved by using several soil factors in addition to the available fraction. (Multi-functional correlation). The calibration of soils methods should not be done within one country but also on a regional basis such as in the uniform area as the arid zone of middle East. A good cooperation can save a lot of individual calibration work.

### 3.1.3 Interpretation of Soil Test Data

In order to obtain fertilizer recommendations from soil test data, the following information is required:

The functional curve (fertilizer response curve) between soil data (available nutrients) and yield data in order to deduce the optimum content of available nutrients required in the soil for maximum yield.

The amount of fertilizer required to cover the difference between a certain **relative yield** and the **maximum yield**, or (in practical terms) the amount of fertilizer required in order to reach the optimum soil nutrient content.

Interpretation can be made in form of mathematical curves or (in a less sophisticated way) in terms of fertility classes. The criteria for soil fertility classes in Nigeria are as follows:

Low- the value below critical level which implies application of high dose.

Medium – the range above critical level variable response to fertilization is expected. Apply  $1/3 - 1/2$  dose.

High- The range where response is unlikely and fertilization may not be necessary.

Nitrogen is defined in terms of total nitrogen, phosphorus in terms of Bray 1 or Bray 2 – P; potassium in terms of  $\text{NH}_4$  OAC exchangeable potassium and organic matter in terms of Walkley and Black total organic matter.

**Table 16. 2: Rating for Soil Fertility Classes in**

**Nigeria Nitrogen (Total N)**

Low	-	0.15/N
Medium	-	0.15 – 0.20/N
High	-	>0.20%N

<b>Phosphorus</b>		<b>Bray 1-p</b>	<b>Bray 2-p</b>
Low	-	8mg kg <sup>-1</sup>	15mg kg <sup>-1</sup>
Medium	-	8-20 kg <sup>-1</sup>	15-25
High	-	20mg kg <sup>-1</sup>	2.5mg kg <sup>-1</sup>

**Potassium (Exch K)**

Low	-	0.20cmol (+) kg <sup>-1</sup>
Medium	-	0.20 – 0.40 kg <sup>-1</sup>
High	-	0.40 kg <sup>-1</sup>

**Organic Matter (%m)**

Low	-	2.0%
Medium	-	2-3.0%
High	-	3.0%

**Soil pH (H<sub>2</sub>O)**

Low	-	4.5 – 5.0s
Medium	-	5.1 – 5.5
High	-	5.5 – 6.5

**Magnesium (Exchangeable Mg)**

Low	-	0.3 – 1.0 cmol kg <sup>-1</sup>
Medium	-	1.0 – 3.0 cmol kg <sup>-1</sup>
High	-	3. – 8.0 cmol kg <sup>-1</sup>

**3.1.4 Soil Sampling Procedures**

In soil chemical analysis, about 2 to 10g of soil is generally being analysed and this is taken as representative of a soil of one hectare (2 x 10<sup>8</sup> kg or 9 x 10<sup>8</sup>g) land areas.

Therefore we must be very careful in sampling. The following steps are usually taken when sampling soil:

**Area per Sample**

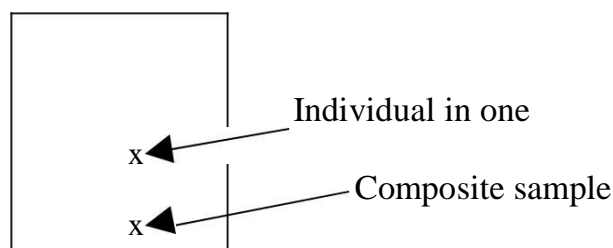
**Size of Area:** not more than 2 hectares. If the area is uniform. In most cases, it is about 0.2ha per one sample.

For Research work it should be 1 plot.

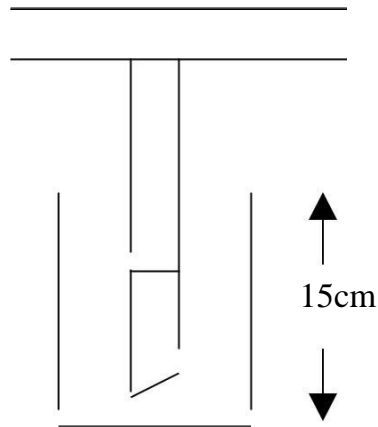
**Composite Sample:** This is a number of individual samples bulked together as one. We should have 15 to 20 individual samples (cores) per composite sample.

**Sub-Samples**

For example, a sample of cores may be taken from a field plot, and a number of small samples taken from each core for chemical analysis. The efficient use of subsampling depends on striking a balance between cost and precision.



**Depth of Sampling:** Usually, we sample to the depth of tillage because most nutrients are concentrated in the surface where most organic matter are found. The depth is usually about 15cm. There should be at least 2 composite samples per one area.



**Tools:** Use sampling tools such as:

Soil probe

Soil auger could work itself round small stones or gravel.

Spade, shovel or cutlasses. We excavate with spade to a growth depth of 15cm and use cutlass to cut off 2cm<sup>2</sup> of soil. The soil sampled is put into plastic bucket or bags.

After taking soil from field, we dry it and mix all individual samples together very well. We then take about 500g or 250g for chemical soil analysis.

**Map of the Area:** We indicate the number of sample/area. We should draw a map to locate the area of the sample.

**Containers:** must be free of contamination and kept clean.

**Areas to avoid in sampling:** Avoid any area that is obviously different from the rest of the area, unless the odd area is large enough to treat as a separate sampling unit. Such areas are:

**Eroded area** where the top soil could have been eroded away.

**Depressing or wet areas:** There will be different oxidation reduction in the soil, thus affecting soil analysis results.

Area adjacent to **animal burrows**

Areas where crop residues have accumulated – such as empty cocoapods which swells up the K in that soil.

Areas under large trees especially oil palm. This applies to cleared areas where we have isolated trees (oil palm) where there will be



accumulation of O.M to swells up C.E.C and nutrients of the soil in that area.

6. Dead furrows in the field.

In general, we must avoid bulking together sampling cores from unusual places. Once we have a representative sample we take it to the laboratory for analysis.

### 3.1.5 Soil Test Correlation

The purpose of soil test correlation is to develop an extraction procedure for a particular nutrient. Therefore, we estimate our results and try to correlate the extractable form of the nutrient with the amount extracted chemically. This procedure is known as **soil test correlation**.

The area to be sampled depends on the area for which the test is done. But there must be a minimum of 20 to 30 samples for the area. Suppose we are extracting for P.

We grow the crop in the greenhouse supplying other nutrients excepts P. We may grow maize or fast growing grass which is grown for about 6-8 weeks.

The crop is harvested, the dry weight of plant material and the concentration of P. in the tissue are analysed. From dry weight and concentration of P, the uptake of the nutrient is calculated.

Uptake of P = Yield X concentration P in tissue.

The uptake = Available P in soil

The next steps are to find a reagent in the laboratory that would extract from the soil the same amount of P. that was available to the plant.

This is an ideal condition. But we must be able to find an extractant that would extract an approximate amount as the plant uptake of the “available” form of the nutrient.

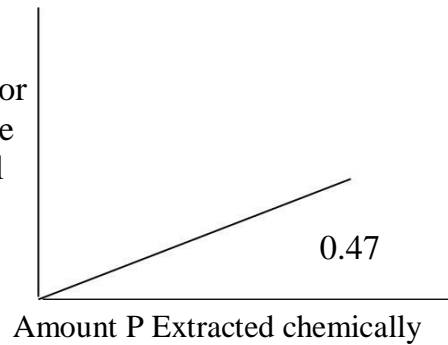
(1)  $\text{NH}_4$  CAC (2) IN HCL (3) 0. INH CL

Bray test (P-1) 0.03N –  $\text{NH}_4$  F in 0.5 N Hcl – This measures P bounded to Al – and Fe –compounds by forming  $(\text{AlF}_6)$  – with AL and Fe particles thus releasing  $\text{H}_2\text{O}_4$ .

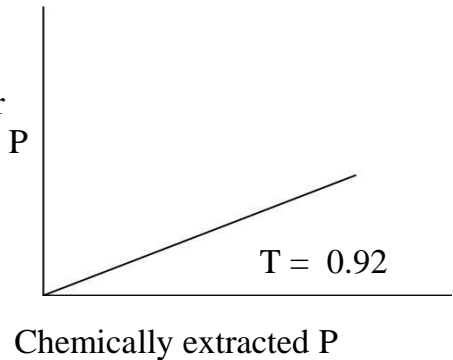
After using so many reagents, we draw a graph of available P against the amount extracted chemically making separate graphs for each reagent used.

Each point on the graph is for each soil sample i.e. 20 to 30 samples give 20 – 30 points

Uptake or available P in soil



uptake or available P in soil



We calculate correlation coefficient for each of the reagents that are selected and choose the reagent that gives the highest correlation coefficient.

Through statistics we use **multiple regression**

$$Y = a + b (\text{O.M}) + c (\text{P-test})$$

$r^2$  = % of availability that can be explained by O.M. and P-test. The more the factors used the better the correlation test.

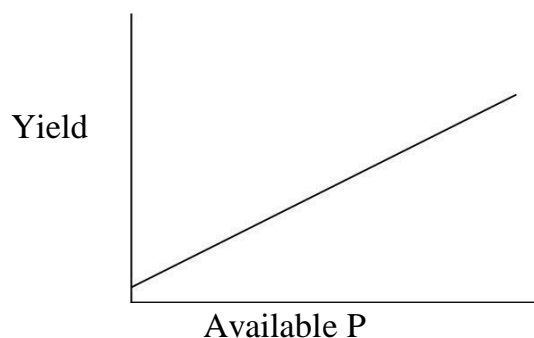
$$Y = a + b \text{ in (Zn test) } + c \text{ pH} + d (\text{silt} + \text{clay}) + E(\text{Fe \& Al oxides}) + f (\text{O.M}).$$

The study is done in Greenhouse rather than the field because

**It is easy to control many variable factors:** Temperature, moisture, light, rooting volume, aeration, other nutrients, insects and disease in the greenhouse.

Sample-taken to the greenhouse more nearly represent the soil in which plant are growing.

We measure uptake of P rather than yield because (1) uptake has more nearly linear curve since uptake will increase continuously.

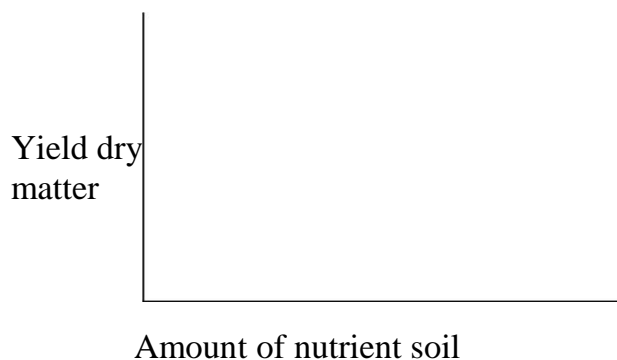


### 3.1.6 Soil Test Calibration

After greenhouse experiment, we have to calibrate this value further under field conditions.

#### Information Needed

Shape of the yield curve for a particular soil to know the point of maximum point of excess.



Amount of available nutrient in the soil. That is done by soil analysis.

Calibration of soil test methods can be carried out in the greenhouse but must be confirmed in the field. **Critical levels** of available nutrients and **optimum fertilizer rates** are determined by testing several rates of each nutrient and obtaining a yield curve. Local experience is employed to determine a **base rate** considered to be optimum and economically feasible. Treatment levels are then spaced below and above the base rate.

Experiment treatments must be adequately randomized and replicated to facilitate statistical analysis of the yield and soil test data. The best statistical design is the simplest that will produce the desired result.

Each soil should be properly characterized physically, chemically and taxonomically in order to facilitate the extrapolation of soil test information to similar soils in similar environments. Each essential economic crop of the area and essential nutrient elements should be calibrated because crops have different nutrient requirements. In Nigeria, mixed or multiple cropping should be considered in soil calibrating work in addition to monocropping.

### Steps in Conducting Soil Test Calibration

Find the soil that has low level of nutrient so that it is used as a starting point for nutrient additions.

Select at least 5 points on the curve so as to define the shape of the curve. e.g. a soil may already have 5kg/ha from soil analyses we would add in this order giving this curve.

<b>P added</b>	<b>Yield obtained</b>
0 (5kg/ha)	1000
5kg/ha	1500
10kg/ha	2000
20kg/ha	2200
40kg/ha	2300

For maximum yield, may be we would need to add between 20 40kg/ha for that soil that fixes more P; therefore we carry out this type of experiment on different soils, on at least 4-5 locations. After maximum yield level it takes a larger amount of uptake to have further increased yield. We may need to find out the toxic level.

The aim of soil calibration data is to know how such nutrient should be added to have maximum yield. We have to do a replicated experiment for 3-5 years in order to take account of variations of weather and other conditions.

We have to find out how much nutrient (e.g. P), should be added to raise level of available nutrient (soil test) to a certain amount because part of the added nutrient will become fixed.

### 3.2 Fertilizer Recommendation

Soil test information should be extended to the farmer who should be instructed on time, rate, and method of fertilizer application. The information should also include improved crop varieties available and

other production management practices. Means of disseminating the package of recommendation include radio, television, newspaper, field days, posters, agricultural shows, meetings, film shows, bulletins and leaflet, training courses, demonstrations and personal contacts.

To make fertilizer recommendation much more reliable especially under multiple cropping systems, the use of **fertilizer factor (ff)** had been developed (Adeoye *et al.*, 1998). Fertilizer factor is the amount of nutrient element required to raise the soil test level by 1mg/kg soil. The means and ranges of fertilizer factors had been developed for some nutrients in the savanna regions of Nigeria. They are P = 3.1 (1-7), K = 4.5 (3-8), Mg = 3 (1-6), Zn = 6.4 (5-8), Fe = 2 (0.8-4), Cu = 2(0.8-5) and Mn = 0.8 (0.2 – 2.5).

The ff is used as a multiplier in calculating fertilizer requirement after determining the **critical soil level**. For example if Bray – I-P soil test of a field is 10mg/kg and the critical P- level is 15mg/kg, fertilizer recommendation for P will then be  $(15-10) \times 3.1 = 15.50\text{MG p/kg soil}$  multiply by a factor of 2 to convert to kg P/ha =  $15.5\text{mgp/kg} \times 2 = 31.0\text{kg p/ha}$ .

Employing only the **critical level** concept (Cate and Nelson model) would have given  $(15-10) \times 2 = 10\text{kg p/ha}$  as the fertilizer recommendation. This quantity of phosphorus will not be sufficient to saturate the exchange complex of the soil and release enough P for the crop.

#### 4.0 CONCLUSION

The aim of fertilizer use is to supplement the natural soil supply for optimum crop yield. It is therefore imperative for the soil scientist to have a thorough knowledge of soil analysis and soil testing data interpretation. It should be emphasized that soil alone is not equivalent to soil testing. Proper interpretation of soil data leads to valid fertilizer recommendations for optimum yield and for satisfactory contents of trace element and minerals for livestock feeding. The major purposes of soil analysis, the research components of soil testing, data interpretation guides and recommendations have been carefully described.

#### 5.0 SUMMARY

In this unit we have learnt that:

- soil analysis is just only a part of soil testing which is carried out for various purposes
- several analytical procedures and extractants are available for a particular nutrient element

soil sample collection on the field is done carefully to adequately represent the field  
soil testing involves soil test correlation in the green-house and soil test calibration in the field  
both correlation and calibration data are employed in making fertilizer recommendations to farmers.

## **6.0 TUTOR-MARKED ASSIGNMENT**

What are the major steps in carrying out soil test correlation and calibration studies on a regional wide basis?

## **7.0 REFERENCES/FURTHER READINGS**

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## **UNIT 3 PRINCIPLES AND PRACTICE OF PLANT ANALYSIS**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 General Purpose of Plant Analysis
  - 3.2 Principles of Plant Analysis
    - 3.2.1 Critical Concentrations
    - 3.2.2 Problems of Plant Analysis
    - 3.2.3 Method of Plant sampling
    - 3.2.4 Sample Preparation
    - 3.2.5 Laboratory Analysis of Plant Samples
  - 3.3 Interpreting Analytical Data
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

The aim of plant analysis is to investigate the composition of plant tissue, both in terms of their elements and their extractable fractions.

Plant tissue is obtained by sampling a particular portion of a crop, at a certain time of the year, or during a certain stage of the crop's morphological development. The samples concentration is usually expressed on a dry matter basis. Once it has been obtained, the sample undergoes analysis for amino acids or other organic compounds, all used in determining a crop's quality.

Plant analysis bases itself on the principle that the concentration of a nutrient in a plant is an integral value of all the factors interacting to affect it. Therefore, plant analysis has been, involved in determining a plant's optimum concentrations of essential nutrients under various conditions. For most crops these include concentrations of N, P, K, Ca, Mg, S, B, Cl, Cu, Fe, Mn, Mo and Zinc; in addition to Co, for most legumes. In some instances, the non-essential element, Al, is also determined because of its adverse effect on growth and yields.

In order to interpret data collected during plant analysis, certain relationships have been developed. These include the basic ones between the growth rate and/or yield of a crop, and its nutrient supply and concentration.

## 2.0 OBJECTIVES

After completing this unit, you should be able to:

- explain why plant tissues are analysed
- take plant samples correctly
- describe important critical concentrations
- describe laboratory analysis of plant samples
- explain how plant tissue tests are used.

## 3.0 MAIN CONTENT

### 3.1 General Purpose of Plant Analysis as a Diagnostic Tool

Optimum nutrient supply is needed in modern agriculture for high yield crops.

Plant analysis is useful tool for the diagnosis of nutritional status/ deficiencies. To investigate the composition of plant tissue both in terms of their elements and their extractable fractions. Plant tissue is obtained by sampling a particular portion of a crop at a certain time of the year, or during a certain stage of the crop's morphological development.

Plant analysis gives a direct index (the best indicator) of the nutritional status of crops and is a useful tool for the detection of the yield limiting factors. It is especially useful in detecting latent deficiency (**hidden hunger**) without visible symptoms. Any symptom/deficiency observed must be corrected within 2 weeks to avoid crop loss.

Plant analysis provides a powerful concept which does not only enable an effective fertilization but also serves as critical measurement for the interpretation of fertilizer experiments. Diagnostic methods must be standardized.

To confirm a suspected nutrient element deficiency, when visual symptoms are present, before supplying a corrective treatment.

Particularly good for confirmation of micronutrients.

Useful in obtaining information for succeeding year.

To monitor the plant nutrient element status in order to determine if the concentration of each tested nutrient is sufficient for optimum yield.



In forestry, in predicting requirements of trees because the leaves/needles are indicators of nutrient status. Topmost leaves are usually sampled.

## 3.2 Principles of Plant Analysis Data Interpretation

### 3.2.1 Critical Concentrations

Critical nutrient concentrations are the different relations that exist between plant growth rates (yields) and nutrient supply and concentrations in the plant tissue (uptake). Some of the very important relations are as follows:

Nutrient absorbed by a plant, and the plant's growth and/or yield. This would show the “**critical level**” or optimum concentration of an element” for a given crop, **maximum growth or yield** occurs at this level. Plants found to contain amounts of an element below this level are considered deficient.

Critical concentration shows the minimum tissue concentration required for maximum yield or crop quality, or the concentration of a nutrient in a particular plant part sampled at a particular growth stage at which yield is maximum.

The **optimum nutrient yield** and **optimum nutrient concentration** for most crops could be plotted or expressed as a **range** rather than as a point on yield curve. Ranges are expressed as low, sufficient or adequate, high and excessive or toxic. (Table 1).

Additional plant characteristics such as variety or hybrid, environmental conditions such as soil moisture, temperature light intensity and quality, and interactions with other nutrients, can alter the relationship between concentration and plant response, e.g. the interaction between K and Ca/Mg concentrations in corm leaf.

**Plant Nutrient Analysis as a Diagnostic Tool:** The nutrient concentration in the plant tissue e.g. the leaf, can be shown to be directly related to the quantity of the elements available in the soil (i.e. soil fertility), to the quantity applied as fertilizer and to plant growing (yield). In effect the plant nutritional levels can be categorized as in fig. 1.

**Minimal percentage:** This is a narrow range. Within the range, yield or response may increase while the elemental concentration is constant. Symptoms of deficiency are clearly evident.

**Poverty adjustment stage:** This is where increase in elemental concentration results in increased response (growth/dry matter yield). Response could be initially linear but later increasing at a decreasing rate.

**Critical nutrient Percentage:** This state is regarded as ideal for production. The critical nutrient percentage is the range below which response is sub-optimum, **at** which it is optimum and **above** which there is luxury consumption.

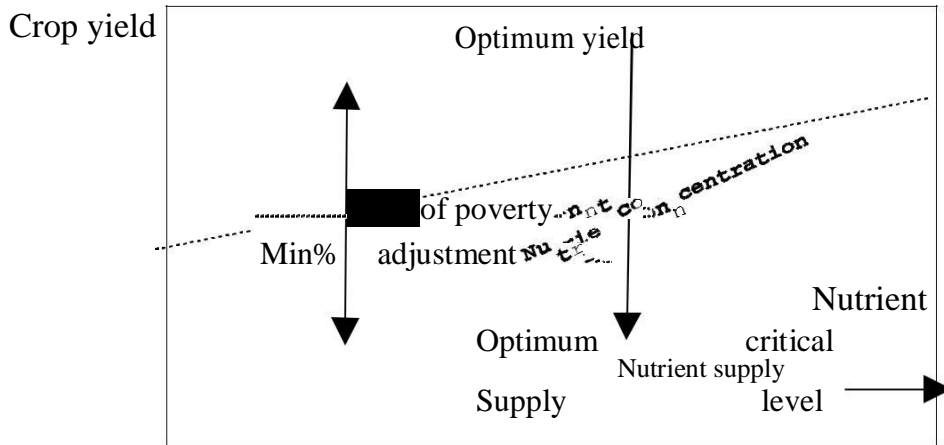
**Luxury Consumption Range:** This is the range at which plant response (Dry matter accumulation) remains constant while the tissue nutrient concentration continues to increase.

**Toxicity Range:** After the luxury stage there may set in the toxicity stage where further increases in the tissue elemental concentrations result in depressed response.

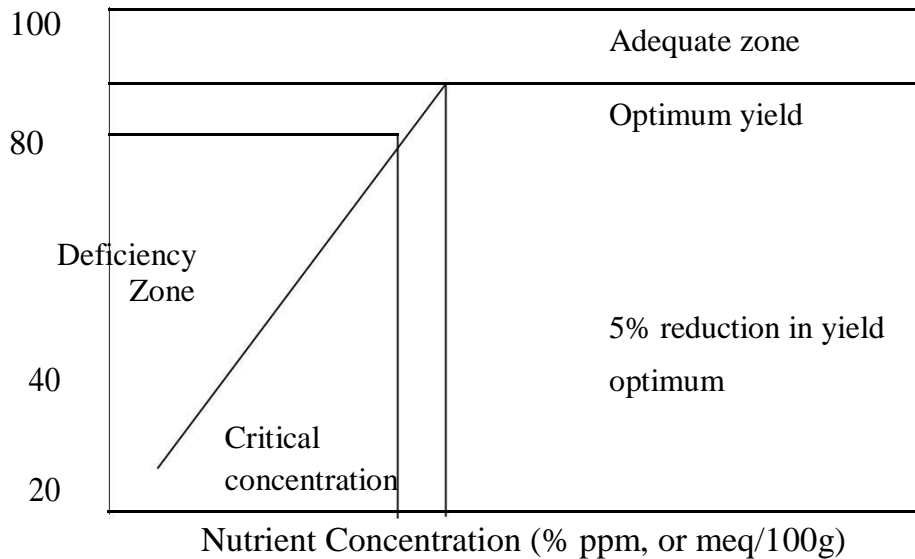
### **Other Growth Response Terminologies**

**Separation of Deficient from non-Deficient:** The level of extractable nutrient in soil that separates the deficient from the non-deficient is call **critical level**.

**Percent yield:** Where soil may differ in their productive potential or where environmental conditions may be different, the yield for the treatment not receiving the nutrient being studied is calculated as a percentage of the yield with the nutrient added. The soil test is then calculated against the percent yield.



**Fig. 17.1: Schematic graph of the manner in which nutrient concentration and crop yield varies with the supply of the nutrient**



**Fig.17. 2: Critical concentration for different crops are determined for specific plant sampled at a given physiological age**

**3.2.2 Problems of Plant Analysis**

The limiting values often decrease in course of time, the highest values are generally found in very young plants. This is due to the “dilution” effect, since the concentrations are based on the dry matter (which contains in course of time less active cell substance and more cell wall material, etc). This problem is avoided by establishing limiting values for different growth stages or for special plant part of the same age etc.

The limiting values are normally **total nutrient contents**, whereas in fact they should represent only the active portion of the total content. For most nutrients, however, total and active contents have high correlation. Problem may arise in case of highly immobile elements such as Fe and Ca of which the active part should be considered. The activity of Fe could be measured indirectly by measuring the Fe-dependent enzyme activity in the plant.

The limiting values for a special nutrient are based on the assumption of an optimum supply of all the other nutrients, it must be emphasized that certain **nutrient ratios** are very important but not as basic as the limiting value concept.

### **Examples of Appropriate Nutrient Ratios Effects**

The different ratios of the treatment which gave the highest alkaloid content of henbane medicinal plant are 30, 58, 50, 136, 24, 2, 2, 3 and 1 for P/Zn, P/Fe, P/Cu, N/Zn, Zn/mg, Zn/Fe, Zn/Cu, Fe/Mn and Fe/Cu respectively.

Application of P caused a relative increase in Zn concentration and contents but decreased Fe and Cu.

#### **Corn (*Zea may L.*)**

Maximum accumulation of each nutrient (N, P, K, Fe, Mn, Zn, Cu) during the growth period differed according to the different treatments.

Awa (1976) found that the application of 20kg Zn SO<sub>4</sub> fed (48 kg/ha) significantly increased the grain yield by 16% over the control and also increased Zn concentration in leaves and grains application of 48kg Zn, SO<sub>4</sub> with 36kg P<sub>2</sub> O<sub>5</sub>/ha increased the grain yield by 28%.

There was evident response to Zn when P/Zn ratio in corn leave at tasseling stage was greater than 68. Ratios less than 54 resulted in deleterious effect of Zn accumulation.

### **3.2.3 Method of Sampling Plant Tissue**

The validity and usefulness of any chemical plant analysis is dependent on how representative the plant tissue sample is. A poor sample can result in incorrect diagnosis, leading to corrective treatments which are costly yet ineffective.

Obtaining a representative plant sample is essential for plant analysis; nevertheless, the researcher or scientist should be aware that this is a

complex task requiring expert knowledge. Suggestions for gathering representative samples should be followed closely. They include:

**Location:** It is recommended that plant samples be taken from mature leaves located just below the growing tip of the main branches and stems. Their nutrient composition is stable compared to that of younger leaves which can undergo rapid change.

**Maturity:** The composition of a plant's nutrient elements can vary considerably, depending on plant maturity. Sampling should occur when the relationship between plant nutrient concentrations and yield, and the plant's physical appearance is at its best.

**The best time:** for sampling is just before the plant begins its reproductive growth. When plants begin setting and developing fruits or seeds, the nutrient concentration of the vegetative portions change considerably. Particularly, in the case of grain crops, sampling after pollination is not recommended.

**Physical and Chemical Conditions:** Plants subjected to stress over a long period of time, can develop nutrient concentrations which are often misleading. One way of avoiding this is to take samples when the plant has been initially affected. Plant tissue taken from normal plants within the same field, and at the same stage of development, can also aid in the interpretation.

Sampling is not recommended if the plant is covered with soil or dust, damaged by insects, mechanically injured or diseased. Dead plant tissue should not be included in a sample either, in addition, sampling is not recommended if plants are under stress caused by moisture or temperature changes.

### 3.2.4 Sample Preparation

Once plant samples have been obtained, they must undergo four preparatory steps before any analysis can be carried out on them:

#### **Cleaning of Material**

It is not uncommon to find plant samples which have been recently collected, covered with a thin film of dust. It is important that this be removed, since its presence can affect the samples' concentrations of Fe and Mg. Dust is difficult to remove by mechanical wiping or brushing only; therefore, washing the tissues in a 0.1 – 0.3% solution to detergent followed by a rinse in pure water, is recommended. This washing should be done quickly in order to prevent any leaching of nutrients such as Na, K or Ca.

### **Drying**

Following washing, plant tissue samples should be dried as rapidly as possible in order to minimize any chemical or biological changes. Drying at 65<sup>0</sup>C is considered adequate to stop enzymatic action. The sample is placed in a hot air oven and dried until the weight is constant. This may required from 24 to 48 hours. After drying, the sample is ready to be ground.

### **Grinding**

This is beneficial for two reasons, it allows the sample to be manipulated with greater ease, and even more important, it ensures greater uniformity in terms of composition. When selecting a mill, it is important to choose one which minimizes the possibility of contamination. This is especially critical when analysis is being performed to determine the presence of any micronutrients. Equipment having grinding surfaces of either steel or stainless steels are recommended. Grinding equipment available includes the hammer mill, wiley mill, jar mill with flint, porcelain with mullite balls, agate or glass mortar and pestle.

### **Store**

Under humid tropical conditions, samples which have been poorly dried are frequently in danger of becoming moldy. Any samples which have to be stored for a prolonged period should be kept in a refrigerator, preferably at temperatures of 5<sup>o</sup>C or lower.

## **3.2.5 Laboratory Analysis of Plant Samples**

Numerous methods have been developed for the analysis of plant tissue. Most procedure require that the organic matter be burned away first, leaving the various elements to be analysed. Some scientists have proposed the use of extraction procedures which utilize dried, green tissue. These techniques, however, have been developed only for a few crops and elements.

### **Method of Ashing**

The ignition of a plant sample should be carried out at a low temperature, in order to avoid any loss of volatile, mineral constituents. This is especially important if the individual minerals left in the ash are to be subsequently determined.

A dry ashing method is normally carried out in a muffle furnace at temperatures not exceeding 500°C. Ashing may require two hours or more depending on the type of tissue.

Tissue which is highly carbonaceous may need a longer ashing period. The use of high-wall crucibles is preferred over flat vessels for holding the materials.

Wet ashing can be done using various combinations of  $\text{HNO}_3$ - $\text{H}_2\text{SO}_4$ - $\text{HClO}_4$ . Aluminum block digestors are also recommended for this ashing process.

### **Method of Analysis**

Various analytical methods are available for the analysis of plant – tissue ash. It is difficult to select any one method or techniques as superior over another. Those listed below are the most commonly used.

- Colorimetric
- Flame emission
- Atomic absorption
- Mass spectrometry
- X-ray fluorescence
- Neutron activation analysis
- Folarography

Small changes in the concentration of elements found in a plant may result in substantial changes in its growth. For this reason, precision is important in any analysis, regardless of the method chosen. Techniques used in sample preparation, ashing and analysis need to be standardized in order to obtain results which are both accurate and reproducible. This is essential, along with good standard reference samples.

### **3.3 Interpreting Analysis Data**

Data which are both reliable and interpretative are lacking for a number of plant crops. This is particularly true for those crops in their initial stages of growth, with concentration values were sought; but it became evident, after continued study, that a plant's nutrient status could be more accurately described using concentration ranges. This is demonstrated in Table 1.

Comparing a plant's concentration of elements with its sufficiency range, is a procedure which is commonly used. The concentration of each element found during analysis is reported as "less than" "greater

than” or “within the range”. For successful, corrective treatments, data on soil analysis and cultural practices are necessary.

**Table 17.1: Nutrient Sufficiency Range for Grain Sorghum at several stages of Development (taken from Jones and Eck 1973, Lockman, 1972 (1)).**

	<b>Whole Plant</b>	<b>Youngest fully developed Leaf</b>	<b>Bloom stage 3<sup>rd</sup> Below Head leaf</b>	<b>Dough stage leaf Below Head</b>	<b>Whitney 3<sup>rd</sup> (1970 Last fully Extended Leave</b>
	23-39 says After Planting	37-56 days After Planting	66-70 Days after Planting	82-97 days After Planting	3.0 – 5.0
Element					
N%	3.5 – 4.0	3.2 – 4.2	3.3 – 4.0	3.0 – 4.0	3.0 – 5.0
P	0.50 – 0.60	3.20 – 0.60	2.20 – 0.35	0.15 – 0.25	0.25 – 0.40
K	3.05.5	2.0 0 3.0	1.4 – 1.7	1.0 1.5	2.75 1.0
Ca	0.9 – 1.3	0.15 – 0.90	0.30 – 0.60	0.2 – 0.6	
Mg	0.35 – 0.50	0.2 – 0.5	0.2 – 0.5	0.1 – 0.5	
			Ppm		
Al ppm	0.0-375.0	0.0-2000.0	0.0-220.0	0.0 – 25.0	
B	1.0 – 13.0	1.0 – 10.0	1.0- 10.0	1.0 – 6.0	
Cu	8.0 – 15.0	2.0 – 15.0	2.0 – 7.0	1.0 – 3.0	5.0 – 15.0
Fe	160.0– 250.0	55.0-2000. 0	65.0-100.0	40.0-80.0	
Mn	40.0-150. 0	6.0-100.0	8.0-190.0	8.0-40.0	
Zn	30.0-60.0	20.0-40.0	15.0-30.0	7.0-16.0	15.0-40.0

#### 4.0 CONCLUSION

Plant tissue tests are used in conjunction with soil tests to obtain a complete picture of plant nutrient requirements. Fertilizer recommendations must be based on both soil analytical data, crop response to fertilizer added in the field and plant analysis. The data therefore must be correctly interpreted by knowledgeable soil scientists to facilitate high crop yield and quality, economic returns and environmental protection.



## 5.0 SUMMARY

In this unit you have learnt that:

plant analysis is useful for several reasons  
yield or growth of plants has certain relationships with nutrient concentration or nutrient added  
standardization is essential in sampling and analyzing plant tissue  
correct interpretation of plant tissue tests would be valid fertilizer recommendations.

## 6.0 TUTOR-MARKED ASSIGNMENT

Give brief explanation of the following:

latent deficiency  
zone of poverty adjustment  
critical concentration  
luxury consumption  
maximum yield

## 7.0 REFERENCES/FURTHER READINGS

Adeoye, G.O. (1998). Interpretation of Soil and Plant Analysis for Agronomic use. *Soil and Plant Analytical Laboratories Network of Africa (SPALNA)*.

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## **UNIT 4 SOIL SALINITY AND ALKALINITY**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Sources of Salt-Affected Soils
  - 3.2 Saline Soils
  - 3.3 Alkaline (Sodic) Soils
  - 3.4 Saline–Alkaline Soils
  - 3.5 General Features of both Saline and Alkaline Soils (Halomorphic Soils)
  - 3.6 Reclamation and Management of Halomorphic Soils
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Soluble salts such as  $\text{MgSO}_4$ ,  $\text{MgCl}_2$ ,  $\text{CaSO}_4$ , or  $\text{CaCO}_3$  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 either saline, alkaline or even saline-alkaline depending on the percent of total soluble salts that is sodium content.

### **2.0 OBJECTIVES**

By the time you should have completed this unit, you should be able to:

- describe salt-affected soils
- list the general properties of salt-affected soils
- enumerate the reclamation and management measures of salt-affected soils.

### **3.0 MAIN CONTENT**

#### **3.1 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  $\text{NaCl}$ ,  $\text{Na}_2\text{SO}_4$ ,  $\text{MgSO}_4$ ,  $\text{MgCl}_2$ ,  $\text{CaSO}_4$ , or  $\text{CaCO}_3$ .

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

**Evapo-Transpiration:** 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.

**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-borne salts.

### 3.2 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  $5 \text{ MS Cm}^{-2}$  (4 million  $\text{hos/cm}$ ) or 4 decisiemens per meter ( $4\text{ds/m}$ ) or has a low **sodium absorption ratio** (SAR) at  $25^{\circ}\text{C}$ , a soluble sodium content of less than half the total soluble cations and a pH value usually between 6.3 – 8.5.

The predominant saline soils have neutral to alkaline reaction but acid saline soils 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 acidic 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 *oxosmosis* 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, affect 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.

### 3.3 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 ratio (SAR) is usually used and expressed as

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

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

in which Mg = 2.5, Ca = 2.0, K = 1.0 Na = 2.5

and Al = 2.0 meq/100g soil

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

$$25\% \text{ Na}$$

if Na = 1.0meq/100g soil

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

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

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

### 3.3 Saline-Alkaline Soils

A soil which is both saline (electrical conductivity > 4mmhos/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.

### 3.5 General Features of Saline and Alkaline Soils (Halomorphic Soils)

The pH of these soils are usually high, between pH 7.5 and 10, which results in the deficiency of micro-nutrients such as Zn, Cu, or Mn.

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”.

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.

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.

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  $\text{Ca}_{10} (\text{OH})_2 (\text{HPO}_4)_6$ .

Soil alkalinity affects plants due to the toxicity of the  $\text{Na}^+$ ,  $\text{OH}^-$  and  $\text{HCO}_3^-$  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  $\text{Na}_2 \text{CO}_3$  while the black colouration of the soil surface is due to the dispersed humus carried upward by capillary water. Irrigation water containing excess  $\text{Na}^+$  and  $\text{HCO}_3^-$  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 silts.

### 3.6 Reclamation and Management of Alkaline and Saline Soils

**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.

**Leaching Excess Salt:** Where the soil remains permeable with adequate internal and surface drainage present, excess salt of saline soils 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 typical warm arid regions where many of the large irrigation schemes in the world are located, accumulation of salts can be very substantial. Therefore irrigation schemes in such semi arid regions must be well managed to remove excess salts regularly from the root zone of the crops. The salt contents of irrigation water should not exceed 0.025 – 2.25 mmhos/cm.

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).

$$LR = \frac{EC_{ir}}{EC_{dr}}$$

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<sup>-1</sup>(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<sup>-1</sup>. 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:

$$LR = \frac{EC_{ix}}{EC_{dr}} = \frac{1.08D_sM^{-1}}{6D_sM^{-1}} = 0.18$$

This decimal (or fraction) is that fraction of the amount of water needed to wet the soil that 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 at times depends on the salt sensitivity or tolerance of the crop to be grown. For example, wheat and sorghum have a LR of 0.08; while lettuce, a more sensitive plant, has 0.20 implying that more water must be added to leach more salt under lettuce.

### **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 places, cotton gin trash, chopped woody plants and crop residues have been found helpful in reducing soil salinity.

### **Replacement of Excess Exchangeable Sodium**

In saline-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<sup>-</sup>) 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 (CaSO<sub>4</sub>·2H<sub>2</sub>O) 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<sup>+</sup>) which leads to lowering the pH of the soil.

### **Water Control**

Application of light irrigation but at 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.

### **Appropriate Planting Position of Crops**

Most salts 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 moulds.

### **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 to the crop to the climate or soil properties and the economic value 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  $\text{Na}^+$  could be grown and then removed completely away from the irrigated area.

**A Good Crop Rotation** can be an insurance against alkali trouble by building up the soil structure (through 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.

## **4.0 CONCLUSION**

Salt- affected soils may be saline, sodic or saline-sodic which must be specially treated and managed carefully to reduce salt problems to make the soils useful for crop production.

## **5.0 SUMMARY**

In this unit, you have learnt

the sources of salt-affected soils  
characteristics of saline, sodic and saline-sodic soils.  
How to reclaim and manage salted soils

## **6.0 TUTOR-MARKED ASSIGNMENT**

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

## **7.0 REFERENCES/FURTHER READINGS**

Plaster, E.J. (1992). *Soil Science and Management*. 2<sup>nd</sup> Ed. New York: .Delmar Publishers Inc.



## **UNIT 5 SOIL AND WATER CONSERVATION**

### **CONTENTS**

- 1.0 Introduction
- 2.0 Objectives
- 3.0 Main Content
  - 3.1 Water and Wind Erosion Defined
    - 3.1.1 Types of Water Erosion
    - 3.1.2 The Universal Soil Loss Equation
    - 3.1.3 Factors in Wind Erosion
  - 3.2 Agronomic Practices for the Control
  - 3.3 Appraisal of Shifting and Continuous Cultivation in Nigeria
- 4.0 Conclusion
- 5.0 Summary
- 6.0 Tutor-Marked Assignment
- 7.0 References/Further Readings

### **1.0 INTRODUCTION**

Tropical soils are opened to erosion agents (water and wind) due to overgrazing, 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.

### **2.0 OBJECTIVES**

After completing this unit, you will be able to:

- define water and wind erosion
- describe the various forms of water and wind erosion
- list the agronomic practices to control both water and wind erosion
- explain the benefits and problems of shifting and continuous cultivation in Nigeria
- define and explain the concept of Universal Loss Equation.

### **3.0 MAIN CONTENT**

### 3.1 Water and Wind Erosion Defined

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

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.

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.

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.

Gullies cut up fields into odd-shaped pieces and make it very difficult to operate farm equipment.

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.

The soil washed away by erosion settles in streams, lakes, harbors, and reservoirs. About 760 million tons of farmland sediment reaches surface waters each year.

#### 3.1.1 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 leads to five types of erosion. All five types can occur at the same time on any given slope.

**Splash Erosion** is the direct movement of soil by splashing. A soil grain can be thrown as far as five feet by raindrop splash. These

splashed particles fill the voids between other aggregates and seal the soil surface.

**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.

**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.

**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 will collect in the old channel, and erosion will begin here.

**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.

### 3.1.2 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 losses within tolerable levels. The USLE also helps the farmer 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 2.6 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:

$$A = R K L S C P$$

“A” is the tons of soil lost per acre 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:

**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 the country or region.

**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.

**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”. LS values can be determined from the chart.

**C** – cover and management factor. C compares cropping practices, residue management, and soil cover to the standard clean-fallow plot. C values are calculated from detailed tables and are valid only within the area for which they are calculated. Many SC’s offices prepare simplified tables for use in the field, and some have computerized the computations.

**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.

**Sample Solution:** For a sample solution of the USLE, use mapping unit 158C. The slope is 2% to 6% and about 100 feet long. (Ask yourself: How do I know the grade?) According to the soil survey for this area,  $K = 0.18$  and  $L = 5.0$ . Assume the grower uses conventional tillage to grow continuous corn

### 3.1.3 Factors in Wind Erosion

The following factors determine the amount of wind erosion:

Soil erodability relates mainly to texture and structure. Soils high in fine sand are most liable to wind erosion; soils high in clay are least liable. Organic soils are also easily eroded by wind after they have been drained. If soil grains are cemented into larger soil aggregates, they are less likely to be blown away.

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 to capture blowing soil.

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.

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.

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. Since WEE is more complex to apply than the USLE, and generally considered less reliable, it will not be detailed in this text.

### **3.2 Agronomic Practices for Control of Soil Erosion (Water and Wind)**

Among the different methods of erosion control, agronomic practices 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 practices used in erosion control include:

- Maintenance of high soil fertility

- Mulching

- Crop rotation

- Contour tillage

- Strip cropping

- Fallowing

- Alley cropping and

## Minimum tillage

### **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 fertilizers, lime and manure increase the fertility of the soil which enhances proper plant growth leading to bumper harvest and an insurance for maximum ground cover.

### **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.

### **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 continuous 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.

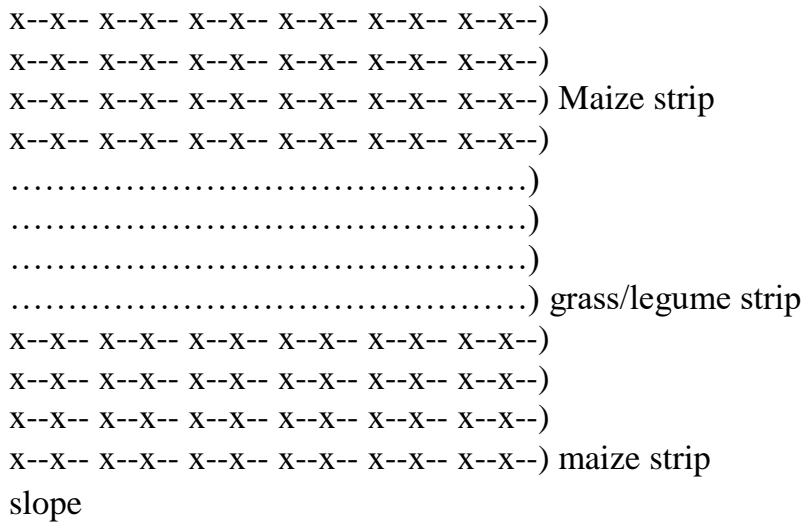
### **Contour Tillage**

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

Contour farming is adopted on a slopy 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:** Strip cropping is used on a slopy 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 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 runoff 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.

**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, protects soil from erosion and helps to restore soil fertility.

**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 mulch materials that are spread on the cultivated land between the rows. Where this is practised, 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.

**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:

- reduces the rate of erosion.
- conserves water due to surface cover of plant residues.
- Reduces the cost of production and
- increases crop yield.

### 3.3 Appraisal of Shifting and Continuous Cultivation in Nigeria

#### Shifting Cultivation

Shifting cultivation is a cropping system whereby a piece of farmland under forest is opened up and used for cropping (usually arable crop such as yam, maize, rice, sorghum, or cassava) for two or more years before moving to another site. The fresh land under forest or bush is cleared by the slash-and-burn method which involves the cutting down and burning the existing vegetation. The system comprises a **cropping period** when food crops are produced for a few years until there is nutrient depletion, reduction in yields and infestation of weeds; the piece of farmland is then abandoned for a **fallow period** (ranging from 2 to 10 years) for the regrowth of the vegetation and the rejuvenation of the soil fertility. There is usually a yearly or bi-annual movement from one piece of land to another.

The practice had been carried out over a wide variety of soils over about 30% of total worldwide arable land. About 300 million people, mainly in the tropics, feed on this shifting cultivation system which also accounts for about 70% of tropical deforestation. For centuries, shifting cultivation was able to maintain soil fertility because the land could be abandoned for more than 10 to 20 persons/km<sup>2</sup>. However, even in Nigeria today population has exceeded this figure by 10 to 25 times. Hence shifting cultivation can not support the present population pressure on arable land to the extent that the fallow period is now either



equal to or even shorter than the cropping period. The system must therefore be modified and improved upon if food production is to cope with population growth rate.

### **Importance of the Fallow Period**

There is restoration of fertility lost during the cropping period. If the cropping period had not been too long, the fallow period may be enough to restore the fertility. If it is otherwise, it may be necessary to apply chemical fertilizer, close cycle is established under a forest canopy, nutrients pass from soil to vegetation and back to the soil.

Suppression of weeds. The land may be abandoned due to invasion of weeds. The emerging vegetation and trees during fallow help to suppress weeds in addition to recycling nutrients from deep in the profile.

High level of organic matter is maintained by the large returns from the vegetation in form of litter and timber fall. The roots help to bind the soils, thus increasing infiltration, minimizing run off and erosion.

Diseases and pests are controlled by fallow. Fallow may deprive insect pests their host plants thus starving them and reducing their population.

### **What Happens When Vegetation is Removed or During Burning?**

Clearing of vegetation causes the close nutrient cycle to be broken. There is an initial flush of nutrients due to increase mineralization of organic matter especially under tropical conditions. Burning provides ashes to raise the soil pH. But there is loss of nitrogen, sulphur, CO<sub>2</sub> and other harmful products which add to the global warming process. Apart from N and S which escape to the atmosphere during burning, other nutrients remain in the ash and are present as carbonates and phosphates such as K<sub>2</sub>CO<sub>3</sub>, K<sub>3</sub>PO<sub>4</sub>, Ca CO<sub>2</sub>, Mg CO<sub>3</sub> which react with soil acids (alkaline effect) to raise soil pH.

The direct heating effect of burning on soil may serve to kill undesirable soil pests and weeds; but the interest is to see much of the organic matter returned to soil without burning. Through burning and high oxidation rate, organic matter content of the soil declines sharply and soil structure deteriorates under impact of rainstorm and lack of fauna activity.

In savanna agroecologies, burning of vegetation (which normally grows much more slowly than the forest zones) causes loss of carbon, nitrogen and sulphur thus preventing fast build-up of soil fertility as in the forest zone. However, the savanna land is more amenable to continuous cropping since there is not much to loose in terms of soil fertility. The main problem is how to maintain soil nitrogen and organic matter. This can be achieved by planting leguminous crops, grass legumes or shrub legumes. Use of agro forestry legumes such as *Leucarnea leocoecphala* used as green manure in alley cropping system may be the solution. Further improvement of shifting cultivation in the savanna zones would also involve judicious use of fertilizer, proper grazing, appropriate measures to control erosion, cultivation of appropriate crop varieties such as cassava and possibility of increasing the length of fallow.

#### **4.0 CONCLUSION**

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 or outlets to carry the excess off the field without erosion.

#### **5.0 SUMMARY**

In this unit we have learnt about:

the devastating effect of water and wind erosion on farmlands  
 different types of water erosion  
 agronomic practices that could combat soil erosion on a farmland.  
 The definition and use of the Universal Soil Loss Equation (USLE)  
 Benefits and problems of shifting cultivation in Nigeria.

## 6.0 TUTOR-MARKED ASSIGNMENT

Discuss the agronomic practices that could lead to:

- (a) soil erosion control      (b) accelerated soil loss in Nigeria.

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