COURSE GUIDE

SLM 507
SOIL MORPHOLOGY AND CLASSIFICATION
(3 UNITS)

Course Team:

Dr. Obasi, Sunday Nathaniel, NOUN	(Course Writer)
Prof. Grace E. Jokthan, NOUN	(Programme Leader)
Prof. Bashir M. Sani, ABU, Zaria	(Course Editor)
Dr. Aliyu Musa, NOUN	(Course Coordinator)

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Plot 91, Cadastral Zone, University Village
Nnamdi Azikiwe Expressway
Jabi, Abuja

Lagos Office
14/16 Ahmadu Bello Way
Victoria Island
Lagos

e-mail: centralinfo@nou.edu.ng
URL: www.nou.edu.ng

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INTRODUCTION

Soil is of interest to man because virtually all activities on the earth take place on the soil, ranging from man's existence, his movement and sources of livelihood. Soil impacts the quality and quantity of our food, and serves as foundation of our structures, as well as interacts with the hydrosphere and atmosphere. When the concepts of soil are being studied in the field of soil science, we look at soil from two perspectives; Soil and it relationship to plants and Soil as a natural body. An understanding of soil properties and processes of formation is therefore critical to the evaluation of the criteria to be adopted for the soil management. The key contents of the course are as follow; the concepts of soil, its full definitions, the processes and factors of soil formations, the field study of soil which has to do with soil morphological properties. Also, soil classifications, principles and historical backgrounds as well as types of soil classification systems; both local and international and uses of soil classification systems were properly covered.

Prerequisites

The background knowledge from biology, chemistry, biochemistry and geology is required.

WHAT YOU WILL LEARN IN THIS COURSE

The course consists of modules in units and a course guide. This course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully.

It gives you guidance in respect of your Tutor-Marked Assignment which will be made available in the assignment file. There will be regular tutorial classes that are related to the course. It is advisable for you to attend these tutorial sessions. The course will prepare you for the challenges you will meet in the field of soil Morphology and classification. The course will expose you to the concepts of soil and its definitions; processes and factors of soil formation; field study of soils, soil classification; principles and historical backgrounds; types of soil classification systems – local and international; uses of soil classification.

COURSE AIMS

The course aims to provide you with an understanding of soil morphology and classification; it also aims to provide you with solutions to problems with soil classification in the field.

COURSE OBJECTIVES

To achieve the aims set out, the course has a set of objectives. Each unit has specific objectives which are included at the beginning of the unit. You should read these objectives before you study the unit. You may wish to refer to them during your study to check on your progress. You should always look at the unit objectives after completion of each unit. By doing so, you would have followed the instructions in the unit. Below are the comprehensive objectives of the course as a whole. By meeting these objectives, you should have achieved the aims of the course as a whole. In addition to the aims above, this course sets to achieve some objectives. Thus, after going through the course, you should be able to:

- Explain the concept of soil, its definition, origin and formation
- Know the detailed roles of parent material, organism, climate, relief and time in soil formation
- Study the morphological characteristics of soil
- Identify surface diagnostic (master) horizons and subordinate distinctions with master horizons
- Know what soil texture is all about and the importance of soil texture to soil fertility and productivity
- Know the historical background of soil classification and the purpose of soil classification

- Different types of classification systems that exist and the purpose of their formation
- How different countries came up with their own classification systems
- The most commonly used classification systems today such as; the USDA Soil Taxonomy and the FAO/UNESCO System – World Reference Base (WRB) for soil resources.

WORKING THROUGH THE COURSE

To complete this course you are required to read each study units, read the textbook and other materials which may be provided by the National Open University of Nigeria. Each unit contains self assessment exercises and at certain points in the course you would be required to submit assignment for assessment purpose. At the end of the course there is a final examination.

The course should take you a total of 17 weeks to complete. Below you will find listed all the components of the course, what you have to do and how should allocate your time to each unit in order to complete the course on time and successfully.

The details that you spend a lot of time to read, I would advise that you avail yourself the opportunity of attending the tutorial sessions where you have the opportunity of comparing your knowledge with that of other people.

THE COURSE MATERIALS

The main components of the course are:

1. The Course Guide
2. Study Units
3. References/Further Reading

4. Assignments
5. Presentation Schedule

STUDY UNITS

The study units in this course are as follows:

MODULE 1: CONCEPTS, DEFINITIONS OF SOIL, PROCESSES AND FACTORS OF SOIL FORMATION

Unit 1: Concept of Soil
Unit 2: Definitions of Soil
Unit3: Processes of Soil Formation
Unit 4: Factors of Soil Formation

MODULE 2: FIELD STUDY OF SOIL

Unit 1: Soil morphology
Unit 2: Soil horizons and Boundaries
Unit 3: Soil Colour
Unit 4: Soil Texture
Unit 5: Soil Structure
Unit 6: Soil Consistence, Root abundance, pH and Effervescence and Special features

MODULE 3: SOIL CLASSIFICATION & PRINCIPLES, HISTORICAL BACKGROUNDS, TYPE OF SOIL CLASSIFICATION SYSTEMS, USES OF SOIL CLASSIFICATION

Unit 1: Soil classification & principles
Unit 2: Historical backgrounds
Unit 3: Types of soil classification systems, uses of soil classification

MODULE 1: CONCEPTS, DEFINITIONS OF SOIL, PROCESSES AND FACTORS OF SOIL FORMATION

UNIT 1: CONCEPTS OF SOIL

CONTENTS

1.0 INTRODUCTION

Soil is of interest to man because virtually all activities on the earth take place on the soil, ranging from man's existence, his movement and sources of livelihood. The Biblical account of creation stated that "God formed man from the dust of the earth" (*Gen. 2:7*) and man will return to the soil at death, so man cannot be separated from the soil. Man plants his crops and rears his animals on the soil. Other activities initiated by man on the soil include construction of his houses, factories, highways as well as disposal of urban and rural wastes. Soil therefore means different thing for different people depending on their activities on it. When the concepts of soil are being studied in the field of soil science, we look at soil from two perspectives; Soil and it relationship to plants and Soil as a natural body. These two conceptions illustrate two major approaches adopted in studying soils namely; Edaphologist (agronomist) and Pedologist. Edaphologist is one who studies the soil in relation to plants, while Pedologist studies soil as a naturally occurring body.

2.0 OBJECTIVES

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

- Understand that there are two basic concepts of soil

- Understand the relationship between the soil and plants
- Know what makes soil exist as a natural body

3.0 MAIN CONTENT

3.1 Important Facts to Know

1. Soil is a natural dwelling place for plant and that is what “Edaphology” or “Agronomy” study is all about.
2. Soil is a natural entity formed through biochemically weathered and synthesized products.
3. Soil’s existence in relation to plants makes man to depend on the soil as his source(s) of livelihood since man depends directly or in directly on plants.
4. The concepts of soil in relation to plants include factors that affect plant growth, root growth and distribution as well as soil fertility and productivity.
5. Soils provide anchorage to plants as its roots hold the soil particles gaining its support as well as drawing its nutrients from the soil.
6. The soil contains the essential nutrients that plants need for growth and developments which include; Carbon, hydrogen, and oxygen which are combined in photosynthetic reactions and as well are obtained from air and water.
7. The remaining elements are largely obtained from the soil. Nitrogen (N), phosphorus (P), potassium (K), calcium Ca), magnesium (Mg), and sulfur (S) are required in relatively large amounts and are referred to as the *macronutrients.*
8. Studying soil as a natural body considers primarily factors of soil formation. There are five soil-forming factors generally recognized which include: *parent material, organisms*, *climate*, *topography*, and *time.*

3.2 Concepts of Soil

Man depends on soil and to some reasonable extent good soils depend on man and how he uses them. The healthy life of a man as well as his standard of living is determined by the quality of plants and animal he grows on the soil. There are two basic concepts of soil; the first considering soil as a natural dwelling place for plants therefore justifying soil studies on this basis. The second however considers soil as a natural entity formed through biochemically weathered and synthesized products. The concepts of soil in relation to plants therefore include factors affecting plant growth, root growth and distribution, nutrient availability (including the roles of root interception, mass flow and diffusion), and soil fertility and productivity.

3.3 Soil in Relation to Plants

This is also called “Edaphology” or “Agronomy”. Edaphology is from the Greek word *edaphos* which means ground. This literally means the study of soils from the stand point of higher plants. It considers the various characteristics of the soils as it relates to plant production. Therefore, the ultimate aim of the edaphologist is the production of food and fibre for mans’ sustenance and utilization.

3.3.1 Roles of Soil as Relates to Plants

The soil can be viewed as a mixture of mineral and organic particles of varying size and composition in regard to plant growth. The particles occupy about 50 percent of the soil's volume. The remaining soil volume, about 50 percent, is pore space, made up of pores of varying shapes and sizes. The pore spaces contain air and water and serve as channels for the movement of air and water. Pore spaces are used as runways for small animals and are avenues for the extension and growth of roots. Roots anchored in soil support plants and roots absorb water and nutrients. For good plant growth, the root-soil environment should be free of inhibitory factors. The three essential things that plants absorb from the soil and use are: *(1) water* that is mainly evaporated from plant leaves, *(2) nutrients* for nutrition, and *(3) oxygen* for root respiration.

i. Support for Plants

Roots anchored in soil enable growing plants to remain upright, so one of the most obvious functions of soil is to provide *support* for plants. Plants grown by hydroponics (in liquid nutrient culture) are commonly supported on a wire framework. Plants growing in water are supported by the buoyancy of the water. Some very sandy soils that are droughty and infertile provide plants with little else than support. Such soils, however, produce high-yielding crops when fertilized and frequently irrigated. There are soils in which the impenetrable nature of the subsoil, or the presence of water saturated soil close to the soil surface, cause shallow rooting. Shallow-rooted trees are easily blown over by wind, resulting in *windthrow*.

ii. Contains Essential Nutrient Elements

Plants however need certain *essential nutrient elements* to complete their life cycle. No other element can completely substitute for these elements. About16 elements or more are currently considered essential for the growth of most vascular plants. These elements include; Carbon, hydrogen, and oxygen which are combined in photosynthetic reactions and as well are obtained from air and water. These three elements compose 90 percent or more of the dry matter of plants. The remaining 13 elements are largely obtained from the soil. Nitrogen (N), phosphorus (P), potassium (K), calcium Ca), magnesium (Mg), and sulfur (S) are required in relatively large amounts and are referred to as the *macronutrients.* Elements required in considerably smaller amount are called the *micronutrients.* They include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Only a few plants needed micronutrient called Cobalt (Co). Plants deficient in an essential element tend to exhibit symptoms that are peculiar for that element.

3.4 Soil as a Natural Body

Soils are made up of what they are by various contributing factors. The most obvious of such factors is the parent material. Soil formation, however, may result in many different kinds of soils from a given parent material. Parent material and the other factors that are responsible for the development of soil are the *soil-forming factors.*

3.4.1 The Soil-Forming Factors

There are five soil-forming factors generally recognized which include: *parent material, organisms, climate, topography,* and *time.* It has been shown that Bt and Bhs horizon development is related to the clay and sand content within the parent material and/or the amount of clay that is formed during soil evolution.

Grass vegetation contributes to soils with thick A horizons because of the growth of fine roots in the upper 30 to 40 centimeters of soil. In forests, organic matter is added to soils mainly by leaves and wood that fall onto the soil surface in the form of litter. Small-animal activities or microbial activities contribute to some mixing of organic matter into and within the soil. As a result of this, organic matter in forest soils end up being incorporated into only a thin layer of soil, resulting in thin A horizons.

The climate contributes to soil formation through its temperature and precipitation components. If parent materials are permanently frozen or dry, soils do not develop. Water is needed for plant growth, for weathering, leaching, and translocation of clay, and so on. A warm, humid climate promotes soil formation, whereas dry and/or cold climates inhibit it.

The topography refers to the general nature of the land surface. On slopes, the loss of water by runoff and the removal of soil by erosion retard soil formation. Areas that receive runoff water may have greater plant growth and organic matter content, and more water may percolate through the soil. The extent to which these factors operate is a function of the amount of time that has been available for their operation.

Soil Bodies as Parts of Landscapes

At any given location on the landscape, there is a particular soil with a unique set of properties, including kinds and nature of the horizons. Soil properties may remain fairly constant from that location in all directions for some distance. The area in which soil properties remain reasonably constant is *a soil body.* Eventually, a significant change will occur in one or more of the soil forming factors and a different soil or soil body will be encountered.

Locally, changes in parent material and/or slope (topography) account for the existence of different soil bodies in a given field. The dark-colored soil in the foreground receives runoff water from the adjacent slopes. The light-colored soil on the slopes developed where water runoff and erosion occurred. Distinctly different management practices are required to use effectively the poorly drained soil in the foreground and the eroded soil on the slope.

The boundary between the two different soils is easily seen. In many instances the boundaries between soils require an inspection of the soil, which is done by digging a pit or using a soil auger.

Studying Soils as Natural Bodies

A particular soil, or soil body, occupies a particular part of a landscape. To learn about such a soil, a pit is usually dug and the soil horizons are described and sampled. Each horizon is described in terms of its thickness, color, arrangement of particles, clay content, abundance of roots, presence or absence of lime, pH, and so on. Samples from each horizon are taken to the laboratory and are analyzed for their chemical, physical, and biological properties. These data are presented in graphic form to show how various soil properties remain the same or change from one horizon to another. Pertinent data are presented by a researcher, using charts, and the properties and genesis of the soil are discussed by the group participants.

Importance of Concept of Soils as Natural Bodies

The nature and properties of the horizons in a soil determine the soil's suitability for various uses. To use soils prudently, an inventory of the soil's properties is needed to serve as the basis for making predictions of soil behavior in various situations.

Soil maps, which show the location of the soil bodies in an area, and written reports about soil properties and predictions of soil behavior for various uses began in the United States in 1896. By the 1920s, soil maps were being used to plan the location and construction of highways in Michigan. Soil materials that are unstable must be removed and replaced with material that can withstand the pressures of vehicular traffic.

4.0 CONCLUSION

Soil is a medium made up of both mineral and organic components thereby supporting the growth of plants. Soil contains the basic nutrients that plants need for their growth and development. Plants deficient in an essential element tend to exhibit symptoms that are peculiar for that element. Soil as a natural body takes into account its mode of formation, soil major components and its distribution. There are five soil-forming factors generally recognized which include: *parent material, organisms, climate, topography,* and *time.*

5.0 SUMMARY

Soil study in relation to plants is called edaphology or agronomy while soil study as a naturally occurring body is called pedology.

6.0 TUTOR-MARKED ASSIGNMENT

1. "Soil means different thing to different people" explain this statement in terms of usage of soil.
2. Explain the concept of soil as a natural body
3. What are the macro and micro nutrients? Enumerate the macro and micro nutrients in the soil and state their sources.
4. Briefly explain the term Edaphology and Pedology

7.0 REFERENCES/FURTHER READING

Ibanga, I.J. 2006. Soil Studies: the pedological approach. Maesot Printing and Computers 48 Mayne Avenue, Calabar, Nigeria.

UNIT 2: SOIL DEFINITION AND ORIGIN

CONTENTS

1.0 INTRODUCTION

Definition of soil considers primarily the origin, process of formation and functions. The soil is at the interface between the atmosphere and lithosphere (the mantle of rocks making up the Earth's crust). It also has an interface with the hydrosphere, i.e. the sphere describing surface water, ground water and oceans. The soil sustains the growth of many plants and animals, and so forms part of the biosphere. A combination of physical, chemical and biotic forces act on organic and weathered rock fragments to produce soils with a porous fabric that contains water and air (pedosphere). We consider soil as a natural body of mineral and organic material that is formed in response to many environmental factors and processes acting on and changing soil permanently. Soils have been cultivated intensively for at least 5500 years. About 2000 years ago some crude soil fertility relationships were proposed for crops. The need for water was clear. Most of our scientific knowledge has been accumulated in the last 70 to 90 years.

2.0 OBJECTIVES

At the end of this unit, student should be able to;

- Know different approaches to soil definitions by different professions
- Have the key knowledge of organism and climate as major factors of in the origin of soil

3.0 MAIN CONTENT

3.1 Important Facts to Know

1. Different people define soil differently depending on their activities on the soil.
2. The soil is a part of the biosphere as it supports the growth of many plants and animals.
3. The soil is at the interface between the atmosphere and lithosphere (the mantle of rocks making up the Earth's crust).

4. Proper definition of soil must contain the basic five soil forming factors which include; parent material, organism, climate, relief and time
5. Soil can be very different from one location to another, but generally consists of organic and inorganic materials, water and air.

3.2 DEFINITIONS OF SOIL

The most acceptable definition of soil therefore is; the unconsolidated material on the surface of the earth that has been subjected to and influenced by the genetic and environmental factors of parent material, climate, organisms, and topography, all acting over a period of time.
Some other definitions of soil have been given depending on how the soil user sees the soil.

1. Traditionally, the soil is regarded as the outer layer of the earth's crust that provides anchorage and nutrition for crops and plants. This is the edaphological definition.
2. Since Soil Scientists, together with Agricultural Engineers, deal with the surface outer crusts of the earth. They define the soil as the medium on which crops grow, and should be managed to optimize the nutrient status, the physical and biological qualities and the engineering properties of the medium for good plant growth and development.
3. The Civil Engineer may regard what is traditionally referred to as the soil as the outer crust that must be removed before further investigation of the materials (laterites) that must be needed for building foundations.
4. The Engineering Geologist is of the view that a soil does not exist *per se* and what exists and is relevant is the mineral soil or rock in which crude oil is deposited and should be explored.
5. The Geographer sees soils as the materials that are formed as a result of litho-logic discontinuities on the surface of the earth.

3.3 Origin of Soil

Soils are a mixture of different things; rocks, minerals, and dead, decaying plants and animals. Soil can be very different from one location to another, but generally consists of organic and inorganic materials, water and air. The inorganic materials are the rocks that have been broken down into smaller pieces. The size of the pieces varies. It may appear as pebbles, gravel, or as small as particles of sand or clay.

Active Factors of soil Origin

1. **Organisms**

   The organic material is decaying living matter. This could be plants or animals that have died and decay until they become part of the soil.

2. **Climatic**

   The amount of water in the soil is closely linked with the climate and other characteristics of the region. The amount of water in the soil is one thing that can affect the amount of air. Very wet soil each are found in a wetland probably has very little air. The composition of the soil affects the plants and therefore the animals that can live there. Physical and biological agents, such as wind, running water, temperature changes, and living organisms, perpetually modify the Earth's crust, changing its upper surface into products that are more closely in equilibrium with the atmosphere, the hydrosphere, and the biosphere.

Earth scientists sum up all processes through which these alterations take place under the collective term *weathering*. One may speak of mechanical weathering in the case that the dominant forces are mainly mechanical, such as the eroding action of running water, the abrading action of stream load or the physical action of wind and severe temperature fluctuations. Similarly, one speaks of biological weathering when the forces producing changes are directly or indirectly related to living organisms. Of these, we can mention several examples, such as the action of burrowing animals, the penetrating forces of plant roots, and the destructive action of algae, bacteria, and their acid-producing symbiotic community of the lichens, or simply the destructive action of man, who continuously disturbs the Earth's crust through various activities. Processes of disintegration, during which mantle rocks are broken down to form particles of smaller size, without considerable change in chemical or mineralogical composition are known as *physical weathering processes*.

4.0 CONCLUSION

Soil is the unconsolidated material on the surface of the earth that has been subjected to and influenced by the genetic and environmental factors of parent material, climate, organisms, and topography, all acting over a period of time. However soil scientists identify climate and organisms as "active" factors of soil formation because their influence over soil development can be directly observed. For example, rain, heat, cold, wind, microorganisms (algae, fungi), earthworms, and burrowing animals can be directly observed influencing soil development. Time, topography, and parent material are noted as "passive" factors because their effects are not immediately observed. The passive factors can, however, control how climate and organisms affect soil development and formation.

5.0 SUMMARY

Soil science approach to soil definition takes into account, its origin, and mode of formation, distribution and agents of formation.

6.0 TUTOR-MARKED ASSIGNMENT

1. Give all the definitions of soil you know and state the one that is mostly acceptable to soil scientist
2. What are the different components that mix to form soil
3. Explain the 2 key factors of soil origin
4. Why is weathering seen as a summary of all the processes of soil formation.

7.0 REFERENCES/FURTHER READING

Foth, H.D. 1990. Fundamentals of soil science. 8th Edition. John Wiley and Sons. New York. 435pp

UNIT 3: PROCESSES OF SOIL FORMATION

CONTENTS

1.0 INTRODUCTION

The layers in a soil are genetically related; however, the layers differ from each other in their physical, chemical, and biological properties. Soil layers are approximately parallel to the land surface and several layers may evolve simultaneously over a period of time. In soil terminology, the layers are called *horizons.* Because soils as natural bodies are characterized by genetically developed horizons, soil formation consists of the evolution of soil horizons. A vertical exposure of a soil consisting of the horizons is *a soil profile.*

However, the processes of soil formation are groups of reactions that take place in the soil; these processes are not mutually exclusive. They may also be referred as internal soil forming processes. These processes occur at different extents in all soils and cannot be seen as the processes occur; therefore we must infer the processes from the morphological, physical and chemical properties of the soil when measured.

2.0 **OBJECTIVES**

At the end of this unit, students are expected to know;

- That soils as natural bodies are characterized by genetically developed horizons
- The major processes associated with soil formation

3.0 MAIN CONTENT

3.1 **Important Facts to Know**

1. The processes of soil formation are groups of reactions that take place in the soil
2. The process of soil formation are not mutually exclusive
3. The processes that add materials to the soil could be sedimentation or enrichment
4. Elluviation and illuviation are opposite reactions with *elluviation* meaning *going out* of a location and *illuviation* meaning *coming into* a location.

5. Leaching is a downward movement of nutrients beyond the root zone
6. Mineralization processes are carried out by soil microbial organisms

3.2 Some Processes of soil Formation

- Eluviation: Movement of soil materials *from one portion* of the soil, say movement of organic matter or clay from the A-horizon. In eluviations, materials in question move *out* of a location.
- Illuviation: Movement of soil materials into another portion of the soil, e.g. movement of clay into the B-horizon. In this case materials move *into* a location.
- Leaching: This has to do with movement of materials out of the soil body or solum completely and lost. E.g. is the movement of the nutrient elements out of the solum beyond the reach of the roots of plants.
- Enrichment: Addition of materials into the soil, e.g. fertilizers, etc.
- Sedimentation (Cumulization): Aeolian and hydrologic addition of mineral particles to the soil surface.
- Decalcification: Reactions that leads to removal of $CaCO_3$ from soil horizons
- Calcification: Accumulation of $CaCO_3$ in a soil horizon e.g. $CaCO_3 + H_2O = Ca(HCO_3)_2$
- Humification: Transformation of raw organic material to humus
- Mineralization: Breakdown of organic matter with the release of oxide solids
- Ripening: Changes in organic matter (peat) after air passes into it thereby allowing microbial activities.
- Paludization: Accumulation of organic matter as in histosol, more than 30cm thick.
- Littering: Accumulation of organic litter on mineral soil surface.
- Leucinization: Burning out organic matter from the soil
- Melanization: Addition of organic matter to the soil
- Decomposition: the breakdown of mineral and organic materials
- Synthesis: the formation of new particles of mineral and organic species
- Salinization: Concentration of soluble salts (Cl, SO_4, NO_3), done by removal of water
- Desalinization: Removal of soluble salts from salic soils by addition of water
- Alkalization: Accumulation of Sodium (Na^+) in the exchange sites in the soil
- Dealkalization: Leaching of Sodium ions (Na^+) and salts from natric horizons. When Na occupies more than 15% of the exchange sites, we have dispersion. The situation is caused by addition of Ca and Mg sulphates to the soil. This will push Na^+ out of the system and cause it to precipitate.
- Lessivage: Translocation of clay from A to B-horizon, common in Ultisols.
- Pedoturbation: Churning and mixing of soil materials, e.g. in Vertisols.

- Podzolization: The long range of reactions that removes Fe (Iron) and allows Si (Silicon) to accumulate in the soil.
- Laterization: The reactions that removes Si leading to the concentration of Fe in the soil.

4.0 CONCLUSION

The processes of soil formation occur at different extents in all soils and cannot be seen as the processes occur; therefore we must infer the processes from the morphological, physical and chemical properties of the soil when measured.

5.0 SUMMARY

Soil layers are approximately parallel to the land surface and several layers may evolve simultaneously over a period of time.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is the difference between elluviation and illuviation?
2. What is mineralization and state its major agent
3. With chemical equation, explain how Calcification occur in the soil
4. Briefly explain the following processes as relates to soil formation; (a) Dealkalinization, (b) Ripening, (c) Lessivage, (d) Podzolization

7.0 **REFERENCES/FURTHER READING**

Ibanga, I.J. 2006. Soil Studies: the pedological approach. Maesot Printing and Computers 48 Mayne Avenue, Calabar, Nigeria.

UNIT 4: FACTORS OF SOIL FORMATION

CONTENTS

1.0. Introduction

Before the latter part of 19th century, soil was however considered as mainly a geologic material and as such was described as regolith unconsolidated debris mantling the solid rock. Around 1890, a Russian Geographer called Dockuchaev and some of his students studied the soil of Russia more closely than they have done in the past. They discovered that soil is a regolith or unconsolidated debris, they concluded that the unique properties which the soil has are due to five variables which were later known as factors of soil formation. These factors determine the kinds of soil that form throughout the world. The factors are basically five and include; Parent material, climate, organisms, relief and time.

2.0 OBJECTIVES

At the end of this unit, students should be able to;

1. Know the detailed roles of Parent material, organism, climate, relief and time in soil formation
2. Know the relationship between these factors of soil formation

3.0 MAIN CONTENT

3.1 Important Facts to Know

1. Parent material is made up of fragments; partly or wholly weathered rocks and minerals.
2. The breakup of rocks into parent material for soil to form is a destructive process while soil formation is a building process.
3. The chemical and mineralogical composition of the parent material often controls the fertility status of the soil.
4. Parent material could be transported, sedentary or of organic origin.

5. The textural composition of the soil is determined by the parent material, therefore the downward movement of water into the soil is controlled by the texture of the parent material.
6. Climate controls the weathering of rocks to form soil parent materials and determine the processes operating on soil parent material during soil formation.
7. The three main elements of climatic are precipitation, temperature and wind.
8. The organic factor of soil formation is made up of plants or animals that either inhabit the soil or grow in it. The nature and number of plants and animals growing/living in and on the soil play important roles in soil formation.
9. Relief encompasses and considers the geometrical relationship between the highlands, valleys and interfluvial slopes that connect the mountains and the valleys. The influence of relief on soil formation is due to its controlling effect on drainage, run-off, erosion, etc.
10. Time as a factor of soil development, could therefore be seen in terms of stage of profile/soil development. Many scientists have started studying soil development on a time sequence.

3.2 FACTORS OF SOIL FORMATION

3.2.1 Parent Material

Parent material is defined as any material that the soil is formed from or presumed to be formed from. In the formation of soil, the first step is the development of parent material which is accumulated largely through rock weathering. Parent material is made up of fragments; partly or wholly weathered rocks and minerals. Parent material approximates to geologists regolith or unconsolidated debris. It is regarded as providing the body of soil and so it is the framework on which the other factors operate to form soils.

The general effect of soil forming processes is to obliterate the differentiating influence of parent material and this happens over a long period of time. The breakup of rocks into parent material for soil to form is a destructive process while soil formation is a building process. However, climate, organism, relief and time are all acting on the parent material for soil to form.

The nature of parent material has great influence of the characteristic of the soils, e.g.

1. The chemical and mineralogical composition of the parent material often controls the fertility status of the soil.
2. The textural composition of the soil is determined by the parent material, therefore the downward movement of water into the soil is controlled by the texture of the parent material
3. These controls the vegetative cover on the land

3.2.1.1 Types of Parent Material

a. Transported parent materials

These are parent materials that were weathered and later transported as loose materials and deposited at a new location on the earth’s surface and soil later forms at this new location. These transported parent material can be differentiated depending on the natural agent responsible for their transportation and deposition.

i. **Colluvial Deposit (Colluvium)**: Colluvial deposits are generally deposited away from river valleys. Those transported by running water such as rivers and streams are termed alluvium. These are sorted deposits laid down by concentrated flow of water. E.g. include leaves, flood plains, alluvial fans and deltas. E.g. of such in Nigeria are the alluvial deposits bordering the river Niger, Benue, Oshun and Cross.

ii. **Aeolian Deposits**: These are windblown mineral particles that are eventually laid down when the transporting speed of the wind diminishes. They include sand dunes (sand sized particles) which are mostly found in the Sahara deserts and loess (silt sized particles). Loessial deposits blown from the Sahara deserts are found in northern part of west Africa including northern Nigeria and assume a great significance as soil parent materials.

iii. **Glacial Deposits**: These are mineral particles laid down be ice sheets called glaciers. Over a million years ago, glaciers formed in parts of Europe, North America and Australia due to extreme cold climates. As the climates in these areas became warmer, the glaciers became unstable and moved over the land surfaces. In North America, three groups of glacial deposits are known; Moraine, till and outwash.

iv. **Marine Deposits**: these are deposits laid down by ocean currents over the years on which vegetation can be established and soil later forms.

b. Sedentary Parent Material (Soils from Residuum)

Sedentary parent materials are the residual of mineral particles arising from the decomposition of rocks and are left in their place of formation. The properties of sedentary parent materials are dictated by the kind of rocks it originated from and the kind of weathering it has undergone. These kinds of parent materials are common in West Africa especially in the southern humid regions. They constitute a deep continual substratum beneath the land surface in a large part of west Africa. Whenever, exposed on the land surface, they give rise to the so called sedentary soils.

Sedentary parent materials could originate from either igneous, sedimentary or metamorphic rocks. The important thing to consider is that the parent rock were formed and later weathered in the same location at which the soil is later formed. There is no assistance of transporting agent needed.

c. Organic Parent Materials

Organic parent materials are formed from the accumulation of undecomposed, partially decomposed and completely decomposed organic remains as well as their decomposed product, called humus. They occur in depressions such as marshes and swamps where stagnant water creates anaerobic conditions which result in slow decomposition of organic residues and preservations of residues and decomposition products. The importance of parent material as a soil forming factor is less evident in wetter climates.

The mineralogical composition of the parent material is the most importance characteristic, but in addition, such features as porosity, permeability, texture, and degree of association must be considered.

3.2.2 Climate

Climate is the sum total of all the weather events operation in an area. Climate is the dominant factor in soil formation and acts on the parent material, directly and indirectly. Climate controls the weathering of rocks to form soil parent materials and determine the processes operating on soil parent material during soil formation. Climate also determines the kind of vegetation existing in a region thereby influencing other soil factors. The three main elements of climatic are precipitation, temperature and wind.

i. Precipitation

Rainfall directly or indirectly contributes to soil formation. The following are the ways in which climate through rainfall affect soil formation.

- Low rainfall causes salts to rise through the soil carrying salts in solution. Near or at the surface, the water evaporates leaving the salts behind.
- In areas of high rainfall, leaching of the soil (removal of finer materials) is bound to occur leading to the formation of acid soils, e.g. include soils of the coastal plains, often referred to as acid soils of the Southern Nigeria. Leaching has to do with the transportation of certain mobile soil constituents totally out of the soil system.
- On a sloppy terrain, excessive rainfall may lead to the development of thin soils due to the amount and intensity of the rainfall causing erosion and the deposition of soil materials downstream, e.g. is the hilly terrain to the north of Enugu.
- It causes the weathering of primary minerals to clay sized secondary mineral. Generally the amount of clay or clay-sized particles formed in the soil increases as the amount of rainfall increases.
- It is a transporting medium for certain agents such as oxygen, carbon dioxide, mineral and organic acids which promote weathering and soil development.
- Precipitation governs the amount of organic matter added to the soil. This is because it determines the type of vegetation existing in an area. In West Africa, more organic matter accumulates in the forest soils than in the soil under savannah. This may also be as a result of continual burning of vegetation under savannah soils.
- Rainfall serve as a medium for transporting soils constituents, for example, fine clay which may be carried from one part of the soil body and subsequently deposited in other parts (illuvial clay).

ii. Temperature

Temperature measures the amount of solar radiation that reaches the earth's surface and often referred to as atmospheric temperature. Temperature varies daily, seasonally, annually and globally. Perhaps more important to soil development is the soil temperature which is directly controlled by atmospheric temperature. Thus the higher the atmospheric temperature, the higher the soil temperature becomes.

High annual temperature encourages rapid weathering of parent materials, e.g. is the northern Nigeria. in west Africa which is mostly in the hot humid region, the rate of soil formation should be faster than that experienced in temperate regions of the world. High diurnal variations in temperature causes rocks to expand during the day and cool during the night resulting in differential expansion and contraction and eventual cracking and splitting of the rock. This is a common occurrence in the desert.

The earth can be divided in the following regions based on soil temperature:

Region	Soil Temperature
Arid region	> 35^{o}C
Humid region	25 – 30^{o}C
Temperate	18^{o}C
Arctic	- 40 -10^{o}C

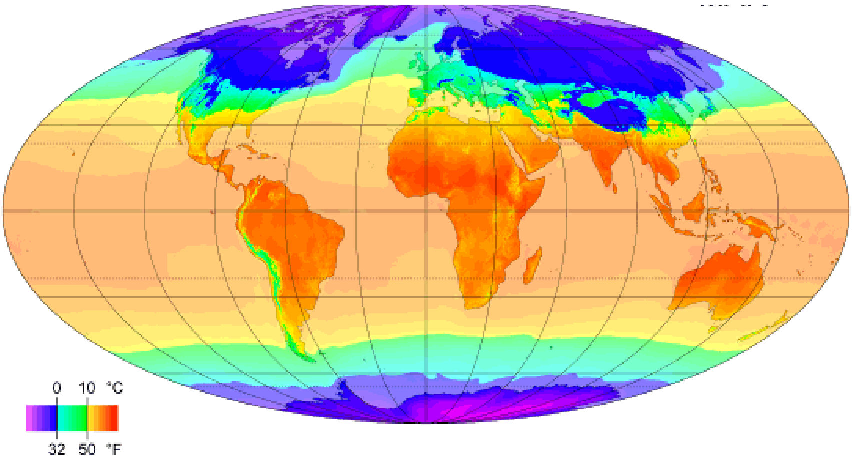

Fig. 1: World Map Showing Temperature at different Regions

iii. Wind

Wind functions as a drying agent and also important agent of erosion in arid regions. When sandy soils dry out, they become very susceptible to erosion by wind. Such happenings have been reported in many northern Nigeria states including; Katsina, Kebbi, Sokoto, Borno and Kano States.

Climate influences soil formation indirectly through its effects on vegetation. In areas of high rainfall, forest becomes the dominant vegetation. This leads to a strong protective influence that allows a deep soil profile to develop. However, when the rainfall is scarce, the vegetation that develops in such areas would be grassland. Grassland vegetation makes soil to be exposed and vulnerable to other agents such as erosion and bush burning, etc. thereby making soil formation very difficult. Temperature and high effective rainfall strongly influence the organic matter content of the soil.

In agricultural activities, water retention is of paramount interest. In the study of soil rainfall relationship, it is always helpful to compare the total average rainfall for a year, season or month with the amount likely to be lost from the soil by direct evaporation and by transpiration by plants, two processes often being referred as evapotranspiration. This comparison of rainfall and the estimated evapotranspiration losses gives some indication of the likelihood of there being a surplus for soil leaching. The factors governing the behaviour of rainfall received and of soil water are very complex and beyond the scope of this study.

However, if we consider the soil of West Africa as a whole, they fall into belts related to climate and vegetation. However, within these belts or zones, there are considerable local differences that are due to differences that arise to differences in relief and parent materials.

iv. Vegetation

The natural vegetation of West Africa can be divided into the closed forest of the southern and generally wetter regions, and the savanna woodland, and savanna areas of the generally not less wet areas to the north of the forest zone. Forest vegetation cannot develop where there is a long severe dry season. Hence forest vegetation is associated with two peak rainfall regimes of the south. It is the amount of rain as well as the distribution that is important. Savanna vegetation consists of grasses and herbs which die back in the long dry season, and of trees adapted to the seasonal water shortages. Savanna of various types is therefore associated with rainfall regimes which have a long severe dry season (see figures 2 and 3 below).

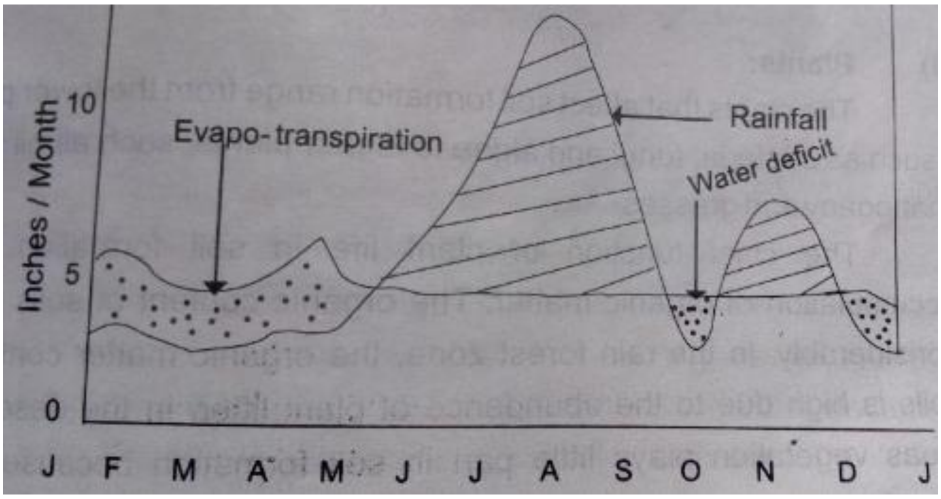

Fig.2. Two peak rainfall regime in Lagos, Nigeria (Ibanga, 2006)

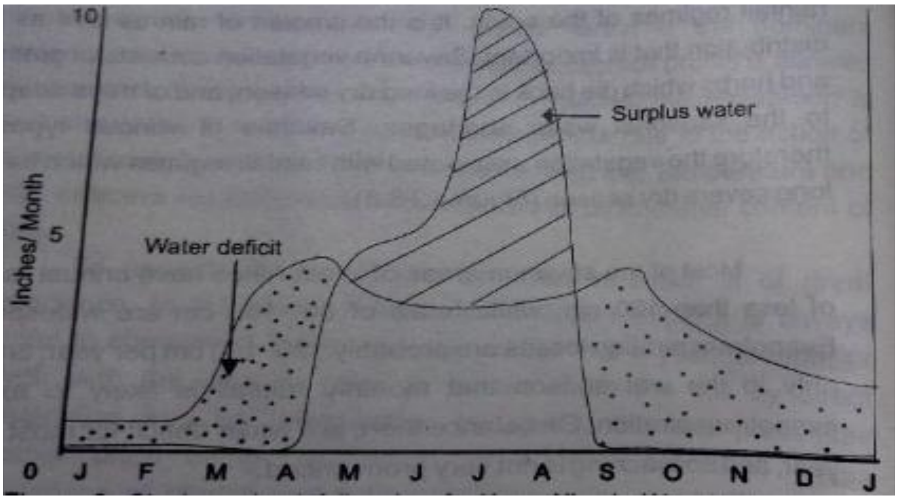

Fig.3: Single peak rainfall regime for Kano, Nigeria (Ibanga, 2006)

Most of the savanna areas of West Africa have annual rainfall of less than 120cm, while totals of 60 – 100cm are widespread. Evapotranspiration losses are about 120 – 150cm per year, and it only in the wet season that monthly rainfall is likely to exceed evapotranspiration. On balance, there is a water deficit for most of the year, and so leaching is not very pronounced.

On the other hand, in forest areas with annual rainfall in excess of 180 cm there is a period when rainfall greatly exceeds evapotranspiration losses. This situation will lead to considerable leaching during the rainy season. Soils found in such areas tend to have acid soil reactions, mostly marked in the top soils due to the washing out of exchangeable cations such as Ca, Mg, K and Na from the exchange complex.

3.2.3 Organism

The organic factor of soil formation is made up of plants or animals that either inhabit the soil or grow in it. The nature and number of plants and animals growing/living in and on the soil play important roles in soil formation.

i. Plants

The plants that affect soil formation range from the lower plants such as bacteria, fungi and algae to higher plants such as oil palm, mahogany and grasses. The major function of plant life in soil formation is in accumulation of organic matter. The organic content of soil varies considerably. In the rain forest, the organic matter content of soil is high due to the abundance of plant litter. In the desert and arid regions, vegetation plays little part in soil formation because of its scarceness.

How Plants contribute to soil formation

- By producing organic acids and carbon dioxide as well as promoting the weathering of soil mineral particles.
- Organic matter accumulation, profile mixing, nutrient recycling and formation of stable soil aggregates, etc., are all possible due to the presence of organisms in the soil.
- Nitrogen is added to the soil system by micro organisms alone or in association with plants (N-fixation).

- Vegetation cover slows down erosion rates thereby reducing the rates of removal of the surface soil.
- Mineral content in the leaves, twigs, stems of natural vegetation strongly influence the characteristics of the soil that develops. As rain water filters through the leave litter, it carries with it some organic acids which cause the bleached E-horizon that is not present in grassland soils.
- The vegetative cover modifies soil climate by soil water, preventing excessive evaporation of soil water and modifying soil temperature by shielding the soil from the direct impact of solar radiation.
- The most visible evidence of the effect of vegetation is seen when comparing properties of soil formed under grassland and forest vegetation colour, organic matter content, moisture, base saturation etc.

Functions of Micro – organisms in the soil

- Micro – organisms decompose organic remains, such as twigs, stems, roots and death animal bodies into humus, which when incorporated into the soil improves soil fertility. The decomposition of and mineralization of organic matter to release nitrogen (N) for plant use are affected by several bacteria and the microbial processes can be shown thus;

  Organic matter $\longrightarrow$ Organic N $\longrightarrow$ NH_4N $\longrightarrow$ NO_2 $\longrightarrow$ NO_3
- Micro – organisms help bind soil particles together by means of their threads or gum they produce, (e.g. fungi) thereby promoting the development of good soil structure.
- Soil bacteria such as Clostridium and Azotobacter are able to fix atmospheric nitrogen and incorporate it into the soil thus improving soil fertility.
- When micro – organisms themselves die and decay, they add humus to the soil.

  ii. Animals

  Several animal species ranging from the lower to the higher forms inhabit the soil, and influence its development.

How Animals contribute to Soil development

- Nematode, centipede and millipedes burrow into the soil creating pores through which water and air can easily penetrate the soil. Burrowing animals and termites play important part in soil formation. By their burrowing action they create channels through which air and water enter (aerate) the soil, bringing up plant nutrients from the lower to the upper layers thus making them more available to plants, mix soil particles with organic fractions and cause inversion of the texture.
- Earthworms re abundant in most West African soils. They ingest large quantities of soil and organic matter, pass these through their guts and excrete out. These are used in building cast which dot several landscapes in the region.
- Termites are very active in decomposing organic matter, including the resistant forms such as cellulose. This possibly accounts for the low amount of litter (roots, leaves, twigs) in West African forests where termites live in the soil. Termites build up mounds from soil particles brought to the surface from the sub soil.

- Ants make mounds from soil particles brought to the soil surface from depths. Rodents such as grass cutters, bush rates, porcupines and moles burrow into the soil exhuming large volumes of soil particles. They cause the mixing, aeration and collapse of soil materials by their activities.
- Man burns the natural vegetation, excavates the soil for several purposes and degrades the soil thereby exposing the soil to erosion. Forest fires cause exfoliation of rocks. Other activities of man include irrigation, construction, waste /refuse disposal in the soil.

3.2.4 Relief

Relief is the total of all the inequalities on the land surface. It encompasses and considers the geometrical relationship between the highlands, valleys and interfluvial slopes that connect the mountains and the valleys. The influence of relief on soil formation is due to its controlling effect on drainage, run-off, erosion, etc. It plays a dominant role as a modifier of climate and vegetation effects. It also controls the amount of profile development taking place within a giving time on a given parent material, and under the same type of vegetation. This largely depends upon the amount of water passing through the soil.

How Relief contribute to soil formation

- The nature of soil in depression is quite different from that in the uplands. On steep slopes soil profiles are not strongly developed due to excessive run-off and erosion. On gentle slope however, profile development is normal but depends on the nature of the parent material which must not be too sandy or too clayey.
- Because of the interaction moisture and topography, trees commonly occupy depressional areas even in grassland areas. These are called riparian forests.
- Soil depth varies greatly from the top to the lower slopes, so are the outer properties such as colour, nutrient content, organic matter, drainage and pH. (See fig. 4)

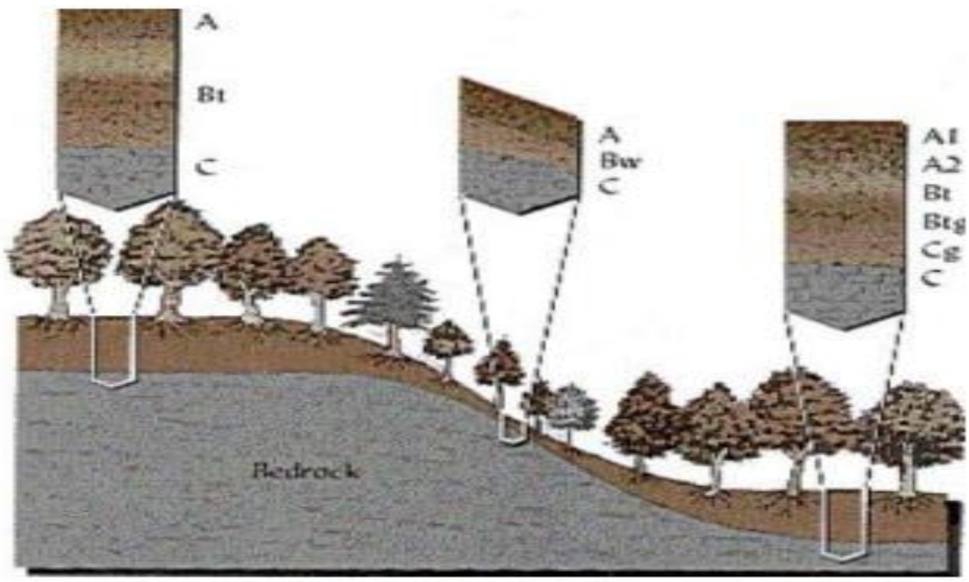

Fig. 4: Effect of slope on soil development

Relief as Conditioner for other Factors

The influence of relief or topography is indirect as it serves mainly to redistribute the matter and energy occurring from the other soil forming factors. However, the indirect effects have very significant influence on soil formation as explained below.

a. Altitude

It is well known fact that soils formed in higher altitudes or elevations are different from those formed in lower altitudes such as drainage basins or coastal lowlands. The effects of altitude on soil formation reflect itself through its influence on soil drainage. Soils on high elevations are usually well drained whereas soils in low topographic positions or valley bottoms are usually poorly drained.

b. Shape of Landscapes

Whether a landscape or landform is hilly, undulating or flat makes a difference in soil development

i. Gently sloping or rolling landforms allow ample infiltration into porous soils, hence soil development is normal depending on the parent material.

ii. Soils on hills of steep slopes receive little infiltration due to accelerated run-off and erosion.

iii. Older soils are usually found on protected upper slopes while younger soils are found in the lower slopes.

iv. Flat landforms generally impede drainage causing water-logging. With flat or concave slopes, runoff is negligible or almost absent. Such slopes retain all the rains that falls on them and often receives additional amounts from adjacent uplands. Considerable amount of eroded materials may be deposited on these slopes. Hydromorphic and halomorphic soils typically occur in these positions.

v. An interfluve may have the relief position carrying different soil series, which may have developed from the same parent material. Such a group of soils is called "catena". The distinguishing criteria are associated with drainage. However it becomes increasingly clear that slopes may have been cut in different lithologic materials so that the soil series encountered on such slope sequence is called a "toposequence". The concept of toposequence is highly applicable to many parts of West Africa, where soils occurring along the same slope vary in parent material as well as drainage.

vi. The morphology and depth of soils formed on hilly, gently sloping and flat landforms vary tremendously. Hilly and steep slopes invariably posses thin soils; gently sloping landforms may possess thick soils that are well drained, and flat landforms though may possess thick soils, the soils, the soils are usually either water-logged or show drainage mottles.

c. Aspect of Slope

Relief can also affect soil formation through its secondary influence of causing variations in exposure of land surfaces to the sun, wind and air movement, especially in temperate regions with pronounced differences in day lengths.

i. South-facing slope are usually warmer and dryer than north-facing slopes (this is true for the northern hemisphere).
ii. North-facing slope tend to support more luxuriant vegetation than south-facing slope because the former can sustain marked fluctuations in temperature and moisture.
iii. Ensuring micro-climate in south-facing slope promotes rate of organic matter decomposition, allows deeper percolation of moisture, and hence favours the formation of deep soils (fig. 5).

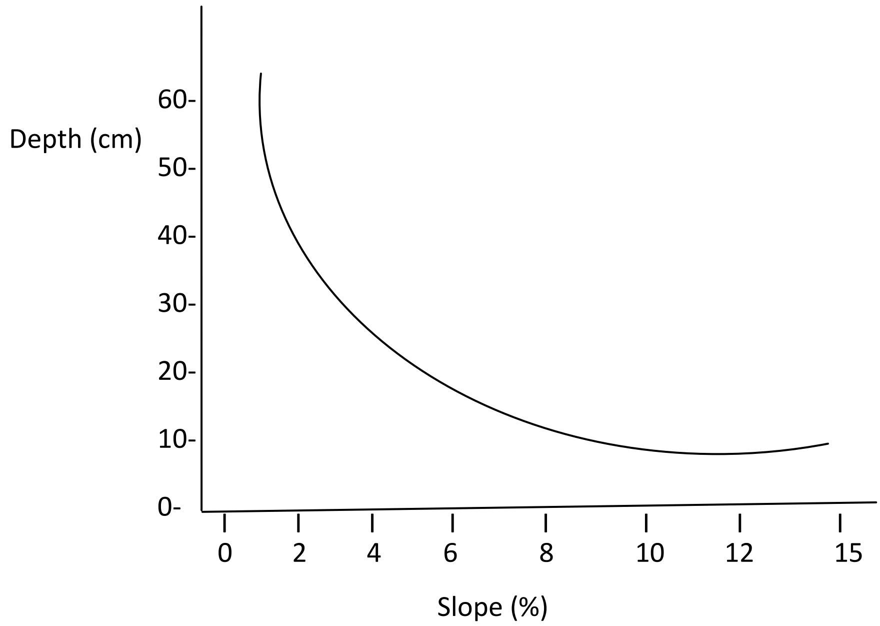

Fig. 5: Influence of slope on soil depth

The Concept of Catena

The realization that particular slope forms were associated with particular soil sequence led to the formation of the catena concept. Catena was originally defined by Milne as "a unit of mapping convenience, a grouping of soils which while they fall wide apart in a natural system of classification on account of fundamental and morphological differences, and are yet linked in their occurrence by conditions of topography and repeated in the same relationship to each other wherever the conditions are met with. Similarly, the catena is defined as a sequence of soil profiles which appear in a regular succession in similar drainage basins and of uniform lithology (parent rock). The soils related in a catena are seen to have properties that can be related to their position on the landscape. The term well drained, imperfectly drained, and poorly drained have been used to describe soils related in toposequence in accordance with their drainage conditions.

Relationship between Topography and Drainage

- Upland and well drained soils in West Africa are frequently somewhat reddish – reddish brown or brownish red. These red colours are as a result of non – hydrated iron oxide in the soil, heamatite (Fe_2O_3). The red colour indicates good drainage and will remain so except it mixes with water molecules.
- In the middle and lower slopes, soil drainage is a little slower than in the upper slope soils. Because these soils remain moist longer and perhaps dry out less frequently, there is an increasing degree of hydration of iron in the soil Colour now changes from red to brown or yellow. The hydrated iron oxides n these soils are mainly goethite ($Fe_2O_3.H_2O$) and limonite ($Fe_2O_3.3/2H_2O$).
- When drainage is very poor, as in the valley bottom where the water table fluctuates and so part of the profile is subjected water-logging, reduction of iron and other compounds in the soil becomes prominent. Typically soil colours are bluish greys, greenish greys and neutral greys. These colours suggest prolonged water-logging. However, where the water is intermittent or seasonal (i.e. fluctuating water table), instead of a uniform grey colour, mottles are likely to be produced. A mottle is a spot or small area of different colour from the surrounding material.
- Gleying is the process giving to the soil a dominant blue, grey or green colour through soil saturation and reducing conditions. Hence very poorly drained soil is known as gley soils (Ibanga, 2006).

3.2.5 Time

The exact length of time that materials have been subjected to weathering, even though difficult to determine, plays a very important role in soil formation. The beginning of soil formation is regarded as time zero. Time is necessary for development of soil from parent material. The length of time depends on other factors involved. The length of time required to form a mature soil is probably greater in arid regions than in more humid ones.

In the early stage of soil formation, materials inherited from parent materials dominate, but as the soil develops, properties which have been acquired (due to environmental influences) becomes more prominent, e.g. those due to organic matter, clay formed as the soil develops, profile layering, etc.

a. Relationship of Time with other soil forming factors

Although time is an important factor of soil formation, it would be more realistic to think in terms of the length of time which other factors (parent material, climate and organism) have been influencing soil development; that is the time factor is usually synthesized into other factors. The recognition of this fact prompted Crocker to formulate the following equation for soil formation.

$$S = \int^{1}_{0} (cl, o, r, p....)dt$$

Where s = soil formation

cl = climate

o = organism

p = parent materials and

t = time

The expression states that soil formation is the integral of the function of all the factors of soil formation with respect to time. The beginning of soil formation can be taken as time zero (t=0) thereby progressing as factor or processes initiated by them operate through time.

b. Time Required for Soil Development

The time required for a unit depth of soil to form depends on other factors. Limited data is available concerning the time taken to form a unit depth of soil.

i. For soil to develop on hard rock, the time may be measured in many centuries
ii. In permeable, unconsolidated materials in warm humid climate supporting forest vegetation, soil development may assume rapid rate and time of development may be measured in a few thousand years.
iii. In permeable unconsolidated material in a cold, dry climate, soil development would be slower than in warmer or warm humid climate.

c. Chronological Development of Soil

The influence of time on soil formation had long been recognized. Dokucheav himself stated that the age of the soil has begun from the moment the parent material has emerged. Time as a factor of soil development, could therefore be seen in terms of stage of profile/soil development. Many scientists have started studying soil development on a time sequence.

Mohr and Van Baren hypothesize five stages of soil development in the tropics, namely; initial, juvenile, virile, senile and final. This grouping is based on the actual/observed soil properties at time of investigation.

i. Initial: The unweathered parent material emerges
ii. Juvenile: Weathering has commenced but much of the original minerals are still unweathered
iii. Virile: Pronounced decomposition of primary minerals leading to increase in clay content; soil maximum capacity to support vegetation or crops.

iv. Senile: Decomposition of residual primary minerals with most resistance minerals surviving, i.e. low weathering potential.

v. Final: Soil development has been completed and the soil has no weathering potential under the prevailing conditions.

Other scientists discussed soil development as progressing through immature (young), mature and old age states

i. Immature stage: Weathering has started showing the beginning of soil formation; high content of primary minerals, low clay content, shallow soils, low suitability for crop production, possibly A and C horizons only.

ii. Mature Stage: Pronounced weathering of primary minerals; high clay content; constant organic matter content owing to equilibrium between gains and losses; maximum capacity to support vegetation and crops; deep soil with A, B and C horizons.

iii. Old Age (Senile): Low weathering potential; declining fertility; resistant materials survive A, B, C horizons remain but horizon boundaries are indistinct.

Inter-relationship among Factors

Since the recognition that soil formation is due to the interaction of soil forming factors, attempts have been made to evaluate the effects of each factor on soil development. Some scientists held the view that climate was the most dominant factor while others claimed that vegetation was most dominant. Jenny in 1941 formulated an equation connecting the five factors as follow;

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

He later modified the equation into;

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

The later equation would allow room for the possibility of other factors being recognized in future. One of such examples is man (discussed earlier under organisms). The idea of Jenny was that the effects of each variable on soil formation can be assessed by holding other variables constant which can be possible naturally. Crocker's equation had pointed out that the variables operate in combination. For instance, climate directly influences the vegetation and relief that may develop in a region. It also controls weathering and hence the formation of soil parent materials. Climate, organisms, relief and parent materials require time to evolve soils.

4.0 CONCLUSION

While soil parent materials are the materials upon which soils form, climate was largely responsible in breaking down the parent rocks to form parent materials. Precipitation, temperature and wind are important climatic elements that aid in soil formation. Micro and macro organisms are responsible for further breaking down of particles and organic components of the soil leading to soil formation. The major function of plant life in soil formation is in accumulation of organic matter. Soils formed in higher altitudes or elevations are different from those formed in lower altitudes such as drainage basins or coastal lowlands. All the factors of soil formation interact with one another and all lead to the formation of soil in the process of time.

5.0 SUMMARY

Soils form from the interplay of five main factors namely; Parent material, climate, organism, relief and time. Organism and climate may be seen as active factors of soil formation since their influence can be seen physically. E.g. rain, heat, cold, wind, microorganisms (algae, fungi), earthworms, and burrowing animals can be directly observed influencing soil development. While Parent material, relief and time are passive factors because their influence may not be directly observed.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is Parent material? Briefly explain the three major types of parent material
2. Explain the following; Precipitation, temperature and wind as important climatic element of soil formation
3. Discuss in full how organism is an active factor of soil formation
4. What is the relationship between topography and drainage in soil formation

7.0 REFERENCES/FURTHER READING

Bradv, N.C. and Weil, R.R (2006): The Nature and Properties of Soil. 13th ed. New Jersey, Prentice Hall Inc.

MODULE 2: FIELD STUDY OF SOIL

UNIT 1: SOIL MORPHOLOGY

CONTENTS

1.0 INTRODUCTION

Soil Morphology deals with the form and arrangement of soil features. Micromorphology is using micro-morphological techniques (e.g. thin sections) and measurements in the laboratory. Field morphology is the study of soil morphological features in the field by thorough observation, description and interpretation. Observations may be refined with the aid of a hand lens. Simple tests are also used in the field to record salient chemical properties (e.g. pH, presence or carbonates). In addition, field observations and measurement may be refined through a range of laboratory analytical procedures that include more sophisticated evaluation of chemical, biological and physical attributes.

However, the quality of field description and sampling ultimately defines the utility of any subsequent laboratory analyses. A keen eye that call discern specific features and their relationship to adjoining features coupled with well-calibrated fingers that can distinguish among relative differences in physical properties of soil material are essential and can only be acquired and maintained through practice, In this course we will focus morphology.

2.0 OBJECTIVES

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

- Know the soil morphological and micro-morphological properties of the soil
- Attempt to identify these properties in the field

3.0 MAIN CONTENT

3.1 Soil Morphology

Field morphology starts with *in situ* (field) examination of a soil profile, Field descriptions are organized by subdividing, in vertical exposure of the soil (soil profile) into reasonably distinct layers or horizons that differ appreciably from the horizons immediately above and below in one or more of the soil features listed below. The delineation of horizons is necessarily a somewhat subjective processes because changes in soil attributes are often gradational rather than abrupt. Thus, obvious boundaries between horizons are not always apparent and their assignment may require integrated assessment of changes in several attributes before a sensible and defensible delineation can he made. Knowledge of similar soils and a well-defined rationale for the purpose of the description helps considerably in development of systematic criteria for criteria for defining and delineating horizons.

The following information is collected for assembling standard profile descriptions:

- Depth intervals of horizons or layers (measured from the top of the mineral horizons)
- Horizon boundary characteristics
- Colour
- Texture
- Structure, pores
- Consistence
- Roots
- pH, effervescence
- Special features such as coatings, nodules, and concretions

4.0 CONCLUSION

Differences between horizons generally reflect the type and intensity of processes that have caused changes in the soil. Ideally, we should always be striving in our descriptions to maintain a link between process and morphology. In many soils, these differences are expressed by horizonation that lies approximately parallel to the land surface, which in turn reflects vertical partitioning in the type and intensity of the various processes that influence soil development. However, there are many exceptions to this preferred horizontal organization.

5.0 SUMMARY

Properties of each horizon are described in the following order; Depth intervals of horizons or layers (measured from the top of the mineral horizons), Horizon boundary characteristics, Colour, Texture, Structure, pores, Consistence, Roots, pH, effervescence, Special features such as coatings, nodules, and concretions. Also, about $^1/_2$ kg or 500g of soil should be taken from each horizon. Sampling should start from the last horizon to avoid contamination of the horizon. Properly labeled and taken to a standard laboratory for analysis.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is soil field morphology?
2. What is soil micro-morphology?
3. Name 5 morphological properties of soil.
4. What are the precautions to take during sampling using a profile pit?

7.0 References/Further Reading

Buol, S.W., Hole, F.D., McCracken, R.J., and Southard, R.J., (1997). Soil Genesis and Classification. Lowa State University Press.

UNIT 2: SOIL HORIZONS AND BOUNDARIES

CONTENTS

1.0 INTRODUCTION

If you look in a soil pit or on a roadside cut, you will see various layers in the soil. These layers are called **soil horizons**. The arrangement of these horizons in a soil is known as a **soil profile**. Soil scientists, who are also called pedologists, observe and describe soil profiles and soil horizons to classify and interpret the soil for various uses. Soil horizons differ in a number of easily seen soil properties such as color, texture, structure, and thickness. Other properties are less visible. Properties, such as chemical and mineral content, consistence, and reaction require special laboratory tests. The distinction between a mineral and an organic horizon is by the organic carbon content. Layers which contain > 20 % organic carbon and are not water saturated for periods more than a few days are classed as organic soil material. If a layer is saturated for a longer period it is considered to be organic soil material if it has:

- ≥12 % organic carbon and no clay, or
- ≥18 % organic carbon and ≥ 60 % clay, or
- 12 – 18 % organic carbon and 0 – 60 % clay.

All these properties are used to define types of soil horizons.

Soil generally consists of visually and texturally distinct layers, which can be summarized as follows from top to bottom:

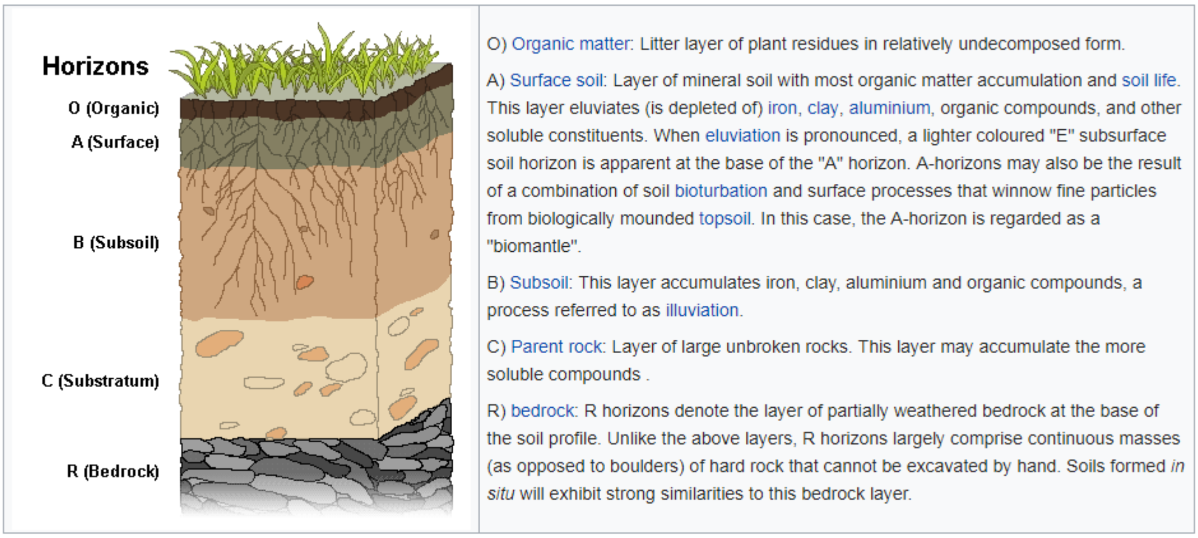

Fig.6: A soil profile revealing the different horizons (Wikipedia)

There are master horizons (Surface horizons) and are designated by capital letters, such as O, A, E, B, C, and R., Sub surface horizons and Transitional Horizons

2.0 OBJECTIVES

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

- Identify surface diagnostic (master) horizons
- Know subordinate distinctions with master horizons
- Identify transitional horizons
- Know and identify subsurface horizons

3.0 **MAIN CONTENT**

3.1 Important Facts to Know

1. Master horizons (major horizons) are designated by capital letters, such as O, A, E, B, C, and R.
2. Some O layers may be undecomposed or partially decomposed litter, such as leaves, twigs, moss, and lichens, that has been decomposed on the surface; they are either on the top of either mineral or organic soils. Other O layers, are organic materials that were deposited in saturated environments and have undergone decomposition.
3. A horizons are mineral horizons that formed at the surface or below an O layer, that exhibition obliteration of all or much of the original rock or depositional structure (in the case of transported materials).
4. B Horizons have some features such as; An illuvial concentration of silicate clay, iron, aluminum, carbonates, gypsum, or humus; Removal of carbonates; A residual concentration of sesquioxides or silicate clays, alone or mixed, that

has formed by means other than solution and removal of carbonates or more soluble salts; Coatings of sesquioxides adequate to give darker, stronger, or redder colors than overlying and underlying horizons but without apparent illuviation of iron.

5. C Horizons are mineral horizons that are little altered by soil forming processes. They lack properties of O, A, E, or B horizons.
6. Transitional horizons are layers or the soil between two master horizons designated as AB, BA, EB, BE. The first letter indicates the material of greatest volume in the transitional horizon. E.g. A/B, B/A, E/B or B/E.

3.2 Soil Horizon and Boundaries

3.2.1 Soil Master Horizons

- **O horizons:** They are dominated by organic material. Some O layers consist of undecomposed or partially decomposed litter, such as leaves, twigs, moss, and lichens, that has been decomposed on the surface; they may be on the top of either mineral or organic soils. Other O layers, are organic materials that were deposited in saturated environments and have undergone decomposition. The mineral fraction of these layers is small and generally less than half the weight of the total mass. In the case of organic soils (peal, muck) they may compose the entire soil profile. Organic rich horizons which are formed by the translocation of organic matter within the mineral material are not designated as O horizons.
- **A horizons:** Mineral horizons that formed at the surface or below an O layer, that exhibition obliteration of all or much of the original rock or depositional structure (in the case of transported materials). A horizons show one or more of the following:
  - An accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by characteristic properties or the E or B horizon or,
  - Properties resulting from cultivation, pasturing or other similar kinds of disturbance.

7. **E horizons:** Mineral horizons in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles and lighter colors. The horizons exhibit obliteration of all or much of the original rock structure.
8. **B horizons:** Horizons in which the dominant features (s) is one or more of the following:

- An illuvial concentration of silicate clay, iron, aluminum, carbonates, gypsum, or humus
- Removal of carbonates
- A residual concentration of sesquioxides or silicate clays, alone or mixed, that has formed by means other than solution and removal of carbonates or more soluble salts
- Coatings of sesquioxides adequate to give darker, stronger, or redder colors than overlying and underlying horizons but without apparent illuviation of iron.
- An alteration of material from its original condition that obliterates original rock structure, that form silicate clay, liberates oxides, or both, and that forms a granular, blocky, or prismatic structure.

- Any combination of these.

- **C horizons:** Mineral horizons that are little altered by soil forming processes. They lack properties of O, A, E, or B horizons. The designated C is also used for saprolite, sediments, or bedrock not hard enough to qualify for R. the material designated as C may be like or unlike the material from the A, E, and B horizons are thought to have formed.
- **R Layers:** Consolidated bedrock (hard bedrock), such as granite, basalt, quarzite, sandstone, or limestone. Small cracks, partially or totally filled with soil material and occupied by roots, me frequently present in the R layers.

Subordinate Distinctions within Master Horizons (Letter Suffixes)

Lower case letters are used to designate specific features within master horizons. They are listed in alphabetical order below:

- **a:** Highly decomposed organic material. The ‘a’ is used only with the O master horizon (Oa). The rubbed fiber content < l7 % of the volume.
- **b:** Buried genetic horizon. It is not used in organic soils or to identify a buried O master horizon.
- **c:** Concretions of hard non-concretionary nodules. This symbol is used only for iron, aluminum, manganese, or titanium cemented nodules or concretions.
- **d:** Physical root restriction. It is used to indicate natural occurring or humanly induced layers such as basal till, plow pans, and other mechanical compacted zones. Roots do not enter except along facture planes.
- **e:** Organic material of intermediate decomposition. This symbol is only used in combination with an O master horizon with rubbed fiber content between 17 – 40 % of the volume.
- **d:** Frozen soil. The horizon must contain permanent ice.
- **g:** Gleying: This symbol is used in B and C horizons to indicate low chroma color (< = 2), caused by reduction of iron in stagnant saturated conditions. The iron may or may not be present in the ferrous form (Fe^{2+}). The g is used to indicate either total gleying or the presence of gleying in a mottled pattern. It is not used in E horizons, which are commonly of low chroma, or in C horizons where the low chroma colors are inherited form the parent material and no evidence of saturation is apparent.
- **h:** illuvial accumulation of organic matter: Used only in B horizon. The h indicates an accumulation of illuvial, amorphous, dispersible organic matter with or without sequioxide component. If the sequioxide component contains enough iron so that the color value and chroma exceed 3 additionally a s is used (hs). The organoosequioxide complexes may coat sand and silt particles, of occur as discrete pellets, or fill voids and cement the horizon (use of m).
- **i:** Slightly decomposed organic material. Used only in Combination with an O master horizon to designate that the rubbed fiber content is > 40 % or the volume.
- **k:** Accumulation of carbonates, usually calcium carbonate. Used with B and C horizons.
- **m:** Cementation or induration: Used with any master horizon, except R, where > 90 % of the horizon is cemented and roots penetrate only through cracks. Tire cementing material is identified by the appropriate letter.

- **km:** carbonate
- **qm:** silica
- **sm:** iron
- **ym:** gypsum
- **kqm:** both lime and silica
- **zm:** salts more soluble than gypsum

- **n:** Accumulation of sodium: This symbol is used on any master horizon showing morphological properties indicative of high levels of exchangeable sodium.
- **o:** Residual accumulation of sesquioxides.
- **P:** Tillage or other cultivation disturbance (e.g. plowing, hoeing, discing). This symbol is only used in combination with the master horizon A or O.
- **q.** Accumulation of silica: This symbol is used with any master horizon, except R, where secondary silica has accumulated.
- **r:** Weathered soft bedrock: This symbol is only used in combination with the master C horizon. It designate saprolite or dense till that is hard enough that roofs only penetrate along cracks, but which is soft enough that it can be dug with a spade or shovel.
- **s:** illuvial accumulation or sesquioxides and organic matter. This symbol is only used in combination with B horizons. It indicates the presence or illuvial iron oxides. It is often used in conjunction with h when the color is = < 3 (chroma and value).
- **ss:** Presence of slicken sides. They are formed by shear failure as clay material swell upon wetting. Their presence is an indicator of vertic characteristics.
- **t:** Accumulation of silicate clay: The presence of silicate clay forming coats on ped faces, in pores, or on bridges between sand-sized material grains. The clay coats may be either formed by illuviation or concentrated by migration within the horizon. Usually used ill combination with B horizons, but it may be used in C or R horizons also.
- **v:** Plinthite: This symbol is used in B and C horizons that are humus poor and iron rich. The 5 material usually has reticulate mottling of reds, yellows and gray colors.
- **w:** Development of color and structure. This symbol is used for B horizons that. have developed structure or color different, usually redder than that of the A or C horizons, but do not have apparent illuvial accumulations.
- **x:** Fragipan character: This symbol is used to designate genetically developed firmness, brittleness, or high bulk density in B or C horizons. No cementing agent is evident.
- **y:** Accumulation of gypsum. This symbol is used in B and C horizons to indicated genetically accumulated gypsum.
- **z:** Accumulation of salts more soluble than: gypsum. This symbol is used in combination with B and C horizons.

Note: Arabic numerals can be added as suffixes to the horizon designations to identify subdivisions within horizons. For example, Btl - Bt2 - Bt3 indicated three subsamples of the Bt horizon.

3.2.2 Transitional Horizons

Transitional horizons are layers or the soil between two master horizons. There are two types of transitional horizons:

- Horizons dominated by properties of one master horizon that also have subordinate properties of an adjacent master horizon. The designation is by two master horizon capital letters:
- The first letter indicates the dominant master horizon characteristics
- The second letter indicated the subordinate characteristics

For example, an AB horizon indicates a transitional horizon between the A and B horizon, but one that is more like the A horizon than the B horizon. An AB or BA designation can be used as a surface horizon if the master A horizon is believed to have been removed by erosion.

- Separate components of two master horizons me recognizable in the horizon and at least one of the component materials is surrounded by the others. The designation is by two capital letters with a slash in between. The first letter designates the material of greatest volume in the transitional horizon. For example A/B, B/A, E/B or B/E.

3.2.3 Diagnostic Subsurface Horizons

The accumulation of substances such as silica, iron, aluminum, carbonate, and other salts can result in cementer layers, which change the physical, chemical, and biological behavior of the soil. For example, a cemented layer retards percolation, and restrict root activity. Furthermore, the availability of nutrients for plant growth is reduced, i.e., the cation exchange capacity is reduced. There are accumulations in the soil which show the enrichment of one substance and / or the depletion of another substance. This can be expressed by **diagnostic subsurface horizons**, which are listed in alphabetically order below. It should be stressed that some characteristics can be measured only in the laboratory and not in the field.

- **Agric horizon:** His formed directly under the plow layer and has silt, clay, and humus accumulated as thick, dark lamallae.
- **Albic horizon:** Typically this is a light-colored E horizon with the color value > = 5 (dry) or > = 4 (moist).
- **Argillic horizon**: It is formed by illuviation of clay (generally a B horizon, where the accumulation of clay is denoted by a lower case ‘t’) and illuviation argillans are usually observable unless there is evidence of stress cutans. Requirements to meet an argillic horizon are:
- 1/10 as thick as all overlying horizons
- > = 1.2 times more clay than horizon above, or:
- lf eluvial layer < 15 % clay, then > = 3 % more clay, or:
- If eluvial layer > 40 % clay, then > = 8 % more clay.
- **Calcic horizon:** This layer has a secondary accumulation or carbonates, usually of calcium or magnesium. Requirements:
- > = 15 cm thick

- > = 5 % carbonate than an underlying layer

➢ **Cambic horizon:** This subsurface often shows weak indication of either an argillic or spodic horizon, but not enough to qualify as either. H may be conceptually regarded as a signature of early stages of soil development, i.e. soil structure or color development. Requirements:

- Texture: loamy very fine sand or finer texture
- Formation of soil structure
- Development of soil color

➢ **Duripan:** It is a subsurface horizon cemented by illuvial silica. Air-dry fragments from more than 50 % of the horizon do not slake in water or HCl but do slake in hot concentrated KOH.

➢ **Fragipan:** These subsoil layers are of high bulk density, brittle when moist, and very hard when dry. They do not soften on welling, but can be broken in the hands. Air-dry fragments slake when immersed in water. Fragipan genesis as outlined in Soil Taxonomy is largely dependent all physical processes and requires a forest vegetation and minimal physical disturbance. Desiccation and shrinking cause development of a network of polygonal cracks in the zone of fragipan formation. Subsequent rewetting washes very fine sand, silt, and clay-sized particles from the overlying horizons into the cracks. Upon wetting, the added materials and plant roots growing into the cracks result in compression or the interprism materials. Close packing and binding of the matrix material with clay is responsible for the hard consistence of the dry prisms. Iron is usually concentrated along the bleached boundaries of the prisms. It has also been postulated that clay and sequioxides cements to be binding agents in fragipans.

➢ **Glossic horizon:** It occurs usually between an overlying albic horizon and an underlying argillic, kandic, or natric horizon or fragipan. Requirements:

- > = 5 cm thick
- Albic material between 15 % to 85 %, rest: material like the underlying horizon

➢ **Kandic horizon**: It is composed of low activity clays, which are accumulated at its upper boundary. Clay skins mayor may not be present It is considered that clay translocation is involved in the process of kandic formation, however, clay skills may be subsequently disrupted or destroyed by physical and chemical weathering, or they may have formed in situ. Requirements:

- Within a distance of < 15 cm at its upper boundary the clay content increases by > 1.2 times
- Abrupt or clear textural boundary to the upper horizon
- A pH 7: low-activity days with CEC of < = I6 cmol/kg and ECEC (effective CEC) of < = 12 cmol/kg

➢ **Natric horizon:** It is a subsurface horizons with accumulations of clay minerals and sodium. Requirements:

- Same as argillic horizon
- Prismatic or columnar structure
- > 15 % of the CEC is saturated with Na^+, or :
- More exchangeable Na^+ plus Mg^{2+} than Ca^{2+}

- **Oxic horizon:** Requirements:
- > = 30 cm thick
- Texture: sandy loam or finer
- At pH 7: CEC of < = I6 cmol/kg and ECEC of' < = 12 cmol/kg (i.e., a high content or 1:1 type clay minerals).
- Clay content is more gradual than required by the kandic horizon
- < 10 % weatherable minerals in the sand
- < 5 % weatherable minerals by volume rock structure (i.e., indicative of a very strongly weathered material)
- **Petrocalcic horizon:** It is an indurated calcic horizon. Requirements:
- At least 1/2 of a dry fragment breaks down when immersed in acid but does not break down when immersed in water.
- **Petrogypsic horizon:** This is a strongly cemented gypsic horizon. Dry fragments will not slake in H_2O.
- **Placic horizon:** This is a dark reddish brown to black pan or iron and/or manganese. Requirements:
- 2 – 10 cm thick
- It has to lie within 50 cm of the soil surface
- Boundary: wavy
- Slowly permeable
- **Salic horizon:** This is all subsurface horizon accumulated by secondary soluble salts. Requirements:
- > = 15 cm thick
- Enrichment of secondary soluble salts such (hat electrical conductivity exceeds 30 dS/m more than 90 days each year
- **Sombric horizon:** Formed by illuviation or humus (dark brown to black color) but not of aluminum or sodium. Requirements:
- At pH 7: base saturation < 50 %
- Not under an albic horizon
- Free-draining horizon
- **Spodic horizon:** This horizon has an illuvial accumulation of sequioxides and/or organic matter. There are many specific limitations dealing with aluminum, iron, and organic matter content, and clay ratios, depending on whether the overlying horizon is virgin or cultivated.
- Sulfuric horizon: this is a very acid mineral or organic soil horizon. Requirements:
- pH < 3.5
- Mottles are present (yellow color: jarosite)

3.3 Boundary

The boundary between the horizons can be described considering the distinctness and topography. ***Distinctness*** refers to the degree of contrast between two adjoining horizons and the thickness of the transition between them. ***Topography*** refers to the shape or degree of irregularity of the boundary. In Figure 3.3 examples for several boundaries are shown.

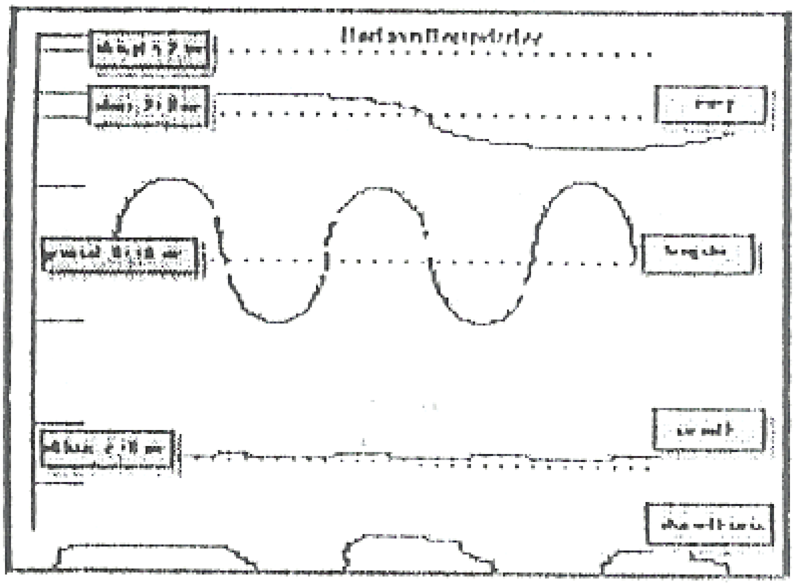

Fig. 7: Boundaries between Soil Horizons.

Table 1: Classification of Horizon Boundaries.

Distinctness	**Abbreviation**	**Cm**
Abrupt	A	< 2
Clear	C	2 – 5
Gradual	G	5 – 15
Diffuse	D	> 15
Topography	**Abbreviation**	**Description**
Smooth	S	Nearly a plane
Wavy	W	Waves wider than deep
Irregular	I	Depth greater than width
Broken	B	Discontinuous

4.0 CONCLUSION

A **soil horizon** is a layer parallel to the soil surface, whose physical characteristics differ from the layers above and beneath. Each soil type usually has three or four horizons. Horizons are defined in most cases by obvious physical features, mainly colour and texture. There are master horizons (Surface horizons) and are designated by capital letters, such as O, A, E, B, C, and R., Diagnostic Sub surface and Transitional Horizons. Soil horizons are identified in the field by careful observation of a standard soil profile pit. The experience of the observer will go a long way in ensuring accuracy of obtained results.

5.0 SUMMARY

O- Horizon (Organic matter): Litter layer of plant residues in relatively undecomposed form.
A-Horizons (Surface soil): Layer of mineral soil with most organic matter accumulation and soil life. This layer eluviates (is depleted of) iron, clay, aluminium, organic compounds, and other soluble constituents. When eluviation is pronounced, a lighter coloured "E" subsurface soil horizon is apparent at the base of the "A" horizon. A-horizons may also be the result of a combination of soil bioturbation and surface processes that winnow fine particles from biologically mounded topsoil. In this case, the A-horizon is regarded as a "biomantle".
B-Horizon (Subsoil): This layer accumulates iron, clay, aluminium and organic compounds, a process referred to as illuviation.
C-Horizon (Parent rock): Layer of large unbroken rocks. This layer may accumulate the more soluble compounds.
R-Layer (bedrock): R horizons denote the layer of partially weathered bedrock at the base of the soil profile. Unlike the above layers, R horizons largely comprise continuous masses (as opposed to boulders) of hard rock that cannot be excavated by hand. Soils formed *in situ* will exhibit strong similarities to this bedrock layer.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain what the letters; O, A, E, B, C, and R associated with master horizons stand for
2. What do you understand by transitional horizons?
3. Briefly explain what you know about subsurface diagnostic horizons
4. List and briefly explain 10 distinctive features (letter suffixes) that can be used to describe master horizon.

7.0 REFERENCES/FURTHER READING

https://en.wikipedia.org/wiki/Soil_horizon

UNIT 3: SOIL COLOUR

CONTENTS

1.0 INTRODUCTION

Soil color and other properties including texture, structure, and consistence are used to distinguish and identify soil horizons (layers) and to group soils according to the soil classification system called *Soil Taxonomy*. Color development and distribution of color within a soil profile are part of weathering. As rocks containing iron or manganese weather, the elements oxidize. Iron forms small crystals with a yellow or red color; organic matter decomposes into black humus, and manganese forms black mineral deposits. These pigments paint the soil (Michigan State Soil). Colour is also affected by the environment: aerobic environments produce sweeping vistas of uniform or subtly changing color, and anaerobic (lacking oxygen), wet environments disrupt color flow with complex, often intriguing patterns and points of accent. With depth below the soil surface, colors usually become lighter, yellower, or redder. The Munsell System allows for direct comparison of soils anywhere in the world. The system has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity) that are arranged in books of color chips. Soil is held next to the chips to find a visual match and assigned the corresponding Munsell notation. For example, a brown soil may be noted as: hue value/chroma (10YR 5/3). With a soil color book with Munsell notations, a science student or teacher can visually connect soil colors with natural environments of the area, and students can learn to read and record the color, scientifically. Soil colour by Munsell notation is one of many standard methods used to describe soils for soil survey. Munsell color notations can be used to define an archeological site or to make comparisons in a criminal investigation. Even carpet manufacturers use Munsell soil colors to match carpet colors to local soils so that the carpet will not show the dirt (soil) tracked into the house.

2.0 OBJECTIVES

At the end of this unit students should be able to;

- Know how colour is impacted on the soil during soil forming processes
- Know how to use soil colour to determine the soil horizon boundaries in a standard profile pit.
- Know how to use the Munsell colour chart to determine soil colours

3.0 MAIN CONTENT

3.1 Important facts to know

1. Colour reflects an integration of chemical, biological and physical transformations and translocations that have occurred within a soil.
2. Soil organic matter imparts a dark brown to black color to the soil.
3. Subsoil color reflects more strongly in most soils the imprint of physico-chemical processes.
4. Colors associated with minerals inherited from parent materials may also influence color in horizons that have not been extensively weathered.
5. Soil color can provide information about subsoil drainage and the soil moisture conditions of soils.
6. Through the use of the Munsell Soil Color Charts, practitioners from a wide range of professions can share reliable and consistent information about the color of soils at a particular site with colleagues anywhere around the world.
7. The system of Munsell colour chart has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity) that are arranged in books of color chips.

3.2 Soil Colour

Colour reflects an integration of chemical, biological and physical transformations and translocations that have occurred within a soil. In general, color of surface horizons reflects a strong imprint of biological processes, notably those influenced by the ecological origin of soil organic matter (SOM). Soil organic matter imparts a dark brown to black color to the soil. Generally, the higher the organic, matter content of the soil, the darker the soil. A bright-light color can be related to an eluvial horizon, where sequioxides, carbonates and/or clay minerals have been leached out.

Subsoil color reflects more strongly in most soils the imprint of physico-chemical processes. In particular, the redox status of Fe and to a lesser extent Mn, strongly influence the wide variation found in subsoil color. Soil color can provide information about subsoil drainage and the soil moisture conditions of soils. In well aerated soils, Fe^{3+} is present which give soil a yellow or redish color. In more poorly drained soils (anaerobic conditions) iron compounds arc reduced and the neutral gray colors of Fe^{2+} or bluish-green colors of iron sulfides, iron carbonates, or iron phosphates are visible. A black color in the subsoil can be related to all accumulation of manganese. In arid and semi-arid environments, the influence of soluble salts (carbon ales, sulfates, chlorides etc.) may impart a strong influence on soil color. For example, in arid or sub-humid regions, surface soils may be white due to evaporation of water and soluble salts.

Colors associated with minerals inherited from parent materials may also influence color in horizons that have not been extensively weathered. For example, light gray or nearly while colors is sometimes inherited from parent material, such as marl or quartz. Parent material, such as basalt, call imprints a black color to the subsoil horizons.

Table 2: Soil Colours Associated with Soil Attributes

Soil Colour	Soil Attribute	Environmental Conditions
Brown to black (surface horizon)	Accumulation of Organic matter (OM), humus	low temperature, high annual precipitation amounts, soils high in soil moisture, and /or litter from coniferous trees favor an accumulation of OM
Black(subsurface horizon)	Accumulation of manganese Parent material (e.g. basalt)	
Bright-light	Eluvial horizon (E horizon)	In environments where precipitation > evapotranspiration there is leaching of sequioxides, carbonates, and silicate clays. The eluviated horizons consist mainly of silica.
Yellow to reddish	Fe^{3+} (oxidized iron)	Well-aerated soils
Gray, bluish-green	Fe^{2+} (reduces iron)	Poorly d rained soils (e.g. subsurface layer with a high bulk density causes water logging, or a very fine textured soil where permeability is very low), anaerobic environmental conditions.
White to gray	Accumulation of salts	In arid or sub-humid environments where the evapotranspiration > precipitation there is an upward movement of water and soluble salts in the soil.
White to gray	Parent material: marl, quartz.	

Soil color is usually registered by comparison of a standard color chart (Munsell Book or Colors). The Munsell notations distinguish three characteristics of the color, Hue, value, and chroma.

- **Hue:** It is the dominant spectral color, i.e., whether the hue is pure color such as yellow, red, green, or a mixture of pure colors.
- **Value:** It describes the degree of lightness or brightness of the hue reflected in the property or the gray color that is being added to the hue.
- **Chroma:** It is the amount of a particular hue added to a gray or the relative purity of the hue.

3.3 The Munsell Soil Colour Chart

The Munsell Soil Color Charts is an affordable way to evaluate the type of soil that is present within a given area. The book is set up to allow users to make soil color evaluations in the field quickly and easily. The soil classification system that has been developed around the Munsell color system is an established and accepted process to assign a soil type. This classification system has been used in the United States for more than 55 years to aid in the management and stewardship of natural resources. Through the use of the Munsell Soil Color Charts, practitioners from a wide range of professions can share reliable and consistent information about the color of soils at a particular site with colleagues anywhere around the world. The Munsell Soil Color Charts are used by a variety of industries and professions such as universities and high schools, forestry, forensics, environmental and soil science, building and contracting, landscaping, real estate, health departments, geology and archaeology.

The following pages are included in the Munsell Soil Color Charts: Munsell 10R Soil Chart, Munsell 10YR Soil Chart, Munsell 2.5Y Soil Chart, Munsell 2.5YR Soil Chart, Munsell 5Y Soil Chart, Munsell 5YR Soil Chart, Munsell 7.5YR Soil, 10Y - 5GY Colors - Olive greens Soil Chart, Gley 1 & 2 (2 - Separate Charts) Soil Charts, Munsell 5R Individual Soil Chart, Munsell 7.5R Individual Soil Chart, White Page, 7.5R, 10YR, & 2.5Y.

Fig. 8a**:** Munsell Soil Color Chart.

Fig. 8b: Soil Scientist using Munsell Colour Chart to detect soil colour

The soil colours are given in the order: hue, value, and chroma. For example, 2.5YR 4/2 describes the hue 2.5YR, dark-grayish brown with a value 4 and a chroma of 2. It should be stressed that soil colour is dependent on soil moisture, hence if soil color is recorded also the soil moisture conditions have to be described (e.g. soil color dry, soil color wet). In the upper mid west and other humid areas, colors are conventionally recorded moist. This convention may differ in other climatic regimes.

Many soils have a dominant soil color. Other soils, where soil forming factors vary seasonally (e.g. wet in winter, dry in summer) lend to exhibit a mixture of two or more colors. When several colors are present the term **mottling or redoximorphic features (RMF)** is used. In such a case, several soil colors have to be recorded, where the dominant color is first, following by a description of the abundance, size, and contrast of the other colors in the mottled pattern. Mottling/RMFs are described by three characteristics: contrast, abundance, and size of area of each color.

Redoximorphic features me a color pattern in a soil due to loss (depletion) or gain (concentration) of pigment compared to the matrix color. H is formed by oxidation I reduction of Fe and/or Mn coupled with their removal and translocation or a soil matrix color controlled by the presence or Fe^{2+}. RMFs are described separately from other mottles or concentrations! Based on the Field Book for Describing and Sampling Soils (Schoeneberger *et al*., 1998) RMFs are described in terms of kind, color & contrast, quantity, size, shape, location, composition & hardness, and boundary. RMFs occur in the soil matrix, all or beneath the surface of peds, and as filled pores, linings of pores, or beneath the surface of pores.

Mottles are areas of color that differ from the matrix color. These colors are commonly lithochromic or lithomorphic attributes retained from the geologic source rather than from pedogenesis. Mottles exclude RMFs and peel & void surface features (e.g. clay films). Based on the Field Book for Describing and Sampling Soils (Schoeneberger *el al.,* 1998) mottles are described in terms of quantity, size, color & contrast, moisture state, and shape. Example: Few, medium, distinct, reddish yellow (7.5YR 7/8), irregular mottles.

However, a variety of other features in a horizon may have colors different from the matrix, such as infillings of animal burrows (krotovinas), clay coatings (argillans) and precipitates of calcium carbonate. In all instances where specific soil features are described, the shape and spatial relationships of the feature (i.e.., where is it located, on a ped face, in the matrix ...) to adjacent features should be described in addition to its color, abundance, size and contrast.

Table 3: RMFs/Mottles in Soils are described in term of Abundance, Size, and Contrast

Abundance	**Abbreviation**	**% of the Exposed Surface**
Few	f	< 2
Common	c	2 – 20
Many	m	20 – 40
Very many	v	> 40
Size	**Abbreviation**	**Diameter (mm)**
Fine	1	< 5 mm
Medium	2	5 – 15 mm
Coarse	3	> 15 mm
Contrast	**Abbreviation**	**Visibility**
Faint	F	Difficult to see, hue, and chroma of matrix and mottles closely related
Distinct	D	Readily seen, matrix and mottles vary 1 – 2 hues and several units in chroma and value
Prominent	P	Conspicuous, matrix and mottles vary several units in hue, value, and chroma

4.0 CONCLUSION

Color development and distribution of color within a soil profile are part of weathering. As rocks containing iron or manganese weather, the elements oxidize. Iron forms small crystals with a yellow or red colour; organic matter decomposes into black humus, and manganese forms black mineral deposits. These pigments paint the soil into different colours we observe in the soil. With a soil color book with Munsell notations, a science student or teacher can visually connect soil colors with natural environments of the area, and students can learn to read and record the color, scientifically.

5.0 SUMMARY

The Munsell notations distinguish three characteristics of the color, Hue, value, and chroma. **Hue** is the dominant spectral color, i.e., whether the hue is pure color such as yellow, red, green, or a mixture of pure colors. **Value** describes the degree of lightness or brightness of the hue reflected in the property or the gray color that is being added to the hue. **Chroma** is the amount of a particular hue added to a gray or the relative purity of the hue.

6.0 Tutor-Marked Assignment

1. Mention and explain the three major characteristics upon which is described
2. What do you understand by Redoximorphic features/mottles in soil colour formation
3. Who can use the munsell colour chart? Briefly describe the munsell colour chart and how it is used

4. In tabular form, mention Soil Colours as well as its associated soil attributes

7.0 REFERENCES/FURTHER READING

Bradv, N.C. and Weil, R.R (2006): The Nature and Properties of Soil. 13th ed. New Jersey, Prentice Hall Inc.

UNIT 4: SOIL TEXTURE

CONTENTS

1.0 INTRODUCTION

Soil is made up of three important primary particles namely; sand (2-0.02 mm), silt (0.02 – 0.002 mm) and clay (<0.002 mm). These particles are usually clustered together to form secondary particles or aggregates. They also bind themselves together alongside organic matter and other minerals in different proportions to form different types of soil such as loamy soil which contains 40% sand, 40% silt and 20% clay. Sand feels gritty between fingers and the particles are generally visible to the naked eyes. Since soil particles are relatively large, their pore spaces between them are wider and promotes faster drainage of water into and out of the soil profile and exchange of gases with the atmosphere. Silt particles are smooth and silky like flour having smaller pores between them and can retain more water for a longer period of time. The clay particles have a larger specific surface area and higher capacity to absorb water and other substances. Clay particles feel sticky or plastic when rubbed in between fingers under moist condition. There are three major methods of determining soil texture of the soil. The feel method, hydrometer method and pipette method. While the feel method is usually employed under field or *in situ* analysis condition, hydrometer and pipette methods are employed in a laboratory analysis. The pipette method has been proven to be most accurate.

2.0 OBJECTIVES

At the end of this unit, students should be able to;

- Know what soil texture is all about
- Know the importance of soil texture to soil fertility and productivity
- Use the textural triangle to find out the texture of any given soil

3.0 MAIN CONTENT

3.1 Soil Textural Classification

Texture refers to the amount of sand, silt, and clay in a soil sample. The distribution of particle sizes determines the soil texture, which can be assessed in the field or by a particle-size analysis in the laboratory. A field analysis is carried out in the following way: a small soil sample is taken, water is added to the sample, it is kneaded between the fingers and thumb until the aggregates are broken down. The guidelines to determine the particle class are as following:

- **Sand:** Sand particles are large enough to grate against each other and they can be detected by sight. Sand shows no stickiness or plasticity when wet.
- **Silt:** Grains cannot be detected by feel, but their presence makes the soil feel smooth and soapy and only very slightly sticky.
- **Clay:** A characteristic of clay is the stickiness. If the soil sample can he rolled easily and the sample is sticky and plastic when wet (or hard and cloddy when dry) it indicates a high clay content. Note that a high organic matter content tend to smoothen the soil and can influence the feeling for clay.

Table 4: Soil Texture Classes

Soil Texture	**Abbreviation**
Gravel	g
Very Coarse sand	vcos
Coarse sand	cos
Sand	s
Fine sand	fs
Very fine sand	vfs
Loamy coarse sand	lcos
Loamy sand	ls
Loamy fine sand	lfs
Sandy loam	sl
Fine sandy loam	fsl
Very fine sandy loam	vfsl
Gravelly sandy loam	gsl
Loam	l
Gravelly loam	gl
Stony loam	stl
Silt	si
Silt loam	sil
Clay loam	cl
Silty clay loam	sicl
Sandy clay loam	scl
Stony clay loam	stcl
Silty clay	sic
Clay	c

A variety of systems are used to define the size ranges of particles, where the ranges of sand, silt and clay that define a particle class differs among countries. In the U.S. the soil texture is classified based on the U.S.D.A. system. The classification or particle sizes are as follow:

i. Sand (2-0.02 mm),
ii. Silt (0.02 – 0.002 mm) and
iii. Clay (<0.002 mm)

Soil texture in the field is determined using a texture triangle (Figure 9). For example, a particle size distribution of 33 % clay, 33 % silt, and 33 % sand would result in the soil texture class 'clay loam'.

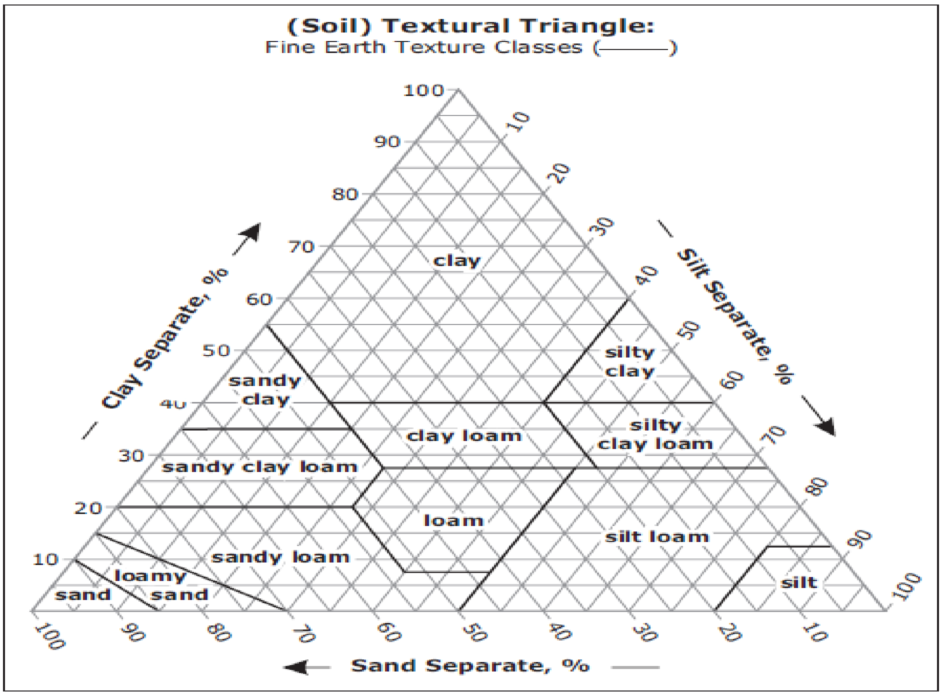

Figure 9: Triangular Diagram of Soil Textural Classes (USDA Triangle).

Particles greater than 2 mm are removed from a textural soil classification. The presence of larger particles is recognized by the use of modifiers added to the textural class (e.g. gravelly, cobbly, stony) (Table 5 and 6).

Table 5: Terms for Rock Fragments

Shape and Size (mm)	Adjective
Spherical and Cubelike:	xxx
2 – 75	Gravelly
2 – 5	Fine gravelly
5 – 20	Medium gravelly
20 – 75	Coarse gravelly

75 – 250	Cobbly
250 – 600	Stony
> 600	Bouldery
Flat:	
2 – 150	Channery
150 – 380	Flaggy
380 – 600	Stony
> 600	Bouldery

Table 6: Modifier for Rock Fragments

Rock Fragments by Volume (%)	**Adjectival Modifier**
< 15	No modifier
15 – 30	Gravelly loam
30 – 60	Very flaggy loam
> 60	Extremely bouldery loam

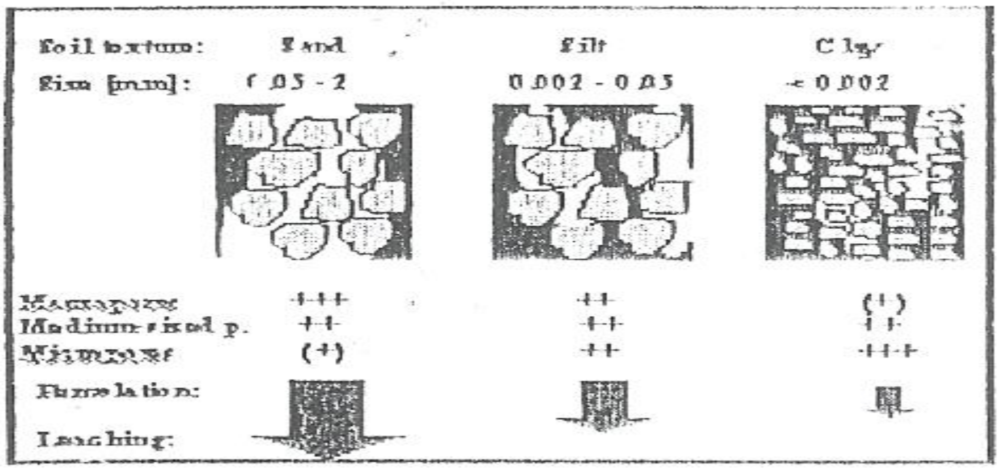

Figure 10: Relationship between Soil Texture and Pore Size.

3.2 Significance of Soil Texture

The fine and medium-textured soils (e.g. clay loams, silly clay loams, sandy silt loams) are favorable from an agricultural viewpoint because of their high available retention of water and exchangeable nutrients. In fine pores the water is strongly adsorbed in pores but not available for plants, i.e. cohesion and adhesion water occupy the micropore space and they are retained in soil by' forces that exceed gravity. In medium-sized pores the available water content is high, whereas in macropores water is more weakly held and percolation is high (gravitational water). In silty soils the distribution of macropores, medium-sized, and fine pores is optimal relating to available water content.

3.3 Importance of Soil Texture

1. The structure of the soil is an important parameter in determining the physical fertility of the soil which is a function of texture. The fine textured soil has a more stable structure with plenty of micro-pores which helps retain more water and less air in the soil, but coarse textured soils have more macro-pores which allows water pass through it very fast.
2. Soils with finer particles gets waterlogged during excessive rains or irrigation and leads to aeration stress to plants with the result that they are not able to take up water and nutrients which are present in the soil in sufficient amounts
3. The finer textured soil retains more nutrients on their surfaces through adsorption thereby reducing losses by leaching. The cation exchange capacity of the soil which is a very important tool in determining the availability of nutrients to plants is a function of texture.
4. The workability of the soil is a function of soil texture. The heavier or lighter a texture is will determine the amount of energy required to cultivate the soil.
5. Most soil physical and chemical properties of the soil are a function of soil texture, either directly or indirectly

3.4 How Textures Relates with Soil Fertility

1. Soil fertility is maintained through various chemical reactions in the soil, which are influenced by microorganisms. These tend to grow and colonize particles surfaces. Microbial reactions are therefore greatly affected by the specific surface area.
2. The fertility of soil is a function of moisture, fine textured soils, which retain more water for longer period of time, are more fertile than the coarse textured soils. Soils with appreciable amount of primary particles are more fertile.
3. The retention of nutrients and water on the surface of solids is a function of surface area of the minerals. The leaching of nutrients also is a function of soil texture.
4. The greater the surface area of a soil, the greater the rate of release of plant nutrients

Table 7: Pore size distribution in soils different in Texture (Scheffer *et al.*, 1989)

Soil Different in Texture	**Pore Volume (%)**	**Macropores (%)**	**Medium-Size Pores (%)**	**Mivropores (%)**
Sandy Soils	46 (+/- 10)	30 (+/- 10)	7 (+/- 5)	5 (+/- 3)
Silty Soils	47 (+/- 9)	15 (+/- 10)	15 (+/- 7)	15 (+/- 5)
Clayey Soils	50 (+/- 15)	8 (+/- 5)	10 (+/- 5)	35 (+/- 10)
Organic Soils	85 (+/- 10)	25 (+/- 10)	40 (+/- 10)	25 (+/- 10)

4.0 CONCLUSION

In general, coarse-textured soils permit rapid infiltration because of the predominance of large pores, while the infiltration rates of finer-textured soils is smaller because of the predominance of micropores. Other factors, like the compaction of the soil, management practices, vegetation, saturation of the soil have also a significant impact on infiltration and have to be considered. Soil texture has an impact on soil temperature. Fine-textured soils hold more water than coarse-textured. soils, which considering the differences in the specific heat capacity results ill a slow response of warming up of fine-textured soils compared to coarse-textured soils.

5.0 SUMMARY

Another issue to address is the effect that with decreasing particle size the surface area increases. Many important chemical and biological properties of soil particles are functions of particle size and hence surface area. For example, the adsorption of cations (nutrients) or the microbial activity is dependent on surface area.

6.0 TUTOR-MARKED ASSIGNMENT

1. State the three methods of texture determination, give the one normally during filed activities
2. What are the three main components of texture? How do they affect soil moisture retention
3. Mention 5 Importance of texture to agricultural productivity
4. How can you determine sand, silt and clay by feel method in the field?

7.0 REFERENCES/FURTHER READING

Scheffer F., Sehachtschabel P., (1989). Lehrbuch der Bodenkunde. Enke - Verlag Stuttgart.

https://www.scribd.com/doc/26537848/importa

UNIT 5: SOIL STRUCTURE

1.0 INTRODUCTION

Structure refers to the arrangement of soil particles. Soil structure is the product of processes that aggregate, cement, compact or unconsolidated soil material. The peds are separated from the adjoining peds by surfaces of weakness. To describe structure in a soil profile it is best to examine the profile standing some meters apart to recognize larger structural units (e.g. prisms). The next step is to study the structure by removing soil material for more detailed inspection. It should be stressed that soil moisture affects the expression of soil structure. The classification of soil structure considers the grade, form, and size of particles. Soil structure describes the arrangement of the solid parts of soil and of the pore spaces located between them. It is determined by how individual soil granules clump, bind together and aggregate, resulting in the arrangement of solid pores between them. Soil structure has a major influence on water and air movement, biological activity, root growth and emergence of seedling.

2.0 OBJECTIVES

At the end of this unit student should be able to;

- Classify structure into grade, form and sizes
- Know how structure is formed in the soil and its influence on biological activities, root growth, water and air movement

3.0 MAIN CONTENT

3.1 Soil Structure

Soil structure is a physical condition that is distinct from that of the initial material from which it formed, and can be related to processes of soil formation. Soil structure is measured in grade, form and size. The grade describes the distinctiveness of the peds (differential between cohesion within peds and adhesion between peds). It relates to the degree of aggregation or the development of soil structure. In the field a classification of grade is based on a finger test (durability of peds) or a crushing of a soil sample.

The form is classified on the basis of the shape of peds, such as spheroidal, platy, blocky, or prismatic. A granular or crumb structure is often found in A horizons, a platy structure in E horizons, and a blocky, prismatic or columnar structure in Bt horizons. Massive or single-grain structure occurs in very young soils, which are in an initial stage of soil development.

Another example where massive or single-grain structure can be identified is on reconstruction sites. There may two or more structural arrangements occur in a given profile. This may be in the form of progressive change in size/type of structural units with depth (e.g. A horizons that exhibit a progressive increase in size of granular peds that grade into sub-angular blocks with increasing depth) or occurrence of larger structural entities (e.g. prisms) that are internally composed of smaller structural units (e.g. blocky peds). I such a case all discernible structures should be recorded (i.e. more rather than less detail).

The size of the particles has to be recorded as well, which is dependent on the form of the peds.

Table 8a: Classification of Soil Structure considering Grade, Size, and Form of Particles

Grade	**Abbreviation**	**Description**
Structureless	0	No observable aggregation or no orderly arrangement of natural lines of weakness
Weak	1	Poorly formed indistinct peds
Moderate	2	Well-formed distinct peds, moderately durable and evident, but not distinct in undisturbed soil.
Strong	3	Durable peds that are quite evident in undisplaced soil, adhere weakly to one another, withstand displacement, and become separated when soil is disturbed.
Form	**Abbreviation**	**Description**
Granular	Gr	Relatively nonporous, spheroidal peds, not fitted to adjoining peds
Crumb	Cr	Relatively porous, spheroidal peds, not fitted to adjoining peds
Platy	Pl	Peds are plate-like. The particles are arranged about a horizontal plane with limited vertical development. Plates often overlap and impair.
Blocky	Bk	Block-like peds bounded by other peds whose sharp angular faces form the cast for the ped. The peds often break into smaller blocky peds.
Angular Blocky	Abk	Block-like peds bounded by other peds whose sharp angular faces form the cast for the ped
Sub-angular Blocky	Sbk	Block-like peds bounded by other peds whose rounded subangular faces form the cast for the ped
Prismatic	Pr	Column-like peds without rounded caps. Other prismatic caps form the cast for the ped. Some prismatic peds break into smaller blocky peds. In these peds the horizontal development is limited when compared with the vertical
Columnar	Cpr	Column-like peds with rounded caps bounded laterally by other peds that form the cast for the peds. In these peds the horizontal development is limited when compared with the

		vertical.
Single grain	Sg	Particles show little or no tendency to adhere to other particles. Often associated with very coarse particles.
Massive	M	A massive structure show little or no tendency to break apart under light pressure into smaller units. Often associated with very fine-textured soils.
Size	**Abbreviation**	
Very fine	vf	
Fine	f	
Medium	m	
Coarse	c	
Very Coarse	vc	

Table 8b: Showing Classification of Sizes of structure

Size	**Angular and Subangular Blocky Structure (mm) diameter**	**Granular and Crumb Structure (mm) diameter**	**Platy Structure (mm) diameter**	**Prismatic and Columnar Structure (mm) diameter**
Very fine	< 5	< 1	< 1 (Very thin)	< 10
Fine	5 – 10	1 – 2	1 – 2 (Thin)	10 – 20
Medium	10 – 20	2 – 5	2 – 5	20 – 50
Coarse	20 – 50	5 – 10	5 – 10 (Thick)	50 – 100
Very Coarse	> 50	> 10	> 10 (Very thick)	> 100

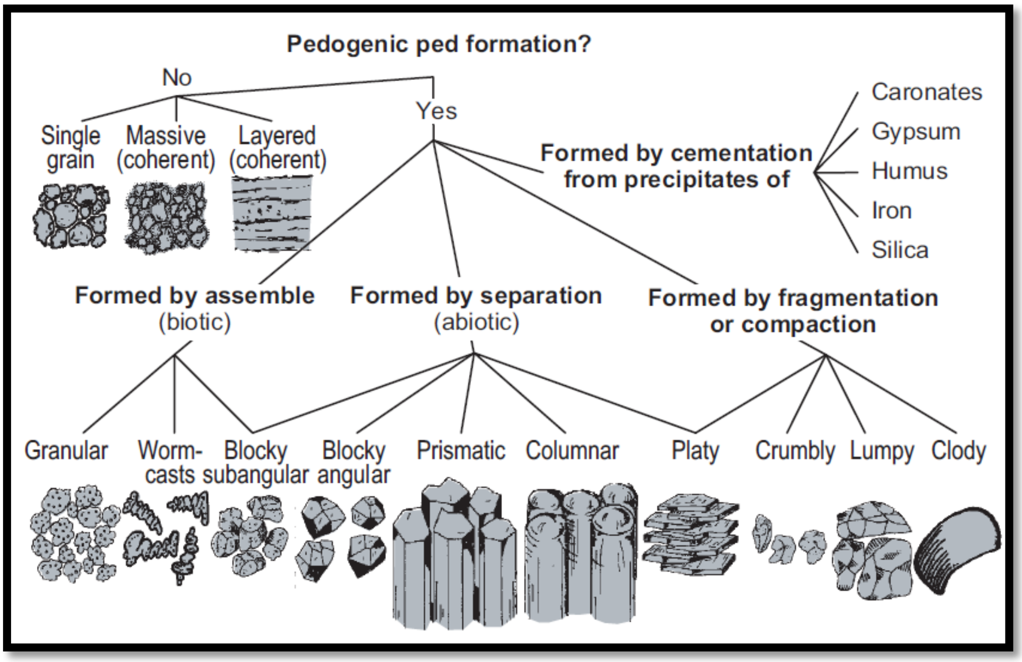

Figure 11: Soil structure types and their formation (FAO, 2006)

The three characteristics of soil structure are conventionally written in the order grade, size and shape. For example, weak fine sub-angular blocky structure.

The distribution of different particle sizes in a soil influence the distribution of pores, which can be characterized by their abundance, size and shape.

Table 9: Abundance, Size, and Shape of Pores

Abundance	**Per Unit Area**
Few	< 1
Common	1 – 5
Many	> 5
Size	**Diameter (mm)**
Very fine	< 0.5
Fine	0.5 – 2.0
Medium	2.0 – 5.0
Coarse	> 5.0
Shape	
Vesicular approx, spherical or elliptical	
Tubular approx. cylindrical or elongated	
Irregularly shaped	

3.2 Significance of Soil Structure

1. Soil formation Starts with a structureless condition, i.e., the structure is single-grained or massive. Soil development also means development of soil structure, which describes the formation of peds and aggregates. Soil structure forms due to the action of forces (hat push soil particles together. Subsurface structure lends lo be composed of larger structural units than the surface structure. Subsoil structure also tends to have the binding agents on ped surfaces rather than mixed throughout the ped.
2. Climatically-driven physical processes that result in changes in the amount, distribution and phase (solid, liquid, and vapor) of water exert a major influence on formation of soil structure. Phase changes (shrinking-swelling, freezing-thawing) result in volume changes in the soil, which over time produces distinct aggregations of soil materials.
3. Physico-chemical processes (e.g., freeze-thaw, wet-dry, clay translocation, formation/removal of pedogenic weathering products) influence soil structure formation throughout the profile. However, the nature and intensity of these processes varies with depth below the ground surface. The structure and hydrological function of plant communities, texture, mineralogy, surface manipulation and topography all serve to modify local climatic effects through their influence on infiltration, storage and evapo-transpiration of water.
4. Biological processes exert a particularly strong influence on formation of structure in surface horizons. The incorporation of soil organic matter is usually largest in surface horizons. Soil organic matter serves as an agent for building soil aggregates, particularly the polysaccharides appear to be responsible for the formation of peds. Plant roots exert compactive stresses on surrounding soil material, which promotes structure formation. Soil-dwelling animals (e.g., earth worms, gophers) also exert compactive forces, and in some cases (e.g., earth worms) further contribute to structure formation via ingestion/excretion of soil material that includes incorporated organic secretions.

4.0 CONCLUTION

Aggregation of soil particles can occur in different patterns, leading to the formation of different structures. Soil structure is mostly usually described in terms of grade (degree of aggregation), form (type of aggregates) and class (average size). In some soils, different type of aggregates may be found together and they are then described separately. The characteristics of structure of a soil can be recognized best when the soil is dry or slightly moist. Make sure you use freshly dug profile pit when you are studying the grade, form and size of structure.

5.0 SUMMARY

Soil structure is measured in grade, form and size. The grade describes the distinctiveness of the peds (differential between cohesion within peds and adhesion between peds). The form is classified on the basis of the shape of peds, such as spheroidal, platy, blocky, or prismatic.

The size of the particles has to be recorded as well, which is dependent on the form of the peds.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define the term soil structure
2. How can you classify the structure of a given soil into grade, form and size
3. Discuss four significances of structure in agricultural productivity
4. With the aid of a diagram, sketch four forms of structure you know

7.0 REFERENCES/FURTHER READING

Foth,H.D., (1984). Fundamentals in Soil Science. John Wiley & Sons, Inc.

Food and Agriculture Organization of The United Nations Rome, 2006

UNIT 6: CONSISTENCE, ROOTS, pH AND EFFERVESCENCE AND SPECIAL FEATURES

1.0 INTRODUCTION

In the course field study of soil or soil morphological study, in addition to all the parameters mentioned in this module as discussed previously, Soil Consistence, Roots, pH and Effervescence and Special features are also studied. Soil consistence is the strength with which soil materials are held together or the resistance of soil to deformation and rupture; it is measured for wet, moist and dry soil samples. Roots abundance in the different genetic horizons is also measured. This is intended to know the rate of agricultural activities taking place in that soil. The type of plant/crop growing on a particular soil will determine the root density and presence or abundance down the soil profile as one study the soil horizons.

2.0 OBJECTIVES

At the end of this unit, students would be able to;

- Know what soil consistence, roots abundance, pH and effervescence, special features and concentrations stands for in soil morphology study

3.0 MAIN CONTENT

3.1 Consistence

Consistence refers to the cohesion among soil particles and adhesion of soil to other substances or the resistance of the soil to deformation. Whereas soil structure deals with the arrangement and form of peds, consistence deals with the strength and nature of the forces between particles. Consistence is described for three moisture levels: wet, moist, and dry. The stickiness describes the quality of adhesion to other objects and the plasticity the capability of being molded by hands. Wet consistence is when the moisture content is at or slightly more than field capacity. Moist consistence is a soil moisture content between field capacity and tile permanent wilting point. When recording consistence it is important to record the moisture status as well. Cementation is also considered when consistence is described in the field. Cementing agents are calcium carbonate, silica, oxides or iron and aluminium.

Table 10: Classification of Consistence (Buol *et al.*, 1997)

Moisture Status	Consistence	Abbreviation	Description
Wet	Non-sticky	Wso	Almost no natural adhesion of soil material to fingers
	Slightly Sticky	Wss	Soil material adheres to only one finger
	Sticky	Ws	Soil material adheres to both fingers
	Very Sticky	Wvs	Soil material strongly adheres to both fingers
	Non-plastic	Wpo	No wire is formable by rolling material between the hands
	Slightly Plastic	Wps	Only short (< 1cm) wires are formed by rolling material between the hands
	Plastic	Wp	Long wires (> 1cm) can be formed and moderate pressure is needed to deform a block of the molded material
	Very Plastic	Wvp	Much pressure is needed to deform a block of the molded material
Moist	Loose	Ml	Soil Material is noncoherent
	Very Friable	Mvfr	Aggregates crush easily between thumb and finger
	Friable	Mfr	Gentle pressure is required to crush aggregates
	Firm	Mfi	Moderate pressure is required to crush aggregates
	Very Firm	Mvfi	Strong pressure is required to crush aggregates
	Extremely Firm	mefi	Aggregates cannot be broken by pressure
Dry	Loose	Dl	
	Soft	Ds	
	Slightly Hard	Dsh	
	Hard	Dh	
	Very Hard	Dvh	
	Extremely Hard	Deh	
Cementation	Weakly cemented	Cw	
	Strongly cemented	Cs	
	Indurated	Ci	

3.2 Roots

Plant roots give evidence of the plant root activity and the penetration. For example, it is important to record if roots only penetrate through cracks, are retarded by waterlogged layers or cemented layers. Other reasons for limited root penetration can be soil compaction or the absence of nutrients. If there is no obstacle to root growth in the soil the roots may he distributed evenly in a soil. It is important to record the quantity and diameter of roots.

Table 11: Classification of Roots

Root Quantity Classes	**Per Unit Area**
Very few	< 0.2
Moderately few	0.2 to 1
Few	< 1
Common	1 to < 5
Many	> = 5
Size Classes of Roots	**Diameter in mm**
Very fine	< 1
Fine	1 – 2
Medium	2 – 5
Coarse	5 – 10
Very Coarse	> 10

3.3 pH and Effervescence

The acidity of a soil can be tested using a simple field test set for fast pH determination. The pH is important for the pH dependent charge of silicates and organic material, therefore for the cation exchange capacity. Furthermore, the pH determines which buffering system is active, i.e. how soils can cope with additional H^+ ions. For example, buffering systems are carbonates, organic matter, silicates, or Iron and Aluminium oxihydroxides.

Using HCl on a small soil sample the reaction (effervescence) can give clues of the calcium carbon content in the sample.

$2\ HCl + CaCO_3 \leftrightarrow CaCl_2 + H_2CO_3$ (effervescence)

3.4 Special Features

Special features occur is soils which should be recorded additionally. Ped exteriors include clay coats, organic matter coats, silt coats, sand coats, carbonate coats, manganese coats, slickensides, stress surfaces, and clay bridges between sand grains. Ped interiors include concentrations of oxides, nodules, soft accumulations, pseudo-rock fragments, plinthite, and streaks. In particular, concretions are resulting from alternate periods of reducing and oxidizing regimes. Another special feature might be the evidence of animal activity by burrowing animals or high earthworm activity.

3.4.1 Concentrations

Def: Soil features that form by accumulation of material during pedogenesis. Processes involved: Chemical dissolution/precipitation, oxidation and reduction, physical and/or biological removal, transport and accumulation.

Types:

- **Finely disseminated Materials:** Small precipitates (e.g. salts, carbonates) dispersed throughout the matrix of a horizon concentrations.
- **Masses:** Non cemented bodies of accumulation of various shapes that cannot be removed as discrete units (e.g. crystalline salts).
- **Nodules:** Cemented bodies of various shapes that can be removed as discrete units from soil.
- **Concretions:** Cemented bodies similar to nodules, except for the presence of visible, concentric layers of material around a point, line or plane.
- **Crystals:** macro-crystals forms of relatively soluble salts (e.g. gypsum, carbonates) that form in situ by precipitation from soil solution.
- **Biological Concentrations:** Discrete bodies accumulated by a biological process (e.g. fecal pellets, insect casts).

Ped and Surface Features

These features are coats/films or stress features formed by translocation and deposition, or shrink-swell processes on or along surfaces. They are described in terms of kind, amount, continuity, distinctness, location and color.

Examples: Ferriargillans (Fe^{3+} stained clay films), Mangans (black, thin films of Mn)

4.0 CONCLUSION

Consistence is described for three moisture levels: wet, moist, and dry. The stickiness describes the quality of adhesion to other objects and the plasticity the capability of being molded by hands. Root abundance, pH and effervescence and special features are also studied.

5.0 SUMMARY

Soil consistence, root abundance, pH and effervescence and special features are among the vital morphological properties of soil to be studied in the field.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand be soil consistence and what are the three moisture conditions on which it is determined?
2. Mention and briefly explain six types of concentrations you know under special features of soil
3. Explain the two major heading upon which soil roots are classified

7.0 REFERENCES/FURTHER READING

Buol, S.W., Hole, F.D., McCracken, R.J., and Southard, R.J., (1997). Soil Genesis and Classification. Lowa State University Press.

MODULE 3: SOIL CLASSIFICATION & PRINCIPLES, HISTORICAL BACKGROUNDS, TYPE OF SOIL CLASSIFICATION SYSTEMS, USES OF SOIL CLASSIFICATION

UNIT 1: SOIL CLASSIFICATION

1.0 INTRODUCTION

Soil classification is a window into knowledge about soils at a given moment in time. It is like a snapshot that reveals the current condition without clear glimpses of the past or hints of the future. Although science continues to advance at a rapid pace, a certain state-of-the-art is encapsulated in its classification. The more popular soil classification schemes of the past century have been morphogenetic ones built around the hypotheses and theories of soil development and pedological transformations of materials at or near the lithosphere's contact with the biosphere and atmosphere.

Technology has provided opportunities to make more precise measurements, causing a major shift from qualitative definitions to quantitative ones to take place (Simonson, 1962). Field studies have revealed the complexity and spatial intricacies of pedi-sediment formation and interruption in unconsolidated materials, and concepts of soil genesis have been modified. Such evidence has had a tremendous influence on research and models of soils as landscapes. Time has taken on fresh connotations as more details of paleopedology have been obtained. Sequential development and polygenetic cycles challenge previous theories of when and how soils form and develop. Even soil forming processes have been revisited, dissected, and combined in interesting ways.

2.0 OBJECTIVES

At the end of this unit, students should be able to;

- Know the historical background of soil classification
- Know the purpose of soil classification
- Know the principles of soil classification

3.0 MAIN CONTENT

3.1 Important facts to know

1. Soil classification is a window into knowledge about soils at a given moment in time.
2. The more popular soil classification schemes of the past century have been, morphogenetic ones built around the hypotheses and theories of soil development and pedological transformations of materials at or near the lithosphere's contact with the biosphere and atmosphere.
3. Soil classification usually means criteria based on soil morphology in addition to characteristics developed during soil formation. Criteria are designed to guide choices in land use and soil management.
4. USDA soil taxonomy provides the core criteria for differentiating soil map units. Soil taxonomy based soil map units are additionally sorted into classes based on technical classification systems.
5. Two broad kinds of soil classifications; namely Technical and Scientific or natural classifications have been identified.

3.2 Soil Classification

Soil classification has been defined by Esu (1999), as the systematic arrangement of soils into groups or categories on the basis of their characteristics. Baldwin, *et al.* (1938) noted that soil classification usually means criteria based on soil morphology in addition to characteristics developed during soil formation. Criteria are designed to guide choices in land use and soil management. As indicated, this is a hierarchical system that is a hybrid of both natural and objective criteria. USDA soil taxonomy provides the core criteria for differentiating soil map units. Soil taxonomy based soil map units are additionally sorted into classes based on technical classification systems. Land Capability Classes, hydric soil, and prime farmland are some examples.

3.2.1 Purpose of Soil Classification

The main purpose of soil classification includes the following as outlined by Buol *et al.,* (1973);

1. Organize knowledge (thereby contributing to economy of thoughts, using a few words to communicate many ideas)
2. Bring out and understand relationships among individuals and classes of the population being classified
3. Remember properties of the objects classified
4. Learn new relationships and principles in the population we are classifying
5. Establish groups or subdivisions of the objects under study in a manner useful for practical, applied purposes such as; predicting their behavior, identifying their best uses, estimating their productivity and providing objects or units for research and for extending and extrapolating research results or our observations.

3.3 The principles of soil classification

About Seven principles of soil classification have been outlined by Arnold (2005) which include;

1. **Principle of Purpose.** Usually there is an overarching reason for wanting to organize knowledge about soils. A scientist, or group of specialists, may decide that they want to show genetic relationships in space and time. Others may want to predict soil behaviour when used and managed in different ways. Applied uses and scientific knowledge have both been major purposes of soil classification. The rationale of why a particular purpose is chosen supports this crucial first principle.
2. **Principle of Domain**. The realm of soils has different connotations, therefore it is necessary to specify what is to be included in soil classification and what is not. One can consider geographic bodies of soils, the pedosphere, or a broader spectrum of surficial materials, the geosphere, or abstract soil space that is based on concepts derived from small representative volumes. As techniques for examining relationships have evolved, it is now possible to consider a domain of subjective functional properties of soils and even include environmental parameters where relevant (Van Alphen and Stoorvogel, 2000). The choice of a domain depends upon the purpose that gives rise to a soil classification.

3. **Principle of Identity.** A domain indicates the population, or universe, that is being included in a soil classification scheme. It does not, however define the entities or members that will be the source of data for the classification. Identity is a means of providing a name for a non-divisible component or individual that would not otherwise be recognizable. In this sense, such an entity if it is divided, is destroyed. There have been a number of objects employed as members of interest such as polypedon, pedon, profile, arbitrary body, soil landscape unit, and continuum segment (Arnold, 1983).

4. **Principle of Differentiation**. If one is aware of a domain and a purpose for classifying its members, it is possible to start with the domain and divide it and subdivide it and so on. It is also possible to group the individuals, then group the groups, and so on. What sometimes if forgotten is that once organized into a hierarchy, it is only possible to employ the system from the top down. The "rules of engagement" have only been devised, or clearly stated, for the processes of separation.

5. **Principle of Prioritization**. It is assumed, or clearly stated, that measurable soil properties and features are the data sources, and not the concepts or theories themselves. The main reason is objectivity. If the values and the methods of measurement are specified then other scientists can repeat the procedure and observe the same, or very similar, values. This removes part of the bias of the classification architects. The properties selected to be measured are obviously subject to the understanding of relationships between concepts and soil property data. These connections give substance to the framework and meaning to the pattern of order that is displayed.

6. **Principle of Diagnostics**. The definitions of soil properties and sets of properties must use values based on the methods of measurement. Obviously there are many

choices, such as color by Munsell color charts or by spectrometers. And the readings may vary according to conditions outdoors or in a laboratory. General availability of methods and equipment often restrict widespread acceptance of the parameters selected. It is thought best to present some information as ratios or percents, others as weights or concentrations. Sets of properties may define horizon sets and be given specific names, such as a mollic epipedon, or a kandic horizon. Depths of occurrence of features may be diagnostic for some features.

7. **Principle of Membership**. Regardless of how the individuals are defined, their membership into classes is characterized by two concepts. One is the central tendency that is like a mean, mode, or idealized abstract entity. The other is the boundary of the class with other classes. The limits of a class include properties with adjacent classes in the same category and with classes in other categories that share a common property. Although to have mutually exclusive groups of members is desirable and theoretically possible, the uncertainties of measuring properties and the relevance of precise limits indicate that actual membership acceptance may be more probabilistic than deterministic.

3.4 Kinds of Soil Classification

Two broad kinds of soil classifications; namely Technical and Scientific or natural classifications have been identified by Akamigbo (2010). Technical classification is one which is targeted at a specific, applied practical purpose. Examples include the classification of soils for engineering purposes (building houses or roads), or agriculture or more specifically classifying soils for irrigated agriculture. In soil survey interpretations, land capability classification (LCC) and land suitability classification are often embarked upon to bring out the utilitarian aspect of soil survey. These two systems; USDA (LCC) and FAO land suitability classification are technical classifications that are widely used.

Natural or scientific 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. In our soil classification, we try to approach a natural classification system as an ideal, though we tend to give weight to properties of higher agricultural relevance. The two most commonly used classification systems in Nigeria are the USDA Soil Taxonomy (Soil Survey Staff, 1975) and the FAO/UNESCO Soil Map of the Word Legend (FAO/UNESCO, 1983) and their updates. These are natural or scientific classification systems.

4.0 CONCLUSION

Soil classification is intended to organize knowledge (thereby contributing to economy of thoughts, using a few words to communicate many ideas). It brings out relationships among individuals and classes of the population being classified. It helps us remember properties of the objects classified and learn new relationships and principles in the population we are classifying. Soil classification establish groups or subdivisions of the objects under study in a manner useful for practical, applied purposes such as; predicting their behavior, identifying their best uses, estimating their productivity and providing objects or units for research and for extending and extrapolating research results or our observations.

5.0 SUMMARY

Soil classification usually means criteria based on soil morphology in addition to characteristics developed during soil formation. Criteria are designed to guide choices in land use and soil management. In our soil classification, we try to approach a natural classification system as an ideal, though we tend to give weight to properties of higher agricultural relevance. The two most commonly used classification systems in Nigeria are the USDA Soil Taxonomy (Soil Survey Staff, 1975) and the FAO/UNESCO Soil Map of the Word Legend and their updates recently used as World Reference Base (WRB) for soil resources.

6.0 **TUTOR-MARKED ASSIGNMENT**

1. What do you understand by soil classification?
2. State four purposes of soil classification
3. Briefly explain 5 principles of soil classification
4. Outline 2 broad kinds of soil classification

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UNIT 2: HISTORICAL BACKGROUNDS OF SOIL CLASSIFICATION

1.0 INTRODUCTION

Before the creation of Pedology in the 19th century, most geologists believed soils were weathered or transported products of rocks. For agriculturalists soils supported and seemed to be well suited to certain crops and plants. For urban people and others whose contact with soils was minimal, soils were dirty and those who tilled the land were almost non-existent social beings. Thus for many people soil was considered to be part of something else, or something to be left alone.

Soils were finally recognized as independent natural bodies worthy of scientific study. Pedology was originally conceived by Russian scientists as genetic soil science whereby soils were recognized as cause-and-effect results of processes that were influenced by natural environmental factors and conditions. This has been the most fundamental change in the concept of soil in history (Cline, 1961). This new paradigm spread throughout the scientific community gaining its own adherents in the process. Soil properties were described and genetic hypotheses proposed to explain the presence and spatial occurrence of soils. Over the years the concept of soil as the outer layer of the earth's crust, the pedosphere, has vacillated back and forth between soil as a continuum to soil as a collection of natural bodies capable of supporting plants.

2.0 OBJECTIVES

At the end of this unit, student should be able to understand

- How soil classification started
- The full history of soil classification

3.0 MAIN CONTENT

3.1 Important facts to know

1. The first period the technical era originated and flourished in Western Europe in about 1853. Before then, China had embarked on technical classification of her soil for tax purposes.
2. . Dokuchaev was the first to understand the full significance of the differences that existed between soils and therefore established the concept of soil as an independent natural body.
3. The early American period (1899-1922) paid more attention to technical or single factor classifications

4. Hilgard was the first American to conceive of soil as a natural body and pointed out correlations between soil properties on the one hand vegetation and the other climate as causal factors.
5. Milton Whitney developed the first soil classification system related to soil survey and used as a basis for soil mapping operations.

3.1 History of Soil Classification

The origin of the concept of soil classification has been subdivided into five general periods (Buol *et al.*, 1973, Akamigbo, 2010);

1. An early technical era
2. The period of the founding of pedology by the Russian groups of scientists.
3. The early American period
4. The middle period of general development of soil classification and soil surveys in the world, and especially in the United States referred to as Marbut period and
5. The present modern period of quantitative pedology.

The first period the technical era originated and flourished in Western Europe in about 1853. Before then, China had embarked on technical classification of her soil for tax purposes. Soils were generally classified into clay, loam, sandy loam, loamy sand, sand and humus. Another classification was largely based on geologic origin and lithologic composition of what we now call parent material. Two classes were identified which include; (a) Residual soils and (b) alluvial soils. Residual soils included those derived from limestone rocks, soils of clay rocks, soils of feldspathic rocks and soils of quartz-bearing rocks. Alluvial soils were those accumulated on gravels, marine soils, soils of Aeolian accumulations, soils on glacial deposits and soils on coarse sediments of continental waters.

The second period saw the Russians making tremendous impact in soil science. Dokuchaev was the first to understand the full significance of the differences that existed between soils and therefore established the concept of soil an independent natural body. He was a geologist who became interested in soil science and therefore got a grant for scientific research, Dokuchaev published the first work in 1883 on soils as a natural body formed by the action of a set of soil forming factors producing genetic layer in the parent material. He did not base his classifications on climate but emphasized the importance of climate. One of his students, Sibirtsev developed the concept of soil zones which emphasizes that the kinds of soils are associated with certain climatic vegetation or ecological zones. Glinka's writing introduced the Russian names of soils such as *Chernozem, Podzol* and *Solenetz* to the western world.

The early American period (1899-1922) paid more attention to technical or single factor classifications. Hilgard was the first American to conceive of soil as a natural body and pointed out correlations between soil properties on the one hand vegetation and the other climate as causal factors. Milton Whitney developed the first soil classification system related to soil survey and used as a basis for soil mapping operations. He gave the first definition of soil *series* which is a term still in use today. The Middle American period was dominated by the work of C.F. Marbut who translated the German edition of Glinka's work into English and also bringing Dokuchaev's idea to America. His major work on soil classification was published in the Atlas of American Agriculture in 1935. He classified soils of America into two higher categories; *Pedalfers* and *Pedocals*. Marbut did not emphasize the 3-dimensional nature of the soil but gave extreme emphasis on 2-dimensional profile.

The modern quantitative period started with the revision of the 1938 USDA Yearbook classification by Thorp, Smith and Reicken. This new system started in 1951, due to the challenges experience in the previous one. Within the period 1951 corresponds with when many other countries started efforts to improve and further develop their soil classification systems. Notable classifications systems that have emerged during this period include the (USDA Soil Taxonomy, the FAO-UNESCO (WRB), the CCTA (Commission for Technical Cooperation in Africa), the French and British classification system and others (Akamigbo, 2010).

4.0 CONCLUSION

The first period the technical era originated and flourished in Western Europe in about 1853. Before then, China had embarked on technical classification of her soil for tax purposes. Soils were generally classified into clay, loam, sandy loam, loamy sand, sand and humus. Another classification was largely based on geologic origin and lithologic composition of what we now call parent material. The second period saw the Russians making tremendous impact in soil science. Dokuchaev was the first to understand the full significance of the differences that existed between soils and therefore established the concept of soil an independent natural body. The early American period (1899-1922) paid more attention to technical or single factor classifications. Hilgard was the first American to conceive of soil as a natural body and pointed out correlations between soil properties on the one hand vegetation and the other climate as causal factors. The modern quantitative period started with the revision of the 1938 USDA Yearbook classification by Thorp, Smith and Reicken. This new system started in 1951, due to the challenges experience in the previous one.

5.0 SUMMARY

The origin of the concept of soil classification has been subdivided into five general periods as; An early technical era, the period of the founding of pedology by the Russian groups of scientists, the early American period, the middle period of general development of soil classification and soil surveys in the world, and especially in the United States referred to as Marbut period and the present modern period of quantitative pedology.

6.0 TUTOR-MARKED ASSIGNMENT

1. State the five historical periods of soil classification
2. Mention the key Scientist(s) involved in these evolution period
3. Explain the history of early American period of soil classification
4. Briefly narrate the history of the modern quantitative period of soil classification

7.0 REFERENCES/FURTHER READING

Akamigbo, F.O.R. (2010). Soils: Fundamental Methods of Soil Resource Survey, Classification, Interpretation and Application. Published and printed by University of Nigeria Press Ltd.

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UNIT 3: TYPES OF SOIL CLASSIFICATION SYSTEMS AND USES OF SOIL CLASSIFICATION

1.0 INTRODUCTION

There are different types of soil classification systems developed world over. Each of the classification systems has a particular aim and objectives by the scientist who had developed it. These aims and objectives are determined by their perception of soil and its properties as at the time of development. This grouping of soil with genetic bias has pre-occupied many soil scientists all over the world. This has led to many national, regional and even international classifications of a hierarchical structure.

2.0 Objectives

At the end this unit, students should be able to know;

- Different types of classification systems that exist and the purpose of their formation
- How different countries came up with their own classification systems
- The most commonly used classification systems today such as; the USDA Soil Taxonomy and the FAO/UNESCO System – World Reference Base (WRB) for soil resources

3.0 MAIN CONTENT

3.1 Important facts to know

1. Classification systems that have claimed to be natural systems include Soil Taxonomy of USDA (1975) and the FAO-UNESCO (WRB) of 1998.
2. Artificial system of classification is when small numbers of selected soil properties are used as the basis for classification
3. The genetic systems are based on the presumed origin of the soils; they are supposed to be defined in terms of processes but in practice, owing to the difficulty of observing those, they are based upon soil forming factors.
4. The numerical system is the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities.

5. The French classification system divides the world soils into ten classes with their broad groups are related to climate and vegetation belts
6. The modern Russian Soil classification involves a strong genetic emphasis, evaluation of soil properties and the pedogenic process in the solum in relation to soil forming factors.
7. The USDA Soil Taxonomy developed in 1951 was the most comprehensive soil classification system as the classification of 1938 used before this time had several loopholes which made classification very difficult.
8. The main objectives of the World Reference Base for Soil Resources was to provide scientific depth and background to the 1988 FAO Revised Legend, incorporating the latest knowledge relating to global soil resources and their interrelations.

3.2 Types of soil classification Systems

The following terms were used by Akamigbo (2010), to explain different types of soil classification systems:

3.2.1 Artificial Systems

In these systems, small numbers of selected soil properties are used as the basis for classification. This is a special or single purpose classification, for example, when texture is used in classifying soils into sandy soils, loamy soils and clayey soils. Sometimes agronomist and most often civil engineers adopt this system of classification for their work.

3.2.2 Natural Systems

These are based on all properties of the soil profile itself regarded not as independent variables but as an entity, irrespective of their origin. They may be based only on properties obtainable from field soil survey or may include those for which laboratory analysis is necessary. Classification systems that have claim to be natural systems include Soil Taxonomy of USDA (1975) and the FAO-UNESCO (WRB) of 1998.

3.2.3 Morphological Systems

These are based also on the properties of the soil profile itself, irrespective of the origin. Examples include the Soil Taxonomy of USDA, the French system and the FAO-UNESCO (WRB) of 1998.

3.2.4 Genetic Systems

These are based on the presumed origin of the soils; they are supposed to be defined in terms of processes but in practice, owing to the difficulty of observing those, they are based upon soil forming factors. Examples include the Russian or Commonwealth of Independent States (CIS) and to some extent Soil Taxonomy and the French System.

3.2.5 Numerical Classification

This is the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities. This taxonomy may claim to be natural but the system of weighing soil properties introduces some elements of subjectivity thereby making it artificial.

Every system has its own advantages and disadvantages. The advantages of the system based on soil properties over that based on genesis or presumed genesis are as follows:

a. It permits classification of soils rather than forming factors
b. It focuses on the soil rather than related sciences such as geology and climatology
c. It permits the classification of soil of unknown genesis, only the knowledge of their soil properties is needed
d. It permits greater uniformity of classification as applied by a large number of soil scientist. Differences in interpretation of how soil was formed do not influence its classification under this scheme. This scheme however calls for standard techniques in obtaining the properties required for use in classification. This system does not completely rule out soil genesis because soil properties must be the consequences of a variety of processes acting on parent materials over time.

3.2.6 The French Classification System

The system divides the world soils into ten classes. The broad groups are related to climate and vegetation belts. This system also lays emphasis on the silica/alumina ratio which it uses as an index of weathering. It considers ferruginization (the liberation, movement and accumulation of iron in soils), leaching, gleying and mottling effects due to reducing conditions associated with water-logging, podzolization (bleaching of lower topsoil), the silt/clay ratio and the C/N ratio of the humus fraction. The use of these criteria recommends this system for consideration in parts of West Africa where soils of the nature qualifying in these criteria are common.

The ten classes of the system are as follow (Buol *et al.,* 1973):

Class 1: Little weathered, skeletal soils

1.1 Due to climate: groups – cold regions, deserts

1.2 Non climatic: groups – eroded or skeletal recently deposited

Class 2: Poorly and minimally developed soils

2.1 Due to climate: groups – Tundra, Rankers, sub deserts

2.2 Non climatic: groups – Regosolic, Andosols, resent materials.

Class 3: Calcomagnesimorphic soils

3.1 Rendzina: groups – thin rendzina, rendzina with horizons, calcimorphic alluvial.

Class 4: Vertisols and Paravertisols

4.1 Topomorphic (depressional): groups – Vertisols and Paravertisols

4.2 Lithomorphic: Groups – Vertisols and Paravertisols.

Class 5: Isohumic soils

1.1 Isohumic soils with partially saturated complex: groups – Bimodal: Brunizems, brunizem with textural BI, Pseudogley; Vertic Brunizem, Alkali Brunizem.

1.2 Isohumic soils with saturated complex: Groups – Chernozem, Chestnut, Brown Soils

Class 6: Mull Soil

6.1 Mull soils of temperate regions: Groups – Lessive, Brown soils

6.2 Mull soils of tropics

Class 7: Podzols and Podzolic Soils

7.1 Soils with moor and R2O3 – enriched horizons

7.2 Soils with moor and R2O3 – enriched horizon and gleyed.

Class 8: Sesquioxide soils with rapidly mineralized organic matter

8.1 Red and Brown Mediterranean soils

8.2 Ferruginous Tropical soils

8.3 Ferrallitic soils

Class 9: Halmorphic soils (saline soils)

9.1 Halomorphic without degraded structure

9.2 Halomorphic with degraded structure

Class 10: Hydromorphic soils

10.1 Organic hydromorphic

10.2 Medium organic matter hydromorphic

10.3Low organic matter hydromorphic

3.2.7 Modern Russian Soil Classification

Buol *et al.*, (1973) accounted for the modern Russian Soil classification as it involves a strong genetic emphasis, evaluation of soil properties and the pedogenic process in the solum in relation to soil forming factors. Three major components used by Russian pedologists include; the soil properties, soil forming or pedogenic processes and the agents or factor of soil formation. The Russian system has ten categoric levels, and the third level, the “soil type” corresponds to the level of generalization in the “order” and “suborder” categories of the Soil Taxonomy of the United States system. The soil type in the Russian sense is defined as having unity of origin, substance transformation, migration and accumulation; that is, they are generalization of many actual soils which have a common origin and similar pedogenic processes”. The diagnosis and definition of soil types in the Russian system are based on the profile morphology, mineral and chemical composition, liquid and gaseous phase of the soil, physicochemical properties, soil moisture, gas and moisture regimes in the soil (Akamigbo, 2010).

The Russian system is said to have ten categories but only seven are elaborated. A summary of the main features of each of the seven categories follows (Buol *et al.*, 1973).

1. **Class:** Taxa are defined according to broad temperature belts and designed as a global classification.

2. **Subclass:** Automorphic (approximately equal to “Zonal”), hydromorphic, semihydromorphic, and alluvial are the subclasses commonly recognized. This category is also designed for global scale classification.

3. **Type**: this is the level most commonly used for boad regional comparisons and generalization. Approximately 110 soil types are recognized in the former USSR. Each type has developed in a single set of bioclimatic and hydrologic conditions and is characterized by a clear manifestation of basis soil morphology, including similarities in type of organic matter accumulation, type of decomposition and synthesis of minerals, translocations of soil materials and structure. In its nomenclature, generally, the name for the colour of the A horizon is combined with “Zem” (meaning land) to produce terms such as Chernozem and Krasnozem. Some names indicating dominant soil features are also used, such as Solonez and Solonchak. A few descriptive folk terms are used such as Podzol.

4. **Subtype**: this category is composed of taxa within the types differing qualitatively in expression of one of the soil forming processes and intensity with which they reflect the main pedogenic process of the type. The nomenclature reflects location and temperature differences from north to south within the Commonwealth of Independent States (CIS) with the use of adjectives northern, warm or cold, or some transitional modification as expressed in soil properties with adjectives such as leached and sod podzolic.

5. **Genera**: taxa are defined according to properties of the parent material as reflected in texture and composition, or according to special dominating effects of chemical composition of the ground water, or according to some relict or fosil features. Examples of some of the genera within the chernozemic subtypes are described as typical, noncalcic, calcic, solonetzic, solodized, vertisolic, iron-illuvial and humus-illuvial.

6. **Species**: taxa are defined within the genera according to degrees of development or expression of the main pedogenic processes within the type. Example, the Podsols are subdivided as weak, medium/strong, and very strong or according to depth of effect of the pedogenic process (such as podzolozation), or according humus content of the A1 horizon in chernozems. Ordinarily, one or more of three types of soil properties are used as differentiating characteristics: 1) amount or supply of a certain material in the solum, expressed as kg/m^2 or matric tons/ha; 2) thickness of a certain horizon in cm; 3) content of a substance in a given horizon expressed as percent.

7. **Varieties**: This category differentiates according to texture (at a lower level of generalization than used at the level of the genera).

Roxov and Ivanova (1968) listed ten categories of the Russian system as follows:

1) Class	2) Subclass	3) Ranges	4) Types
5) Subtypes	6) Genera	7) Species	8)Varieties
9) Categories	10) Phases		

3.2.7.1 The classes of the Russian Classification System

The classification divided the soils of the then USSR into twelve classes. The Russian system may be comparable to the system used by Briddges (1970) in which soils are grouped into four main classes depending on their geographical locations. Latitudes are regarded as essential soil-forming factor. The soils of the high latitude are soils with tundra climate. The soils of the mid-latitudes and cool climates are the typical soils of the temperate climates. Podsols are said to be typical of the more northern areas where they are associated with boreal forest. The third group in this system of classification includes the soils of the mid-latitudes, warm climates. This class includes the Mediterranean humid sub-tropical, temperate continental areas and deserts. Typical soils are brown earths, brown and red Mediterranean soils. The fourth class is the low latitude soil group. The humid tropical regions of the world are the geographical locations of the soils of this class. Common soils in this class are the red coloured soils, most of which are described as either ferrallitic, ferrisols or ferruginous tropical soil. The Russian system starts from the soils of the arctic regions to those of the tropical deserts, and so considers temperature and environment as important criteria. Akamigbo (2010) listed the classes as follows:

Class1: Arctic tundra soils: this class includes four subclasses: a) Tundra Arctic; b) subarctic sod; c) Bog tundra and d) Arctic solonchak.

Class 2: Boreal taiga soils: this contains three subclasses: a) frozen taiga; b) frozen bog (wet ground, formed of decaying plants); c) frozen solonetz.

Class 3: Boreal taiga and forest soils: this contains three subclasses: a) taiga forest; b) Sod taiga; and c) Bog.

Class 4: Bubboreal humid forest and meadow soils: this has four subclasses: a) Burozem; b) Meadow-Burozem; c) Sod moist forest; d) Bog.

Class 5: Subboreal steppe soils: this contains five subclasses: a) Steppe; b) Meadow; c) Meadow-bog; d) Solonetz; e) Solonchaks.

Class 6: Subboreal desert soils: this contains four subclasses: a) Desert; b) Takyr; c) Solonetz desert; d) Solonchak desert.

Class 7: Subtropical humid forest soils: this contains three subclasses: a) Zeltozem; b) Krasnozen; c) Bog subtropical.

Class 8: Subtropical dry forest savanna and steppe soils: this contains four subclasses: a) Cinnamon earth; b) Sod subtropical; c) Meadow subtropical; d) subtropical solonetz.

Class 9: Subtropical desert soils: this has only one subclass: namely, serozem desert.

Class10: Tropical humid savanna and forest soils: from this class, the soil types are not worked out. This point to the fact that this system is meant to serve Russia and this could be said to be a major weak point of this system, which is leaving out some major soils groups from the system.

Class 11: Tropical dry forest and savanna soils

Class 12: Tropical desert soils

3.2.8 The USDA soil taxonomy

The United State Soil Taxonomy developed in 1951 was the most comprehensive soil classification system as the classification of 1938 used before this time had several loopholes which made classification very difficult. New ideas were more elaborated which included the new nomenclature and introduction of diagnostic horizons. After several approximations and series of amendments a final copy of the classification published in 1975 by soil Survey Staff, as “Soil Taxonomy: A Basis System of Soil Classification for Making and Interpreting Soil Surveys”.

However, several amendments followed the 1975 publication, which led to another publication in 1999. The latest being the eleventh edition of keys to soil taxonomy, (2010) which incorporated all the changes that have taken place since the publication of the second edition in 1999. This edition included the suborders; Wassents and Wassists for subaqueous entisols and histosols. The classification contains twelve (12) orders in the highest category as it is a multi-categorical and hierarchical system. It has 68 suborders, 317 Great groups and 2434 subgroups. The families and series have no specific numbers, even though there are about 20,000 soil series in the United States. The system is not restricted to United States of America only since experience from Europe and other continents have been used in its compilation. This system studies the morphology and properties of pedon as well as use the nature and properties of mineral horizon (B horizon) as basic criteria in preference to superficial horizons in classifying mineral soils.

3.2.8.1 Hierarchy of Categories in the Soil Taxonomy

There are six levels in the hierarchy of categories: Orders (the highest category), suborders, great groups, subgroups, families and series (the lowest category) (Soil Survey Staff, 1999).

Orders: There are twelve orders, differentiated on gross morphological features by the presence or absence of diagnostic horizons or features which show the dominant set of soil-forming processes that have taken place. The twelve orders and their major characteristics are shown in Table 2.1.

Suborders: It is the next level of generalization. It permits more statements to be made about a given soil. In addition to morphological characteristics other soil properties are used to classify the soil. The suborder focuses on genetic homogeneity like wetness or other climatic factors. There are 68 suborders within the 12 orders. The names of the suborders consist of two syllables. The first connotes the diagnostics properties; the second is the formative element from the soil order name. For example, an Ustalf is an alfisol with an ustic moisture regime (associated with sub-humid climates).

Great groups: The great group permits more specific statements about a given soil as it notes the arrangement of the soil horizons. A total of 317 great groups (140 of which occur in the tropics) have been defined for the 68 suborders. The name of a great group consists of the name of the suborder and a prefix suggesting diagnostic properties. For example, a Plinthustalf is an ustalf that has developed plinthite in the profile. Plinthite development is selected as the important property and so forms the prefix for the great group name.

Subgroups: There are three kinds of subgroups:

1. The typical subgroup which represents the central concept of the great group, for example Typic Paleustalfs.
2. Intergrades are transitional forms to other orders, suborders or great groups, for example Aridic Paleustalfs or Oxic Paleustalfs.
3. Extragrades have some properties which are not representative of the great group but do not indicate transitions, for example, Petrocalcic Paleustalf.

Families: The grouping of soils within families is based on the presence or absence of physical and chemical properties important for plant growth and may not be indicative of any particular process. The properties include particle size distribution and mineralogy beneath the plough layer, temperature regime, and thickness of rooting zone. Typical family names are clayey, kaolinitic, isohyperthermic, etc. There are thousands of families.

Series: The soil series is the lowest category. It is a grouping of soil individuals on the basis of narrowly defined properties, relating to kind and arrangement of horizons; colour, texture, structure, consistence and reaction of horizons; chemical and mineralogical properties of the horizons. The soil series are given local place names following the earlier practice in the old systems in naming soil series. There are tens of thousands of series.

Table 12: Brief descriptions of the twelve soil orders according to Soil Taxonomy

SOIL ORDERS	DESCRIPTION
ALFISOLS	- Soils with a clayey B horizon and exchangeable cation (Ca + Mg + K + Na) saturation greater than 35% calculated from NH_4OAC-CEC at pH 7.
ANDISOLS	-The unique property of andisols is a dominance of Al- humus complexes that result from weathering of minerals. Most andisols formed in volcanic or vulcaniclastic minerals, rich in P retention, available water and CEC.
ULTISOLS	- Soils with a clayey B horizon and base saturation less than 35%. They are acidic, leached soils from humid areas of the tropics and subtropics.
OXISOLS	- Oxisols are strongly weathered soils but have very little variation in texture with depth. Some strongly weathered, red, deep, porous oxisols contain large amounts of clay-sized Fe and Al oxides.
VERTISOLS	- Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.
MOLLISOLS	- Prairie soils formed from colluvial materials with dark surface horizon and base saturation greater than 35%, dominating in exchangeable Ca.
INCEPTISOLS	- Young soils with limited profile development. They are mostly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols, presently classified under the Andept suborder.
GELISOLS	- Presence of permafrost, and soil features associated with freezing and thawing. e.g. irregular or broken horizons and incorporation of organic materials in the lower horizons
ENTISOLS	- Soils with little or no horizon development in the profile. They are mostly derived from alluvial materials.
ARIDISOLS	- Soils of arid region, such as desert soils. Some are saline.
SPODOSOLS	- Soils with a bleached surface layer (A2 horizon) and an alluvial accumulation of sesquioxides and organic matter in the B horizon. These soils are mostly formed under humid conditions and coniferous forest in the temperate region.
HISTOSOLS	- Soils rich in organic matter such as peat and muck.

Source: Soil Survey Staff, 1999

Table 13: Categories, number of taxa and nature of differentiating characteristics of USDA Soil Taxonomy

Category	No. of Taxa	Nature of Differentiating Characteristics
Order	12	Soil-forming processes as indicated by presence or absence of major diagnostic horizons.
Suborder	68	Genetic homogeneity. Subdivisions of order according to presence or absence of properties associated with wetness, soil moisture regimes, major parent materials, and vegetational effects as indicated by key properties; organic fibre decomposition stage in Histosol.
Great Group	317	Subdivisions of orders 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	2434	Central concept taxa for great group and properties indication integrada-tions to other great groups, subgroups, and orders; extragradations to “not soil”
Family		Properties important for plant root growth; broad soil textural classes arranged over control section of solum; mineralogical classes for dominant mineralogy of solum; soil temperature classes (based on mean annual soil temperature at 50cm depth)
Series	20,000 (approximated) in United States	Kind and arrangement of horizons; colour, texture, consistence, and reaction of horizons; chemical and mineralogical properties of the horizos.

Sources: Soil Survey Staff, 2003, 2010, and Akamigbo 2010.

Table 14: List of soil orders and suborders

	Orders	Suborders		Orders	Suborders
1.	ALFISOLS	Aqualfs	7.	INCEPTISOLS	Aquepts
		Cryalfs			Anthrepts
		Ustalfs			Gelepts
		Xeralfs			Cryepts
		Udalfs			Ustepts
2.	ANDISOLS	Aquands			Xerepts
		Cryands			Udepts
		Torrands	8.	MOLLISOLS	Albolls
		Xerands			Aquolls
		Vitrands			Rendolls
		Ustands			Gelolls
		Udands			Cryolls
3.	ARIDISOLS	Cryids			Xerolls
		Salids			Ustolls
		Durids			Udolls
		Gypsids	9.	OXISOLS	Aquox
		Argids			Torrox
		Calcids			Ustox
		Combids			Perox
4.	ENTISOLS	Aquents			Udox
		Arents	10.	SPODOSOLS	Aquods
		Psamments			Gelods
		Fluvents			Cryods
		Orthents			Humods
		Wassents			Orthods
5	GELISOLS	Histel	11.	ULTISOLS	Aquults
		Turbels			Humults
		Orthels			Udults
6.	HISTOSOLS	Folists			Ustults
		Fibrists			Xerults
		Saprists	12.	VERTISOLS	Aquerts
		Hemists			Cryerts
		Wassists			Xererts
					Torrerts
					Usterts
					Uderts

Sorces: Soil Survey Staff, 2010, Akamigbo, 2010

3.2.8.2 The Diagnostic Horizons of U. S. Soil Taxonomy

Esu (2005) stated that the US Soil Taxonomy uses observable, quantitative, diagnostic horizons and features which only reflect our present understanding about soil genesis. Also, in the process of field soil characterization of the profile pit, diagnostic horizons can be identified using key differentiating properties such as soil moisture and temperature regimes, colour, texture and structure. This will enable a competent soil scientist to objectively place a soil in appropriate taxa. Other chemical properties considered in soil classification include; soils organic matter, clay, iron and aluminum oxides, soil pH, percentage base saturation and effective soil depth.

3.2.8.3. Soil Moisture Regime

This usually refers to water held at a tension of less than 1500 kPa in the soil or in specific horizons during periods of the year. Water held at a tension of 1500 kPa or more is not available to keep most mesophytic plants alive (Soil Survey Staff, 2003). At suborder level, soil moisture regime is used as differentiating characteristics in most soil orders (Esu, 2005). Akamigbo, (2010) noted that water present or absent during specified periods of the year is what is called *the Moisture control section* of the soil. The depth of this control section varies with the type of soil texture as soils of fine-loamy, coarse-silty, fine-silty or clayey have their control section extend from about 10 to 30 cm below the soil surface. Particle-size class of coarse-loamy extends from 20 to 60 cm depth while particle-size class of sandy is about 30 to 90 cm depth. Rocky Fragmentary soils have their control section deeper.

Soil Survey Staff, (2003) divided the soil moisture regime into the classes as follows; Aquic, Aridic and Torric, Udic, Ustic and Xeric moisture regimes.

Aquic moisture regime: the aquic *(L. aqua,* water) moisture regime is a reducing regime in a soil that is virtually free of dissolved oxygen because it is saturated with water.

Aridic and Torric: (*L. aridus,* dry and *L. torridus,* hot and dry) moisture regimes, these are used for the same moisture regime but in different category of the taxonomy. Soils with these moisture regimes occur in areas of arid climates.

Udic moisture regime: the Udic (*L. udus*, humid) moisture regime is one in which the soil moisture control section is not dry in any part for as long as 90 cumulative days in normal year. This is common in soils of the humid climate with well distributed rainfall.

Ustic moisture regime: the ustic (L. ustus, burnt; implying dryness) moisture regime is intermediate between the aridic regime and uduc regime. The moisture is limited but present when conditions are suitable for plant growth.

Xeric Moisture regime: the Xeric (G. xeros, dry) moisture regime is the moisture regime in areas of the Mediterranean climates, where winters are moist and cool and summer are warm and dry.

3.2.8.4. Soil Temperature Regime

Soil temperature has significant effect on the biological, chemical and physical processes taking place in the soil (Soil Survey Staff, 1975). Soil temperature is usually estimated from climatological information with precision that is suitable for present needs of soil surveys. Akamigbo (2010) stated that 1^oC is usually added to the mean annual temperature to get an estimate of the soil temperature. Also soil temperature can be determined by taking average of readings of a soil thermometer buried at 50cm depth from the surface for about 5 years.

Akamigbo (2010) further stated that soil temperature regimes are used in differentiating soils at a lower categoric level of the Soil Taxonomy. It is usually applied at the "family" categoric level which is the taxonomic level at which technology transfer concerning the utilization potentials of such soil is recommended. The regimes are based on mean annual soil temperature and the difference between mean summer and winter temperature. In the case of tropical humid environment, the regimes range from extremely cold to very hot soil temperatures at 50 cm depth. The difference is usually mean dry season and rainy season temperatures.

These include; *Cryic, Frigid, Mesic, Thermic, Hyperthermic, Isofrigid, Isomesic, Isothermic*, and *Isohyperthermic*

Cryic (*Gr. Kryos*, coldness, meaning very cold soils): soils in this temperature regime have mean annual temperature lower than 8^oC but do not have permafrost.

Frigid: Soils in this temperature regime are warmer in summer than soils with cryic regime. Their mean annual soil temperature is lower than 8^oC.

Mesic: the mean annual soil temperature is 8^oC or higher but lower than 15^oC.

Thermic: the mean annual soil temperature is 15^oC or higher but lower than 22^oC.

Hyperthermic: the mean annual soil temperature is 22^oC or higher, and the difference between mean summer and mean winter soil temperature is more than 6^oC.

Isofrigid: the mean annual soil temperature is lower than 8^oC.

Isomesic: the mean annual soil temperature is 8^oC or higher but lower than 15^oC.

Isothermic: the mean annual soil temperature is 15^oC or higher but lower than 22^oC.

Isohyperthermic: the mean annual soil temperature is 22^oC or higher.

3.2.9. The FAO/UNESCO system

According to (FAO, 1976), the FAO/UNESCO system was devised more as a tool for the preparation of a small-scale soil map of the world than a comprehensive system of soil classification. The system was an attempt to correlate all units of the various soil maps in the world as well as obtain a worldwide inventory of soil resource with a common legend. The map shows only the presence of major soils, being associations of many soils combined in general units. The legend of the soil map of the world lists 153 units classified into 28 groupings. The soil units correspond roughly to great groups from the USDA Soil Taxonomy, while larger main grouping are similar to the USDA soil suborder. Table 4 shows the rough correspondence between the Soil Taxonomy and the FAO/UNESCO system.

The objectives of FAO/UNESCO classification system was to;

i. Make first appraisal of the world soil resources
ii. Supply a scientific basis for the transfer of experience in areas with similar environments.
iii. Promote the establishment of a generally accepted soil classification and nomenclature.
iv. Establish a common framework for more detailed investigation in developing regions.
v. Serve as a basic document for educational, research, and developmental activities.
vi. Strengthen international contacts in the field if soil science.

In 1986 FAO published a soil map of Africa following the FAO/UNESCO system of soil classification. In this map, all the soils of Africa have been grouped into 10 soil associations. Though it is not very precise, the map provides an overview of the soil resources of the continent of the ten major associations, the desert and shallow soil associations (comprising Yermosols, Xerosols and Luvisols) occupy about one-third of Africa's land area. However, only a part of the area occupied by these associations falls in the tropics.

Akamigbo (2010) noted that the FAO/UNESCO classification system has certain merits as it enjoys the authority of the leading international organizations in soil science. It is however a compromise document, incorporating features and nomenclatures from various national systems. It has achieved a moderate successful rapport between artificial and natural classifications, being an artificial system outwardly but with parameters chosen to address natural classes. Therefore it is not a classification system, but a map legend. It should not replace any national classification scheme, but should serve as a common denominator.

Table 15: Correlation between systems of soil classification: the Soil Taxonomy, FAO/UNESCO legend

FAO/UNESCO	Soil Taxonomy*
Acrisols	Ultisols
Andosols	Andepts
Arenosols	Psamments
Cambisols	Tropepts
Ferralsols	Oxisols (Latosols)
Fluvisols	Fluvents (Alluvial soils)
Gleysols	Aquepts and Aquents (Aquic great groups of Entisols, Inceptisols)
Histosols	Histosols
Lithosols	Lithic subgroups
Luvisols	Alfisols
Nitisols	Tropics, Rhodic great groups of Alfisols and Ultisols
Podzols	Spodosols
Regosols	Orthents, Psamments
Vertisols	Vertisols

* = Name in old USDA system.

Data from Ibanga, 2006

3.2.10 The World Reference Base (WRB) for Soil Resources

This international standard soil classification system was developed by an international collaboration coordinated by the International Soil Reference and Information Centre (ISRIC) and sponsored by the International Union of Soil Science (IUSS) and the FAO via its Land & Water Development division. The main objectives of the World Reference Base for Soil Resources was to provide scientific depth and background to the 1988 FAO Revised Legend, incorporating the latest knowledge relating to global soil resources and their interrelations. WRB is designed as an easy platform of communication among scientists to identify, characterize and name major types of soils. It is not designed to replace the national soil classification systems, but to be a tool for better correlation between national systems (FAO/UNESCO, 1998).

Akamigbo (2010) stated the following objectives of the WRB;

i. To develop an internationally acceptable system for delineating soil resources to which national classification can be attached and related, using FAO's Revised Legend as a framework.

ii. To provide this framework with sound scientific basis so that it can also serve different applications in related fields such as agriculture, geology, hydrology and ecology.

iii. To recognize within the framework important spatial relationship of soils and soil horizons as characterized by topo and chronosequences.

iv. To emphasize the morphological characterization of soils rather than to follow a purely laboratory – based analytical approach.

Akamigbo (2010) noted that the objectives and principles of the WRB ran parallel with those of the earlier FAO/UNESCO classification. Moreover, the revised legend of the FAO/UNESCO Soil Map of the world was used as a basis for the development of the WRB in order to take advantage of the international soil correlation work which has already been done. The term "Reference Base" is connotative of the common denominator function which the WRB will assume. Really, the basic framework of the FAO legend with its two categoric levels and guidelines for developing classes at a third level was adopted, but it has been decided to merge the lower levels. Each reference soil group of the WRB is provided with a listing of possible qualifiers in a priority sequence, from which the user can construct the various lower – level units.

The broad principles which govern the WRB class differentiation as given by FAO/UNESCO (1998) are as follow;

a. At the higher categoric level, classes are differentiated mainly according to the primary pedogenic process that has produced the characteristic soil features, except where 'special' soil parent materials are of overriding importance.
b. At the lower categoric levels, classes are differentiated according to any predominant secondary soil forming process that has significantly affected the primary soil features.

There are thirty reference soil groups in the first tier or higher categoric level of this system. The lower categoric levels consist of combinations of a set of prefixes as unique qualifiers added to the reference soil groups, allowing very precise characterization and classification of individual soil profiles.

The soil units are 541. The 30 major soil groups of the WRB are: *Aerisols, Albeluvisols, Alisols, Andosols, Anthrosols, Arenosols, Calcisols, Cambisols, Chernozems, Cryosols, Durisols, Ferralsols, Fluvisols, Gleysols, Gypsisols, Histosols, Kastanozems, Leptosols, Lixisols, Luvisols, Nitisols, Umbrisols and Vertisols.*

The major soil groups of the WRB and their physical properties have been summarized by Esu, (2005); Spaagaren (2005) and Akamigbo, (2010) as follows.

Table 16: The major soil groups of the WRB and their physical properties

	Factors of soil formation	Major soil groups and soil units
Set 1	Organic soils, high water content, high organic matter content, low bulk density, low bearing capacity, high ground water table which is subject to subsistence upon drainage.	**HISTOSOLS** There are 14 lower level units e.g. Dystric, Eutric, Salic, Fibric, Toxic, Thionic
Set 2	Mineral soils under long-time cultivation, modified to the extent that the original soils have been completely changed (not confined to any particular region). Topsoil structure may be destroyed or improved. Improved water holding capacity and the land surface may be raised.	**ANTHROSOLS** There are 14 lower level units, e.g. Hortic, Plaggic, Luvic, Arenic, Hydragric, Irragric.
Set 3	Mineral soils whose formation was conditioned by their parent material. - Soils developed in volcanic material. Under acidic conditions aluminum-organic complexes. Under non or slightly acidic condition, such minerals as allophones and imogolite.	**ANDOSOLS** 25 lower-level units e.g. Vitric, Melanic.
	- Soils developed in residual and shifting sands. Loamy sand or sandy texture to a depth of 100 cm. low water-holding capacity and easy to work .	**ARENOSOLS** 20 lower-level units, e.g. Plinthic, Gleyic, Aridic
	- Soils developed in cracking clays (expanding clays). Wide cracks when dry. Low porosity (mainly only micropores) and low-water transmission capacity. Irregular surface porosity.	**VERTISOLS** 16 lower-level units, e.g. thionic, Natric, Eutric, Haplic.
Set 4	Mineral soils whose formation was conditioned by the topography/physiography of the terrain. - Soil in (sub) recent alluvial, marine or lacustrine deposits, receiving at regular intervals new materials (or having received this material in the recent past). They vary widely in texture, from clay to gravel, and have irregular organic matter content.	**FLUVISOLS** 21 lower-level units, e.g. Histic, Thionic, Eutric, Dystric, Haplic, Arenic, Takyric, Gleyic.

	- Soils that are permanently or temporarily saturated with groundwater within 50 cm from the soil surface. Features are associated with the reduction and oxidation of iron and manganese. They have poor internal drainage	**GLEYSOLS** 25 lower-level units, e.g. Histic, Dystric, Eutric, Toxic, thionic
	- Soils that are either shallow (< 25 cm deep) over hard rock, or that overlay highly calcareous materials, or that are extremely gravelly (>90 % gravel, stones or boulders by weight) low-water-holding capacity and sometimes prone too erosion.	**LEPTOSOL** 16 lower-level units, e.g. Lithic, Gleyic, Umbric, Vertic, Eutric, Dystric
	- Very weakly developed soils in unconsolidated materials, with no diagnostic horizons other than ochric or umbric A-horizon. They are not Leptosols, Gleysols, Arenosols or Fluvisols. Often prone to erosion due to lack of cohesion between the soil particles	**REGOSOLS** 29 lower-level units, e.g. Leptic, Gleyic, Arenic, Eutric, Dystric, Aridic, Humic.
Set 5	Mineral soils whose formation is conditioned by their limited age (soils conditioned by time) moderately developed with beginning horizon differentiation evident from changes in colour, structure or carbonate content. Good structural stability. High porosity, good water-holding capacity and good internal drainage.	**CAMBISOLS** 26 lower-level units, e.g. Vertic, Fluvic, Plinthic, Dystric, Eutric, Rhodic, Chromic.
Set 6	Mineral soils whose formation was conditioned by climate: - Soils conditioned by tropical and subtropical climates. Strongly leached soils with “ferralic” horizons and accumulation of Iron (hydr) oxides (gibbsites), Low activity clay e.g. kaolinites, residual Quartz and other weathering-resistant minerals. Very stable microstructure, good water-holding and water transmission capacity, low bulk density (around 1.0kg/cm^3), not much prone to erosion.	**FERRALSOLS** 22 lower level units, e.g. Plinthic, Gleyic, Andic, Acric, Arenic, Lixic, Humic, Mollic, Ferric, Rhodic, Xanthic, Haplic, Umbric, Histic

	- Soils strongly leached and acid soils with a low activity “argic” horizon, pronounced increase in clay content with depth, dominance of low activity clay, low base saturation, weakly developed soils structure, particularly in the upper part of the soil, often hard- setting when dry, prone to slaking, crusting and erosion	**ACRISOLS** 23 lower level units, e.g. Leptic, Plinthic, Gleyic, Rhodic, Haplic, Ferric.
	- Strongly leached soils with pronounced increase in clay content with depth (Argic horizon). Dominance of low activity clays, slightly acid to neutral soil reaction, indicative of moderate to high base saturation. Weakly developed soils structure, particularly in the upper part of the soil, often hard-setting when dry, prone to slaking, crusting and erosion.	**LIXISOLS** 20 Lower-level units, e.g. Gleyic, Andic, Arenic, Stagnic, Albic, Vertic, Ferric, Rhodic, Chromic, Calcic.
	- Soils that have strongly developed nut-shaped structure, mainly derived from basic rock and having argillic clay horizon. Good water-holding capacity, good structural stability and not much prone to erosion.	**NITISOLS** 12 lower level units, e.g. Andic, Mollic, Dystric, Entric.
	- Soils with a high amount of exchangeable aluminium, which is released from rapidly weathering clay minerals (e.g. chlorite, vermiculite) strongly developed soil structure. Prone to slaking, crusting and erosion.	**ALISOLS** 17 lower level units, e.g. Vertic, Nitric, Humic, Ferric, Haplic, Rhodic.
	- Wet soils with iron accumulation that irreversibly hardens upon repeated drying and wetting (plinthite). Occurs in low-lying level positions (valley floors, river terraces), from under the influence of ground water and lateral water flow from adjacent uplands. Dense subsoil, obstructing deep percolation of water and inhibiting root penetration (bulk density of plinthite varies from 1.8 to 2.2 kg/dm^3). Low water storage capacity if “petroplinthite” is close to the surface	**PLINTHOSOLS** 17 Lower-level units, e.g. Petric, Ferric, Humic, Haplic

Set 7	Mineral soils whose formation was conditioned by arid and semi-arid climates: - Soils with accumulation of secondary gypsum ($CaSO_4.2H_2O$), forming "gypsic", "hypergypsic" or "petrogypsic" horizons. Gypsie: >15% gypsum; hypergypsie; >50% gypsum; Petrogypsum: hardened gypsum rock. Surface slakes easily and crusts on Gypsisols are common. Low water-holding capacity due to many large pores and cavities after dissolution of the gypsum	**GYPSISOLS** 17 lower-level units, e.g. Petric, Sodic, Vertic, Luvic, Aridic, Yemic
	- Soils with of secondary silica, forming "duric" or "petroduric" horizons hamper root penetration, unless they are fractured. Bulk density of duric horizons varies between 1.3 and 1.7kg/dm3 and petroduric horizon between 1.6 and 2.0 kg/dm3	**DURISOLS** 13 lower-level units, e.g. Petric, Vertic, Luvic, Arenic, Aridic, Haplic
	- Soils with accumulation of secondary calcium carbonate (CaCO3). Good water-holding capacity prone to slaking and crusting. Petrocalcic horizons hamper root penetration, unless they are fractured.	**CALCISOLS** 15 Lower level units, e.g. Leptic, Vertic, Gleyic, Aridic, Sodic
	- Soils with accumulation of salts more soluble than gypsum. Prone to crusting and erosion, because of the dispersion effect of salt.	**SOLONCHAKS** 21 lower-level units, e.g. Histic, Vertic, Gleyic.
	- Soils with a high amount of exchangeable sodium (> 15% of the adsorbed cations), accumulated in the subsoil in a so-called "nitric" horizon. Clay and humus easily disperse clogging pores. Subsoils are slowly permeable and soils are waterlogged.	**SOLONETZ** 15 lower level units, e.g. Vertic, Gleyic, Mollic, Humic, Aridic
Set 8	Mineral soils whose formation was conditioned y steppe climate. These soils have the mollic horizons. - Soils of tall-grass steppes, with a thick, very dark brown or black, humus-rich surface horizon and accumulation of carbonates within 2 m from the surface. Chernozems form the	**CHERNOZEMS** 9 lower-level units, e.g. Vertic, Gleyic, Luvic, Glossic, Vermic, Haplic.

	central concept of "steppe soils", bordered by Kastanozems on the drier side and phaeozems on the water side. Chernozems have high porosity (between 50 and 60 volume percentage). Good moisture holding capacity (20 volume percent AWC) and stable micro-aggregate structure.	
	- Soils of short-grass steppes, chestnut brown in colour, with accumulation of calcium carbonate or gypsum close to the surface. Surface horizon not as thick and dark coloured as in Chernozems, and physical properties are comparable but slightly less favourable.	**KASTANOZEMS** 9 lower-level units e.g. Vertic, Siltic, Chromic, Luvic
	- Soils of the wetter steppes with a dark brown, humus-rich, and base-saturated surface horizons, but lacking carbonates with within 2 m. Good moisture holding capacity. Stable micro-aggregate structure, erosion resistant, even on slopes.	**PHAEOZEMS** 20 lower-level units, e.g. Leptic, Vertic, Gleyic, Vermic.
Set 9	Mineral soils whose formation was conditioned by temperature and subhumid climates. - Moderately leached soils with pronounced increase in clay content with depth ("argillic horizon"), acid to neutral soil reaction; moderate to high available water content, subsoil porosity decreases over time due to clay illuviation, reducing water infiltration and inducing water stagnation.	**LUVISOLS** 19 lower-level units, e.g. Leptic, Vertic, Gleyic, Arenic, Chromic, Cutanic, Dystric, Ferric, Haplic
	- Soils with a pronounced "albic" (white, clay depleted) horizon tonguing into an underlying "argillic" (clay-enriched) horizon. These are considered to be "relicts" soils formed under perigracial conditions. Poorly structured topsoil. Dense subsoil, often impenetrable for roots, restrict water movement.	**ALBELUVISOLS** 14 lower-level units, e.g. Histic, Gelic, Umbric, Arenic, Fragic

	- Soils in siliceous parent materials characterized by "cheluviation" processes, i.e. movement of soluble metal-humus complexes (chelates) downwards. The processes lead to ash-grey layer near the surface and a brownish to blackish illuvial layerbelow. Podzols are of sandy texture. Weak aggregation into structural elements. Low water-holding capacity. Illuviation may lead to very dense subsoil ("ortstein") or iron banks.	**PODZOLS** 15 lower-level units, e.g. Gelic, Densic, Carbic, Histic, Entic, Anthric, Haplic, Umbric, Stagnic, Rustic.
	- Soils with an abrupt textural change and evidence of water stagnation. It is also known as a duplex soil. It may have a sandy or slty topsoil overlaying a clayey subsoil with mottles or iron-manganese concretions just above the abrupt transition. Water stagnation during part of the year. Very weakly expressed and unstable structural elements in the upper parts of the soil. The compact subsoil impairs root penetration.	**PLANOSOLS** 27 lower-level units, e.g. Histic, Vertic, Thionic, Gleyic, Sodic, Alic, Luvic, Umbric, Arenic, Gelic, Albic, Ferric, Eutric
	- Soils with acid, dark brown, humus-rich but base-saturated surface horizon. Occur over siliceous parent materials and in wet climates. Well drained, well aerated and prone to erosion of on slopes.	**UMBRISOLS** 11 lower-level units, e.g. Gelic, Arenic, Humic, Ferralic, Haplic
Set 10	Mineral soils whose formation was conditioned by cold climate (permafrost regions). - Soils with evidence of freezing and thawing such as frost leaves of coarse materials, cryoturbation and mechanical weathering. Water saturated during the thawing season, therefore poorly trafficable. There is occurrence of variable amounts of ice in the subsoil.	**CRYOSOLS** 19 lower-level units, e.g. Histic, Lithic, Letic, Turbic, Natric, Andic, Umbric, Aridic, thionic, Oxyaquic, Haplic

Adapted from Esu (2005), Spaargaren (2005), Akamigbo 2010

3.3 Classification of Nigerian Soils

There has not been significant effort by African Scientists to develop their own indigenous soil classification system. The first soil classification system in Africa was for South Africa published in 1977. It was based on many years of survey information from several sources and was called “Soil classification – a binomial system for South Africa” known as the “red book”. Nigeria does not have any soil classification system developed specifically for Nigerian soils. Nigeria scientists have adopted the USDA soil classification systems for the classification of her soils.

The first work aimed at the taxonomic classification of Nigerian Soils was carried out by Vine (1954) who divided the soils into three broad zones which were further divided into 16 soil groups based on differences in mechanical composition and organic matter content (Ojanuga and Awojuola, 1971). Vine further defined “Soil fasees” roughly equivalent to families at the lowest level of his classification system. He divided the soils of Nigeria into 27 “fasees” which he grouped together into three separate zones of latosol, based on the degree of leaching and human content of the profile (Ojo-Atere and Oladimeji, (1977). Ohaeri (1961) recognized a wide level of coastal plain in it. Less well drained part, the delta; the coastal plain is connected with the sea by a large number of creeks. Jungerius and Levelli (1964), studies the clay mineralogy of soils over the sedimentary rocks in Eastern Nigeria over and observed that the soils in this area derived most of the clay mineral from the underlying sedimentary rocks. Kaolinite is dominant in all the soils.

Jungerius (1964), in his work observed that the coastal plain sands are the youngest formation, which covers the wide plain extending from Owerri southward to the coastal areas. Ogunkunle (1995) noted that the soil classification in Nigeria at the soil series level differ between regions. The implication of this according to him is the hindrance to direct transfer of newly developed technology.

It is however true that soil survey started in Nigeria with Vine (1954) a more comprehensive work with the production of soil map was done by Smith and Montgomery (1962). The FDALR (1985) exercise resulted in the grouping of Nigerian soil into 58 soil groups showing different characteristics associated features of the soil. It is on the basis that soil classification was done in Nigeria using soil taxonomy and FAO-UNESCO system of soil classification.

3.4 Uses of Soil classification

Soil classification systems are established to help people predict soil behavior and to provide a common language for soil scientists. Soil classification has found its uses in the following areas;

1. **Farmers**

Knowledge of soil classification helps predict soil behaviour and soil behaviour helps predict soil performance for growing agricultural crops. Part of the works of extension agents is to provide soil survey maps of local soil classification to help farmers make decisions about crops to grow in particular areas. E.g. soil classified as vertisol has a high clay content which shrinks and swells depending on their moisture status. Such soil may be very good for lowland rice farming.

2. **Fertile Soil**

Mollisol earth is the most productive soil for agricultural activity. Mollisol earth and its eight suborders make up about 21.5% of the lands in the United States. The productive agricultural areas of the Great Plains are mollisol earth. The topsoil layer is thick with organic matter and dark in colour. The high fertility results from long term addition of organic materials derived from the grassy plant roots indigenous to the region.

3. **Engineers and Community Planners**

Engineers use soil classification survey to determine the potential pehaviour and limitations of soil. Pipelines, bridges, buildings, recreational areas and landfills must be built on soil suitable to the engineering need of the earth project. Community gardens, green belts, recreational areas, and septic absorption fields can be effectively planned by community planners using adequate soil information of the region

4. **Maintaining Soil Fertility**

Poor land use practices such as overgrazing, deforestation and soil destroying activities can be prevented with proper knowledge of soil types and classifications. Erosion of formally fertile soils layers affected 65% of the global land mass. Eroded soils are agriculturally unproductive. Soil classification systems therefore teach the biological factors that affect soil formation, soil productivity and prevent erosion.

4.0 CONCLUSION

The USDA Soil Taxonomy developed in 1951 was the most comprehensive soil classification system as the classification of 1938 used before this time had several loopholes which made classification very difficult. The main objectives of the World Reference Base for Soil Resources was to provide scientific depth and background to the 1988 FAO Revised Legend, incorporating the latest knowledge relating to global soil resources and their interrelations.

5.0 SUMMARY

Artificial system of classification is when small numbers of selected soil properties are used as the basis for classification**.** The genetic systems are based on the presumed origin of the soils; they are supposed to be defined in terms of processes but in practice, owing to the difficulty of observing those, they are based upon soil forming factors. The numerical system is the numerical evaluation of the affinity or similarity between taxonomic units and the ordering of these units into taxa on the basis of their affinities. The French classification system divides the world soils into ten classes with their broad groups are related to climate and vegetation belts**.** The modern Russian Soil classification involves a strong genetic emphasis, evaluation of soil properties and the pedogenic process in the solum in relation to soil forming factors. The Russian system starts from the soils of the arctic regions to those of the tropical deserts, and so considers temperature and environment as important criteria. The USDA soil Taxonomy is the most widely used soil classification system. After several approximations and series of amendments a final copy of the USDA classification published in 1975 by soil Survey Staff, as “Soil Taxonomy: A Basis System of Soil Classification for Making and Interpreting Soil Surveys”.

However, several amendments followed the 1975 publication, which led to another publication in 1999. The latest being the eleventh edition of keys to soil taxonomy, (2010) which incorporated all the changes that have taken place since the publication of the second edition in 1999. The objectives and principles of the WRB ran parallel with those of the earlier FAO/UNESCO classification. Moreover, the revised legend of the FAO/UNESCO Soil Map of the world was used as a basis for the development of the WRB in order to take advantage of the international soil correlation work which has already been done.

6.0 TUTOR-MARKED ASSIGNMENT

1. Mention and explain all the classification systems you know
2. Discus the USDA soil taxonomy under the following headings; Order, Suborder, Great group, Subgroup, Family and Series
3. What is the relationship between FAO/UNESCO Legend and WRB for soil resources
4. List and briefly explain four areas that soil classification information can be used

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