NATIONAL OPEN UNIVERSITY OF NIGERIA

SLM 303

Introduction to Pedology and Soil Physics

Module 1

SLM 303 (Introduction to Pedology and Soil Physics) Module 1

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Published in 2013, 2021 by the National Open University of Nigeria

Module 1 Soil Origin, Formation, Morphological Characteristics and Components

Unit 1 Origin of Soil

1.0 Introduction

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, you should be able to:

- give details of soil quality
- list the combination of the soil.

3.0 Main Content

3.1 Important Facts to Know

1. The concept of "soil" and its many variations in composition, qualities and origins.
2. The ionic forms of the plant macronutrients and the importance of aluminium, sodium and iron in soil solutions.
3. The difference between minerals and rocks and some common minerals and rocks from which soils form.
4. The origin of "organic soils"
5. The origin and nature of certain landforms, particularly moraines, alluvial deposits, loess peats and mucks.
6. The meaning of "soil formation" and "soil development" and the processes active in soil changes.
7. The meaning of these special letters which designate soil horizons: **O, A, E, B, C, R, k, g, s, m, p, t and x**
8. The dominant influence of parent material and climate on the properties of developed soils.

9. The many conditions that retard soil development, particularly cold, dryness, high quartz sand content, low-permeability material, slow erosion or deposition action at the surface and profile mixing.

The general climatic-time weathering relationships among the soil orders of Entisols, Inceptisols, Andisols, Aridisols, Mollisols, Alfisols, Spodosols, Ultisols, Oxisols and Histosols

Because soil is important for cultivation and agricultural production, soil fertility and productivity are important issues to address. Detailed pedological knowledge is useful for land evaluation purposes, i.e. the classification in fertile productive soils and less valuable soils. Soils are an integral part of landscapes and the knowledge of the distribution of different soils helps to preserve a high standard in environmental quality. For example, site specific management cannot be developed without detailed knowledge of soils. Critical sites, e.g. shallow hillslope soils prone to erosion and leaching of nutrients, can be identified using pedology. Soil surveys furnish basic inputs to soil conservation planning and provide information used in equations for predicting soil loss and water pollution under various management practices on different soils.

3.2 Soil: Its Origin and Formation

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. 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. 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.

3.3 Origin of Soil

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 speaks 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*. Changes of this type prevail under extreme climatic conditions as in deserts or arctic regions. They are also prevailing in areas of mountainous relief. The most prominent agents of physical weathering are: _ differential stress caused by unloading of deep-seated rocks on emerging to the surface; _ differential thermal expansion under extreme climatic conditions; _ expansion of interstitial water volume by freezing that leads to rupturing along crystal boundaries. Other mechanical agents enhance the effect of mechanical weathering. These may include processes such as gravity, abrasion by glacial ice or wind-blown particles.

The word 'soil' occurs many times in this course. In agriculture this word is used to describe the thin layer of surface earth that, like some great blanket, is tucked around the wrinkled and age-beaten form of our globe. The harder and colder earth under this surface layer is called the _subsoil_. It should be noted, however, that in waterless and sun-dried regions there seems little difference between the soil and the subsoil. Plants, insects, birds, beasts, men,--all alike are fed on what grows in this thin layer of soil. If some wild flood in sudden wrath could sweep into the ocean this earth-wrapping soil, food would soon become as scarce as it was in Samaria when mothers ate their sons. The face of the earth as we now see it, daintily robed in grass, or uplifting waving acres of corn, or even naked, water-scarred, and disfigured by man's neglect, is very different from what it was in its earliest days. How was it then? How was the soil formed? Scientists think that at first the surface of the earth was solid rock. How was this rock changed into workable soil? Occasionally a curious boy picks up a rotten stone, squeezes it, and finds his hands filled with dirt, or soil. Now, just as the boy crumbled with his fingers this single stone, the great forces of nature with boundless patience crumbled, or, as it is called, disintegrated, the early rock mass. The simple but giant-strong agents that beat the rocks into powder with a club like force a million fold more powerful than the club force of Hercules were chiefly (1) heat and cold; (2) water, frost, and ice; (3) a very low form of vegetable life; and (4) tiny animals--if such minute bodies can be called animals. In some cases these forces acted singly; in others, all acted together to rend and crumble the unbroken stretch of rock.

4.0 Conclusion

Soil originated from the decay of rocks and minerals by combining with organic matter. It takes some hundred million years to form soil.

5.0 Summary

Soil formation hypothesis states that soil is formed as a result of the interaction of many variables the most important of which are:

- parent material
- climate
- organisms
- relief and
- time, these variable soil forming factors.

(Source: Pilot Phase II – Biology Hand Book for Student Grade 4-6. 2001)

6.0 Self-Assessment Exercise

1. Briefly describe the origin of soil.
2. What are the factors of soil formation?
3. Explain how soil formation factors influence the kind of soil that is finally formed.

7.0 References/Further Reading

Albrecht, W.A. (1975). *The Albrecht Papers*. Charles Walters (Ed.). Acres USA.: Raytown. Missouri.

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Unit 2 Soil Formation

1.0 Introduction

Soils are that portion of the earth's crust in land plants can grow, if water and temperature are adequate, at least the minimum nutrients are available, and toxic substances are in low concentration. Some soils are very shallow (few centimeters deep) and some are few meters deep. All soils developed from weathered rock, volcanic ash deposits, or accumulated plant residues. Most soils are formed weathered rocks and minerals. These minerals include quartz, feldspars, micas, homblende, calcite, and gypsum. Combinations of minerals into solid masses are called rocks.

2.0 Objectives

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

- explain the origin of "organic soils"
- classify the origin and nature of certain landforms, particularly moraines, alluvial deposits, loess and peats and mucks
- define the meaning of "soil formation" and "soil development" and the processes active in the soil changes
- evaluate soil-forming factors.

3.0 Main Content

3.1 Soil formation

Let us glance at some of the methods used by these skilled soil-makers.

Heat and cold are working partners. You already know that most hot bodies shrink, or contract, on cooling. The early rocks were hot. As the outside shell of rock cooled from exposure to air and moisture it contracted. This shrinkage of the rigid rim of course broke many of the rocks, and here and there left cracks, or fissures. In these fissures water collected and froze. As freezing water expands with irresistible power, the expansion still further broke the rocks to pieces. The smaller pieces again, in the same way, were acted on by frost and ice and again crumbled. This process is still a means of soil-formation. Running water was another giant soil-former. If you would understand its action, observe some usually sparkling stream just after a washing rain. The clear waters are discoloured by mud washed in from the surrounding
hills. As though disliking their muddy burden, the waters strive to throw it off. Here, as low banks offer chance, they run out into shallows and drop some of it. Here, as they pass a quiet pool, they deposit more. At last they reach the still water at the mouth of the stream, and there they leave behind the last of their mud load, and often form of it little three-sided islands called deltas.

In the same way mighty rivers like the Amazon, the Mississippi, and the Hudson, when they are swollen by rain, bear great quantities of soil in their sweep to the seas. Some of the soil they scatter over the lowlands as they whirl seaward; the rest they deposit in deltas at their mouths. It is estimated that the Mississippi carries to the ocean each year enough soil to cover a square mile of surface to a depth of two hundred and sixty-eight feet.

The early brooks and rivers, instead of bearing mud, ran ocean ward either bearing ground stone that they themselves had worn from the rocks by ceaseless fretting, or bearing stones that other forces had already dislodged. The large pieces were whirled from side to side and beaten against one another or against bedrock until they were ground into smaller and smaller pieces. The rivers distributed this rock soil just as the later rivers distribute muddy soil. For ages the moving waters
ground against the rocks. Vast were the waters; vast the number of years; vast the results.

Glaciers were another soil-producing agent. Glaciers are streams "frozen and moving slowly but irresistibly onwards, down well-defined valleys, grinding and pulverising the rock masses detached by the force and weight of their attack.

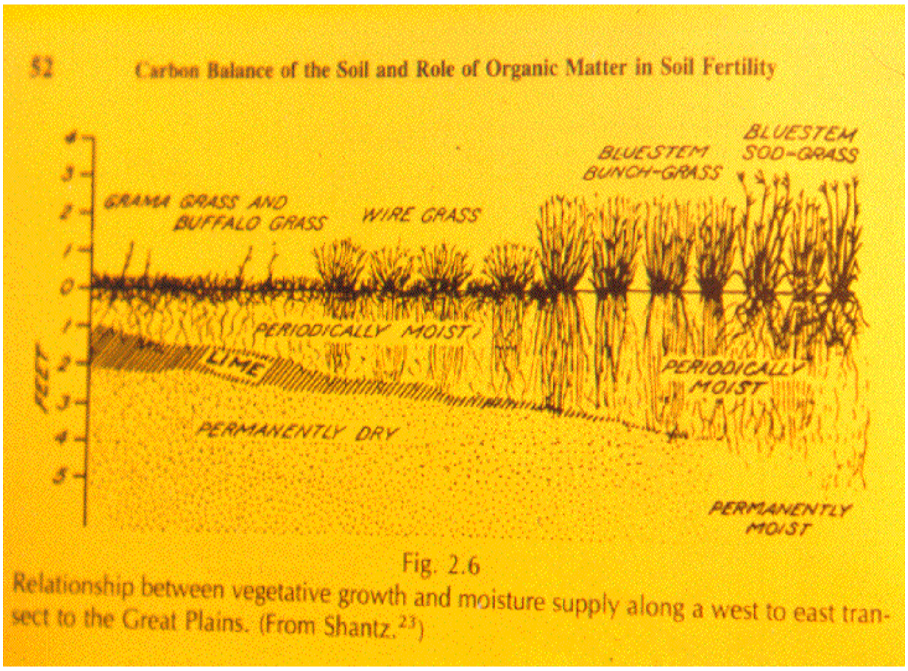

Fig. 2.6
Relationship between vegetative growth and moisture supply along a west to east transect to the Great Plains. (From Shantz.[23])

3.2 Types of Soil

Sand, silt, and clay are the basic types of soil. Most soils are made up of a combination of the three. The texture of the soil, how it looks and feels, depends upon the amount of each one in that particular soil. The type of soil varies from place to place on our planet and can even vary from one place to another in your own backyard.

3.3 The Soil-Forming Factors

Even if all soils were formed through the same weathering processes, they could still differ because of other influences. Five items, called soil-forming factors, are primarily responsible for the developed soil:

- Parent material
- Climate (temperature and precipitation mostly)
- Biota (living organisms and organic residues)
- Topography (slope, aspect and elevation)
- Time

3.4 Parent Materials and Soil Formation

Parent materials influence soil formation by their different rates of weathering, the nutrients they contain for plant use, and the particle sizes they contain (sandstones = sandy; conglomerates = rocky; shale's = clayey). The less developed a soil is, the greater will be the effect of parent material on the properties of the soil. However, even the properties of well developed soils will be greatly influenced by the parent material. Clay formation is favoured by a high percentage of decomposable dark minerals and by less quartz. The results of leaching and many translocations and transformations affected by water movement in soil will be evident even when the soil is well developed. All soils at the lowest category of soil classification (series) are placed into separates series if parent materials are different.

3.5 Climate and Soil Formation

Climate is an increasingly dominant factor in soil formation with increased time, mainly because of the effects of precipitation and temperature. Some direct effects of climate on soil formation include the following:

A shallow accumulation or retention of lime (carbonates) in areas having low rainfall occurs because calcium bicarbonates (from dissolving carbon dioxide, minerals and lime) are not leached if sufficient water is not present. Such soils are usually alkaline

- acidic soils form in humid areas due to intense weathering and leaching out of basic cations (calcium, sodium, magnesium, potassium)
- erosion of soils on sloping lands constantly removes developing soil layers
- deposition of soil materials downslope covers developing soils
- weathering, leaching and erosion are more intense and of longer duration in warm and humid regions, as in Hawaii, where the soil does not freeze. The reverse is true in cold climates, as in Alaska.

3.6 Biota and Soil Formation

The activity of living plants and animals and the decomposition of their organic wastes and residues (the living environment, the biota) have marked influences on soil development. Differences in soils that have resulted primarily from differences in vegetation are especially noticeable in the transition where trees and grasses meet. In Nigeria for example, the differences soils follows closely the difference in vegetation types: there are more work from earth, the vegetation get sparser and as its get shallower and fewer in organic matter. Some soils beneath humid forest vegetation may develop many horizons, are leached (washed, eluviated) in the surface layers, and have slowly decomposing organic matter layers on the surface. In contrast, some grassland soils near the transition zone of forests are rich in well-decomposed organic matter, frequently to depths of 30cm or more (1ft or more) into the mineral soil.
Burrowing animals, such as rats, earthworms, ants and termites are highly important in soil formation when they exist in large numbers. Soils that harbour many burrowing animals have fewer but deeper horizons because of the constant mixing within the profile, which nullifies the organic colloid and clay movements downward.

Microorganisms help soil development by slowly decomposing organic matter and forming weak acids that dissolve minerals faster than pure water. Some of the first plants to grow on weathering rocks are crust- like lichens, which are beneficial (symbiotic) combination of algae and fungi. Man also plays a role in soil formation by modifying, soils; this is done through many various activities such as tillage, bush burning, construction, etc.

3.7 Topography and Soil Formation

The earth's surface contour is called its **topography** (sometimes called relief). Topography influences soil formation primarily through its associated water and temperature relations. Soils within the same general climatic area developing from similar parent material and on steep hillsides typically have thin A and B horizons because less water moves down through the profile as a result of rapid surface runoff and because the surface erodes quite rapidly. Similar materials on gently sloping hillsides have more water passing vertically through them than do materials on steeper slopes. The profile on gentle slopes generally is deeper, the vegetation more luxuriant, and the organic matter level higher than in similar materials on steep topography.

4.0 Conclusion

Soil is the combination of rock, mineral fragments (pieces) made by weathering (wind, rain, sun, snow, etc.), and organic matter (living things), water, and air.

5.0 Summary

Soil is a 3-dimensional body with properties that reflect the impact of (1) climate, (2) vegetation, fauna, Man and (3) topography on the soil's (4) parent material over a variable (5) time span. The nature and relative importance of each of these five `soil forming factors' vary in time and in space. With few exceptions, soils are still in a process of change; they show in their `soil profile' signs of differentiation or alteration of the soil material incurred in a process of soil formation or `pedogenesis'.

6.0 Self-Assessment Exercise

1. What are the factors of soil formation? Explain how these factors influence the kind of soil that is finally formed.
2. Write short notes on any 3 of the following:

a. Topography and Soil Formation
b. Biota and Soil Formation
c. Climate and Soil Formation
d. Types of Soil.

7.0 Reference/Further Reading

Eswaran, H. *et al.* (Eds.). (2002). *Soil Classification: A Global Desk Reference*. Boca Raton, Fla.: CRC Press.

Unit 3 Soil Morphology

1.0 Introduction

Soil morphology is the field observable attributes of the soil within the various soil horizons and the description of the kind and arrangement of the horizons. C.F. Marbut (2003) championed reliance on soil morphology instead of on theories of pedogenesis for soil classification because theories of soil genesis are both ephemeral and dynamic.

The observable attributes ordinarily described in the field include the composition, form, soil structure and organisation of the soil, colour of the base soil and features such as mottling, distribution of roots and pores, evidence of translocated materials such as carbonates, iron, manganese, carbon and clay, and the consistence of the soil.
The observations are typically performed on a soil profile. A profile is a vertical cut, two dimensional, in the soil and bounds one side of a pedon. The pedon is the smallest three dimensional units, but not less than 1 meter square on top, that captures the lateral range of variability.

2.0 Objectives

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

- identify the micromorphology, porosity and soil texture.

3.0 Main Content

3.1 Micromorphology

While soil micromorphology begins in the field with the routine and careful use of a 10x hand lens, much more can be described by careful description of thin sections made of the soil with the aid of a petrographic polarising light microscope. The soil can be impregnated with an epoxy resin, but more commonly with a polyester resin (crystic 17449) and sliced and ground to 0.03 millimeter thickness and examined by passing light through the thin soil plasma.

3.2 Porosity

Porosity of topsoil typically decreases as grain size increases. This is due to soil aggregate formation in finer textured surface soils when subject to soil biological processes. Aggregation involves particulate adhesion and higher resistance to compaction. Typical bulk density of sandy soil is between 1.5 and 1.7 g/cm^3. This calculates to porosity between 0.43 and 0.36. Typical bulk density of clay soil is between 1.1 and 1.3 g/cm^3. This calculates to porosity between 0.58 and 0.51. This seems counterintuitive because clay soils are termed heavy, implying lower porosity. Heavy apparently refers to a gravitational moisture content effect in combination with terminology that harkens back to the relative force required to pull a tillage implement through the clayey soil at field moisture content as compared to sand.

Porosity of subsurface soil is lower than in surface soil due to compaction by gravity. Porosity of 0.20 is considered normal for unsorted gravel size material at depths below the biomantle. Porosity in finer material below the aggregating influence of pedogenesis can be expected to approximate this value.

Soil porosity is complex. Traditional models regard porosity as continuous. This fails to account for anomalous features and produces only approximate results. Furthermore it cannot help model the influence of environmental factors which affect pore geometry. A number of more complex models have been proposed, including fractals, bubble theory, cracking theory, Boolean grain process, packed sphere, and numerous other models.

3.3 Soil Texture

An experienced soil scientist can determine soil texture in the field with decent accuracy, but not all soils lend themselves to accurate field determinations of soil texture. The mineral texture can be obfuscated by high soil organic matter, iron oxides, amorphous or short-range-order aluminosilicates, and carbonates. Soil texture is the relative relations of the components sand, silt and clay most often reported as percentages on a mass basis. Laboratory methods employ chemical pretreatments to mediate the effects of organic matter, iron oxides, amorphous or short-range-order aluminosilicates, and carbonates

Cultivation disturbs the soil, causing fragmentation, compaction and displacement (Roger-Estrade *et al*., 2000). Consequently, two types of earth may appear within the soil profile: fine and compacted zones (most often defined as clods). The presence of a large portion of high penetration-resistant clods is one of the most serious factors limiting soil exploration by plant roots (Hoad *et al.,* 1992). Since water content fluctuates during the growing season and clod penetration resistance is strongly linked to moisture, impedance of clods to root growth changes considerably. An additional factor closely linked to these interactions is the intensity of soil compaction, which can be readily interpreted as an increase of bulk density of a specific soil type (Goldsmith *et al*., 2001).

If soil becomes compacted to the level that plant growth is impaired, the compaction must be alleviated through several measures intended to returning satisfactory growth conditions. Especially, loosening and sub-soiling aim at eliminating soil compaction and preventing reduced soil-rooting depth (Carter, 1988). However, it is safe to assume that even optimal techniques and excellent timings of agronomic operations cannot fully eliminate soil compaction. Thus, soil impedance remains one of the most important factors influencing crop yield (Atwell, 1988, Stenitzer and Murer, 2003). Some previous studies showed that soil compaction decreased root development and delayed root colonisation of deeper soil layers (e.g. Ehlersb *et al.* 1982). Frequently, the relation between the relative root elongation rate and soil penetration resistance was used to demonstrate the importance of soil compaction for root growth (Bennie, 1991). However, it appears that there is a lack of studies on alterations of other morphological properties of roots due to soil compaction, and hence on plant physiological processes and crop production (Bengough, 2003). The relationship between soil compaction and root growth was usually studied using a homogeneous substrate (see for instance Unger and Kaspar 1994), structured soil conditions were considered very rarely (Amato and Ritchie, 2002).

4.0 Conclusion

Soil morphology is composed of composition, form, soil structure and organisation of the soil, colour of the base soil and features such as mottling, distribution of roots and pores, evidence of translocated materials such as carbonates, iron, manganese, carbon and clay, and the consistence of the soil.

5.0 Summary

Soil morphology, classification and survey are three intimately related sub-disciplines that made soil morphology. They are used one after the other.

6.0 Self-Assessment Exercise

1. Discuss the morphological characteristics of soil
2. Write short notes on the following:

a. Micromorphology
b. Soil porosity
c. Soil texture.

7.0 References/Further Reading

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Unit 4 Soil Characteristics

1.0 Introduction

Soil scientists study many different aspects of the soil. Below are the soil characteristics which are the most important aspects of soil science.

2.0 Objectives

At the end of this unit, you should be able to:
- explain the various characteristics of soil.

3.0 Main Content

3.1 Soil Characteristics

- a layer of natural materials on the earth's surface containing both organic and inorganic materials and capable of supporting plant life
- the material covers the earth's surface in a thin layer
- it may be covered by water, or it may be exposed to the atmosphere.
- soil contains four main components: inorganic material, organic matter, water, and air
- ideal soil should contain about 50% solid material and 50% pore space
- about half of the pore space should contain water and half of the space should contain air
- inorganic material consists of rock slowly broken down into small particles
- the organic material is made up of dead plants and animals varying in stages of decay.
- the percentages of the four main soil components varies depending on the kind of vegetation, amount of mechanical compaction, and the amount of soil water present.
- soil is formed very slowly
- it results from natural forces acting on the mineral and rock portions of the earth's surface
- the rock is slowly broken down to small particles resulting in soil
- soil parent materials are those materials underlying the soil and from which the soil was formed
- there are five major categories of parent material: minerals and rocks, glacial deposits, loess deposits, alluvial and marine deposits and organic deposits
- minerals are solid, inorganic, chemically uniform substance occurring naturally in the earth
- some common minerals for soil formation are feldspar, micas, silica, iron oxides, and calcium carbonates
- rocks are different from minerals because they are not uniform
- there are three types of rocks, igneous, sedimentary, and metamorphic
- igneous rocks are those formed by the cooling of molten rock
- sedimentary rocks are those formed by the solidification of sediment.
- metamorphic rocks are simply igneous or sedimentary rocks which have been reformed because of great heat or pressure
- during the ice age, glaciers moved across areas of the northern hemisphere

- they ground, pushed, piled, gouged, and eventually deposited great amounts of rocks, parent material, and already formed soil material
- loess deposits are generally thought of as windblown silt.
- alluvial and marine deposits are water borne sediments
- alluvial deposits are left by moving fresh water
- marine deposits are formed on ancient ocean floors
- organic deposits are partially decayed plants that live plants are able to root and grow in
- these are found in swamps and marshes
- when minerals are exposed to weather, they begin to break down into smaller pieces.
- this is mostly done by heating and cooling of the minerals and rock
- some minerals are water soluble which means they dissolve when exposed to water.
- some rocks may contain some minerals that are water soluble and only that part of the rock will dissolve. Ex: some caves
- when a tree or other types of plants begin growing in the cracks of rocks, this may speed up the breakdown of the rock because of the pressure the roots may exert
- ice can also speed up the weathering process on rocks
- if a rock has a crack that can fill up with water, when the water freezes, it can literally crumble the rock into small pieces
- rocks can also be broken down by mechanical grinding such as wind blowing sand at high speeds or glaciers causing rocks to grind each other.

4.0 Conclusion

New soil is continually being made, but it takes a long time to create new soil and if it isn't managed properly, soil can be eroded away quicker than it can be made.

5.0 Summary

Soil characteristics property used to describe the relative proportion of different grain sizes of mineral particles in a soil. Particles are grouped according to their size into what are called soil separates. These separates are typically named clay, silt, and sand. Soil texture classification is based on the fractions of soil separates present in a soil. The soil texture triangle is a diagram often used to figure out soil textures.

6.0 Self-Assessment Exercise

1. What are the general characteristics of soil
2. Write short notes on the following:

a. Major Soil types
b. Soil Profile
c. Soil microorganisms.

7.0 References/Further Reading

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Unit 5 Soil Components

1.0 Introduction

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. 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. 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 like you would find in a wetland probably has very little air. The composition of the soil affects the plants and therefore the animals that can live there.

2.0 Objectives

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

- identify the component of soil
- state the importance of soil component to a farmer who wants to undertake large-scale crop production.

3.0 Main Content

3.1 Soil Components

Soils consist of four major components:
(1) mineral (or inorganic), (2) organic, (3) water, and (4) air.

The relative proportions of these four soil components vary with soil type and climatic conditions. Review the approximate proportions (by volume) of the four soil components in a mineral soil under optimum conditions for plant growth.

3.2 Mineral Components

Mineral particles are inorganic materials derived from rocks and minerals. They are extremely variable in size and composition.

3.2.1 Types of Primary and Secondary Minerals

a. **Primary minerals** are formed at high temperature and pressure, under reducing conditions without free oxygen**.** These minerals are mainly present in soils as sand and silt particles. They are not crystallised and deposed from molten lava.
b. **Secondary minerals** are formed at low temperature and pressure through oxidation. They are the weathering product of primary minerals, either through alteration of their structure or through re-precipitation. Secondary minerals are usually present in soil as clay particles.

3.2.2 Size of Soil Particles

The mineral particles present in soils vary enormously in size from boulders and stones down to sand grains and minute clay particles that cannot be seen by an optical microscope. An arbitrary division is made by size-grading soil into material:
a) that passes trough a sieve with 2-mm diameter holes - the **fine earth** (consisting of sand, silt, and clay particles),
b) that is retained on the sieve (> 2 mm) - the **coarse fragments** (gravel, cobbles, and stones).

Coarse fragments (diameter > 2 mm) are defined as rock fragments and do not include fragments of pads or concretions.

3.3 Soil Texture

Soil texture refers to the relative proportions of sand, silt, and clay in a soil. It is often the first and most important property to be determined when describing a soil, since many conclusions can be drawn from this information (water intake or infiltration, water storage in the soil, soil aeration, soil fertility, trafficability, etc.).

3.4 Weathering

Weathering refers to the breakdown and changes in rocks and sediments at or near the Earth's surface brought about by biological, chemical, and physical agents or combinations thereof. Weathering also involves the synthesis of new (secondary) minerals that are of great importance in soil (e.g. clay minerals).
Examples of **physical weathering** include processes such as crystal growth, thermal expansion, moisture swelling, abrasion, etc.

Chemical weathering consists of the following processes:

1) **Hydration** – intact water molecules bind to a mineral transforming hematite into ferrihydrate:

$$5Fe_2O_3 + 9H_2O \xrightarrow{hydration} Fe_{10}O_{15} \cdot 9H_2O$$

2) **Hydrolysis** – water molecules split into their hydrogen and hydroxyl components and hydrogen replaces a cation from the mineral structure (e.g. transformation of feldspar to kaolinite):

$$KAlSi_3O_8 + H_2O \xrightarrow{hydrolysis} HAlSi_3O_8 + K^+ + OH^-$$

3) **Dissolution (or solution)** – water is capable of dissolving many minerals by hydrating the cat ions and anions until they become dissociated from each other and surrounded by water molecules. (e.g. dissolution of gypsum):

$$CaSO_4 \cdot 2H_2O + 2H_2O \xrightarrow{dissolution} Ca^{2+} + SO_4^{2-} + 4H_2O$$

4) **Carbonation** – weathering is accelerated by the presence of acids that increase the activity of hydrogen ions in water. For example, when carbon dioxide dissolves in water (a

process enhanced by microbial and root respiration) the carbonic acid (H2CO3) produced hastens the chemical dissolution of calcite into limestone (or marble):

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 + CaCO_3 \xrightarrow{carbonation} Ca^{2+} + 2HCO_3^-$$

5) **Oxidation-reduction** – minerals that contain Fe, Mn, or S are especially susceptible to oxidation-reduction reactions. When for example, iron is oxidized from divalent to trivalent form, the change in valence and ionic radius causes destabilising adjustments in the crystal structure of the mineral.

Biological weathering effects include:

- the breakup of rock particles by roots
- the transfer and mixing of materials by burrowing animals and
- the formation of organo-mineral complexes (soil biological processes produce organic acids that can solubilise Al and Si ions, which are removed from a mineral by this process).

Biological Weathering

An example of biological weathering of a rock under the influence of clams

Image Source: Maja Krzic

3.5 Most Common Elements in Soils

The median and range of various elements present in soils from around the world are given in Table 1. The elements that are found in soils in the highest quantities are O, Si, Al, Fe, C, Ca, K, Na, and Mg. These are also major elements found in the Earth's crust and in sediments. Oxygen is the most prevalent element in the Earth's crust and in soils. It comprises about 47% of the Earth's crust by weight and more than 90% by volume.

Table 1: Contents of some Elements in Soils, the Earth's Crust and Sediments (extracted from Sparks, 2003)

Element	Soils (mg/kg)		Earth's crust (mean)	Sediments (mean)
	Median	Range		
O	490,000	-	474,000	486,000
Si	330,000	250,000-410,000	277,000	245,000
Al	71,000	10,000-300,000	82,000	72,000
Fe	40,000	2,000-550,000	41,000	41,000
C (total)	20,000	7,000-500,000	480	29,400
Ca	15,000	700-500,000	41,000	66,000
Mg	5,000	400-9,000	23,000	14,000
K	14,000	80-37,000	21,000	20,000
Na	5,000	150-25,000	23,000	5,700
Mn	1,000	20-10,000	950	770
Zn	90	1-900	75	95
Mo	1.2	0.1-40	1.5	2
Ni	50	2-750	80	52
Cu	30	2-250	50	33
N	2,000	200-5,000	25	470
P	800	35-5,300	1,000	670
S (total)	700	30-1,600	260	2,200

3.6 Particle and Bulk Density

Particle density (ρ_σ) is mass of solids (M_s) per volume of solids (V_s).
$\rho_\sigma = M_s/V_s$

In most mineral soils the mean density of the particles is about 2.6-2.7 gm/cm^3 (or 2600 - 2700 kg/m^3). Soils with a high content of iron oxides and various heavy minerals have a particle density of 5.2-5.3 gm/cm^3, while soils with high organic matter content can have a particle density as low as 1.3 gm/cm^3.

Bulk density (ρ_b) is the mass of solids (M_s) per total soil volume (V_t).
$\rho_b = M_s / V_t$
$\rho_b = M_s / (V_s + V_a + V_w)$
V_s=volume of solids; V_a=volume of air; V_w=volume of water
Bulk density is always smaller than rs. Since in a general case pores constitute half the volume, rb is about half ofrs, namely 1.3-1.35 g/cm3 (or 1300-1350 kg/m3).

4.0 Conclusion

Soil is made up of an extensive variety of substances, minerals, and rocks. These substances can be categorised into four main groups. These groups are organic materials, inorganic materials, air, and water

5.0 Summary

Because soils develop under a variety of conditions, the soil in one location can be very different from the soil in another location. In order to understand soil, and how one soil differs from another, geologists look at and measure the soils properties.

6.0 Self-Assessment Exercise

1. Briefly describe the soil components.
2. Explain how organic matter and microorganisms influence soil fertility.
3. Discuss the importance of knowledge of the soil component to a farmer who wants to undertake large-scale crop production.

7.0 References/Further Reading

Driessen, P.*et al.*(2001). Lecture Notes on the Major Soils of the World. Rome: FAO.

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