COURSE GUIDE

SLM 503
SOIL PHYSICS

Course Team

Dr. Aisha Abdulkadir (Course Developer/Writer) - ABU Zaria
Prof. Grace E. Jokthan (Programme Leader) - NOUN
Dr. Sanda Ahmad Rabo (Course Editor) - KSUST, Aleiro
Dr. Aliyu Musa (Course Coordinator) - NOUN

NATIONAL OPEN UNIVERSITY OF NIGERIA

National Open University of Nigeria
Headquarters
University Village
Plot 91, Cadastral Zone
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

Printed 2024

ISBN: 978-978-058-894-6

CONTENTS PAGE

INTRODUCTION..iv
WHAT YOU WILL LEARN IN THIS COURSE iv
COURSE AIM..v
COURSE OBJECTIVES...vi
WORKING THROUGH THIS COURSE..vi
COURSE MATERIALS...vi
STUDY UNITS vi
TEXT BOOKS AND REFERENCES.. viii
ASSESSMENT.. viii
TUTOR-MARKED ASSIGNMENT viii
FINAL EXAMINATION AND GRADING..ix
SUMMARY..ix

INTRODUCTION

Soil Physics is a branch of soil science that deals with soil physical properties as well as measurements, prediction and control of the physical processes taking place in the soil. The fundamental study of soil physics and physical measurements aims at achieving the basic understanding of the mechanisms governing the behavior of the soil and effects of different management practices these soil physical properties. Soil physical processes greatly influences the chemical and biological processes of a soil systems. For a soil to be healthy, its physical, chemical and biological functioning must be maintained at an optimal and balanced level. Soil physical properties that are crucial to the overall soil health function include the porosity, moisture content and moisture transmission within the soil that aids other chemical and redox reactions as well as microbial activities. By the end of this course, we shall take you through the important physical properties and processes in the soil that drives a healthy soil function.

WHAT YOU WILL LEARN IN THIS COURSE

This course carries two credit units.

This course guide tells you briefly what to expect from reading this course material. The study of Soil Physics consists of two aspects. The physical aspects of the soil such as soil texture, soil structure, surface area and the hydraulic aspect which deals with soil water retention, water flow within soil spaces and water cycles. The soil is composed of solid particles and air spaces (which may be saturated with water, or air or both water and air). The proportion of soil particles and their configuration or orientation defines how the spaces within a soil will be, which will further drive the processes (physical, chemical and biological) that occurs in the soil.

A soil with good proportion of primary particles such as loamy soil is described to be good for agricultural crop production. A well-structured soil is also needed for good root growth and optimum crop production. A soil with adequate surface to provide for chemical reaction and water absorption will be examined within this course. Soil properties may vary within space and time. The extent of variability of soil properties will be discussed.

Water is a very important aspect of crop production and possesses properties that determine its behavior in the soil. Soil water is often expressed in volume- or mass- basis. Soil water is often measured to know the amount that was used up for evapotranspiration as crop water use. These measurements may be either in the field (in-situ) or in the laboratory which will also be discussed.

Water flows through the soil pore spaces. The flow could be under completely water saturated pores or under unsaturated pores. The Darcy's law is used to describe the ease with which water moves through the soil which is known to be the hydraulic conductivity or permeability. Water movement through the soil could be either through a homogeneous single layer of a heterogeneous layered soil. The nature of the soil layers defines the ease at which water will pass through them and will be discussed.

Soil water passes through the soil and runs beyond the root zone by gravitational force. Such water is defined as drainage water or drained water and is not available for plant use. When drainage stops, some amount of water is held in the soil pores. This water content is said to be at field capacity and is available for plant use. When plants continue to use the water via evapotranspiration, the water held in the soil continues to reduce until it reaches a point where water cannot be extracted by the plants. The water is said to be at permanent wilting point and is not available for plant use. The graphical relationship between soil water at different suctions or regimes is referred to as the soil moisture retention curve. Soil water is held in the pores under different matric potential energy or suction. Furthermore, the phenomenon of hysteresis shows that differences in the moisture retention curve during a wetting and drying cycle of the soil, which will be discussed in this course.

The soil, plant and atmosphere systems have a connection on how water passes through each section as driven by certain energy potential. Water passes through the plants from the soil and back to the atmosphere. This shows the water cycle and the components of the water or hydrologic cycle. Water that drains beyond the root zone joins the ground water. When drainage becomes excessive, it leads to loss of water e.g in porous sandy soils. When the soil is poor in drainage e.g clay soil, water will be logged and also cause a problem of water logging. Soils that are poorly drained may need to be artificially drained although they are suitable for rice production. This will all be discussed in this course.

COURSE AIM

The course aims to provide a good understanding of soil physical properties and processes as influenced by soil management practices. This knowledge will be geared towards proper soil use through irrigation and drainage practices, tillage, soil and water management etc, for sustainable crop production.

COURSE OBJECTIVES

After going through this course, you should be able to:

- Understand soil physical properties and their variability is space
- Know the water flow in saturated and unsaturated soils
- Soil water retention and the concept of hysteresis
- understand field water cycle
- Appreciate know the concept of water continuum in soil-plant-atmosphere system
- Identify that soil drainage occurs as well as in ground water drainage.

WORKING THROUGH THIS COURSE

This course has been carefully put together to prepare the reader with the basic concepts of soil physical properties. It is an introductory course that ensures that concepts were explained adequately with illustrations as diagrams, tables and figures, where necessary, to describe and show the processes that occurs and the mechanisms that drive the system. You are advised to spend good time to study the work and ensure that you attend tutorial sessions where you can ask questions and compare your knowledge with that of your classmates.

COURSE MATERIALS

You will be provided with the following materials:

- Course guide
- Study Units.

In addition, the course comes with a list of recommended text books which are not compulsory for you to acquire or read, but are essential to give you more insight into the various topics discussed.

STUDY UNITS

The course is divided into 11 units. The following are the study units contained in this course:

Module 1

Unit 1 Soil Physical properties
Unit 2 Spatial variability of soil properties

Module 2

Unit 1	Soil water
Unit 2	Flow of water in saturated and unsaturated soils and Darcy's laws
Unit 3	Flow of water in heterogeneous layered medium
Unit 4	Diffusivity
Unit 5	Soil moisture retention characteristics
Unit 6	Hysteresis

Module 3

Unit 1	Field water cycle
Unit 2	Soil plant atmosphere continuum.
Unit 3	Drainage and Ground water drainage

Module 1
In unit one you will be taken through the different soil physical properties such as soil texture and types, soil structure and the types that exist, physical composition of the soil and the specific surface area of soils. In the same unit, you will also learn about the physical composition of soils and some basic relationships that exist between them and some worked examples. In unit two, you will be taken through the definition of spatial variability of soil properties and the extent for spatial variability (small or large).

Module 2
In unit one, you will be taken through the definition of soil water, its properties and measurements in soil. You will also understand the concept of soil water content and the forms in which it is expressed. Unit two will introduce you to the flow of water in saturated and unsaturated soil. You will understand the Darcy's Law and some basic calculations on hydraulic conductivity.

In unit three, you be taken through the concept of flow of water in a homogeneous or uniform layer of soil and in a layered or heterogeneous soil column. In Unit four, you will be taken through the definition of diffusivity on how particles or heat can easily spread following a particular concentration gradient. You will also learn the importance of diffusivity and the factors that control it. In unit five, you will be taken through the soil water retention characteristics and factors that affect soil water retention. You will also learn the importance of soil water regimes in agricultural production. Unit six, you will be taken through the phenomenon of hysteresis. You will also learn about the factors that affect the shape of the moisture curve during wetting and drying cycles.

Module 3

In unit one, you will learn about the hydrologic cycle and its components that make up the water balance equation. In unit two, you will be taken through the concept of Soil-Plant-Atmosphere- continuum (SPAC) and the different points of water flow within the SPAC. You will also learn about actual and potential evapotranspiration in crop production for proper water management and factors that affect evapotranspiration. In unit three, you will learn about water drainage and the different types of drainage and why it is important in the soil-water system. You will also learn the benefits and detrimental effects of artificial drainage.

TEXT BOOKS AND REFERENCES

Brady, N. C. and Weil, R. R. (2008). The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey.

Six, J., Elliott, E. T. and Paustian, K. (2000). Soil structure and organic matter: II A normalized stability index and the effect of mineralogy. *Soil Science Society of America Journal,* 64:1042-1049.

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press.

Hirschfelder, J.; Curtiss, C. F.; Bird, R. B. (1954). Molecular theory of gases and liquids. New York: Wiley.

Smith, W. F. (2004). Foundations of materials, science and engineering (3rd ed.). McGraw-Hill. Welty, J. R.; Wicks, C. E.; Wilson, R. E.; and Rorrer, G. (2001). Fundamentals of momentum, heat and mass transfer. Wiley.

ASSESSMENT

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

TUTOR-MARKED ASSIGNMENT

The TMA is the continuous assessment component of your course. It accounts for 30% of the total score. The TMAs will be given to you by your facilitator and you will return it after you have done the assignment.

FINAL EXAMINATION AND GRADING

This examination concludes the assessment for the course. It constitutes 70% of the whole course. You will be informed of the time for the examination.

SUMMARY

This course intends to provide you with the basic knowledge of soil physical and hydraulic properties. By the end of this course you will be able to answer the following questions.

- What is soil texture, soil structure, and surface area of soils?
- Discuss the physical composition of soil and different types of soil textures and soil structures.
- Discuss on the different types of water flow in the soil system• Explain the flow of water in homogeneous and heterogeneous/layered soils.
- Discuss diffusivity and its importance.
- Describe soil water retention and factors that affect it.
- Discuss the concept of hysteresis and the reasons that makes it to occur
- Describe and explain the hydrologic cycle and its components.
- Describe types of field drainage and its importance
- Discuss the benefits and demerits of artificial drainage system

We wish you success in this course and hope that you will have a better understanding of the soil physical and hydraulic properties for good water management and better crop production.

MAIN COURSE

CONTENTS

Module 1

Unit 1 Soil Physical Properties
Unit 2 Spatial variability of soil properties

Module 2

Unit 1 Soil water
Unit 2 Flow of water in saturated and unsaturated soils and Darcy's laws
Unit 3 Flow of water in heterogeneous layered medium
Unit 4 Diffusivity
Unit 5 Soil moisture retention characteristics
Unit 6 Hysteresis

Module 3

Unit 1 Field water cycle
Unit 2 Soil plant atmosphere continuum
Unit 3 Drainage and Ground water drainage

MODULE 1

Unit 1 Soil Physical Properties
Unit 2 Spatial variability of soil properties

UNIT 1 SOIL PHYSICAL PROPERTIES

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Soil Texture
3.1.1 Soil Textural classes
3.2 Structure of mineral Soils
3.2.1 Types of Soil Structure
3.2.2 Description of soil structure in the field
3.3 Surface area of soil minerals
3.4 Physical composition of soil
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

Soil physical properties profoundly influence how soils function in an ecosystem and how they can best be managed. Success or failure of both agricultural and engineering projects often hinges on the physical properties of the soil used. The occurrence and growth of many plant species are closely related to soil physical properties, as is the movement over and through soils of water and it dissolved nutrients and chemical pollutants.

The physical property to be discussed in this unit relate to the solid particles of the soil and the manner in which they are aggregated or arranged.

If we think of a soil as a house, the primary particles are the building blocks from which the house is constructed. Soil texture describes these sizes of the soil particles. In building a house, the manner in which the building blocks are put together determines the nature of walls, rooms, and passageways. Organic matter and other substances act as cement between individual particles, encouraging the formation of clumps or aggregates of soils. Soil structure describes the manner in which soil particles are aggregated. This property therefore, defines the nature of the system of pores and channels in the soil.

Soil structure helps determine the ability of the soil to hold and conduct water and air necessary for sustaining life. This property also determine how soil behave when manipulated by tillage through its influence on the movement of water through and off the soil. Soil structure also exert considerable control over the destruction of soil itself by erosion because a weakly structured soil is vulnerable to degradation by water erosion because the soil particles (building blocks) are weakly held together.

2.0 OBJECTIVES

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

- Define soil structure.
- Know the various types of soil structures.
- Describe soil structure in the field.

3.0 MAIN CONTENT

3.1 Soil Texture

Texture refers to the relative proportions of particles of various sizes such as sand, silt and clay in the soil. The proportions of the separates in classes commonly used in describing soils are given in the textural triangle shown in Figure 1. In using the diagram, the points corresponding to the percentages of silt and clay present in the soil under consideration are located on the silt and clay lines respectively. Lines are then projected inward, parallel in the first case to the clay side of the triangle and in the second case parallel to the sand side. The name of the compartment in which the two lines intersect is the textural class name of the soil in question. For examples a soil containing 15% clay, 20% silt and 65% sand is sandy loam and a soil containing equal amounts of sand, silt and clay is clay loam.

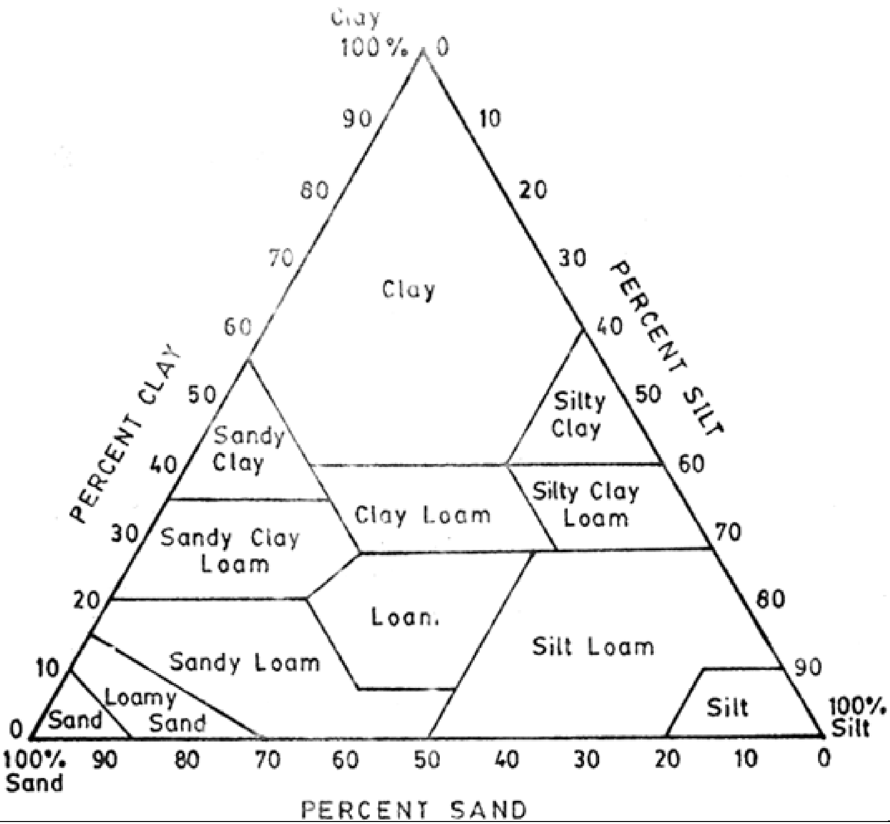


Figure 1: Soil textural triangle

The percentages of sand, silt and clay in a soil could be determined in a soil laboratory by two standard methods - hydrometer method and pipette method. Both methods depend on the fact that at any given depth in a settling suspension the concentration of the particles varies with time, as the coarser fractions settle at a faster rate than the finer fractions. Thus, the soil textural name can be known once the proportions of the particles sizes are determined in the laboratory

3.1.1 Soil Texture classification

The primary particles of soil can be classified from the sizes of the separates such as their diameter. The most common classification by the United States Department of Agriculture (USDA) is given in Table 1.
Table 1: Soil separates and their equivalent diameters

Soil Separates		Equivalent diameter size (mm)
Gravel		>2
Sand	Very Course	1-2
	Course	0.5-1
	Medium	0.25-0.5
	fine	0.1-0.25
	Very fine	0.05-0.1
Silt		0.002-0.05
Clay		<0.002

3.2 Structure of mineral Soils

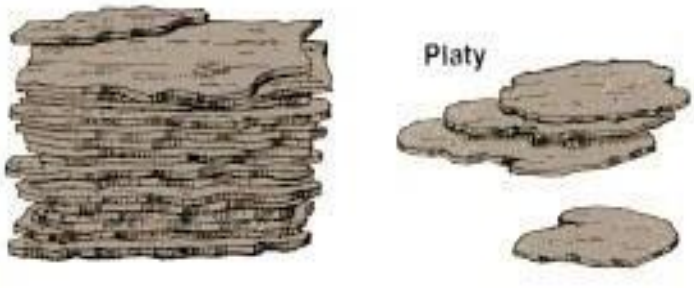
The term soil structure relates to the arrangement of primary soil particles that is sand, silt, clay and organic matter in soil. The particles become aggregated due to various forces and at different scales to form distinct structural units called peds or aggregates. When a mass of soil is excavated and gently broken apart, it tends to break into peds because particles within a ped or aggregate are more strongly attracted to one another than to the particles of the surrounding soil. Although, aggregate and ped can be used synonymously, the term ped is most commonly used to describe the large-scale structure, evident when observing soil profiles and involving structural units which range in size from few mm to about 1m. At this scale, the attraction of soil particles to one another in pattern that define structural units is influenced mainly by such physical processes as freeze-thaw, wet-dry, shrink-swell, the penetration and swelling of plant roots, the burrowing of soil animals, and the activities of people and machine.

3.2.1 Types of Soil Structure

Many types or shapes of peds occur in the soil. Some soil may exhibit a single grained structural condition in which particles are not aggregated. The loose sand in wind-blown dunes or loose dust accumulations such as freshly deposited loess is example of single grain structural condition. Some soils such as clay sediments occur as large, cohesive masses of material and are described as exhibiting a massive structural condition. However, most soils exhibit some type of aggregation and are composed of peds that can be characterized by their shape or type, size, distinctiveness or grade. The four principal shapes of soil structures are:

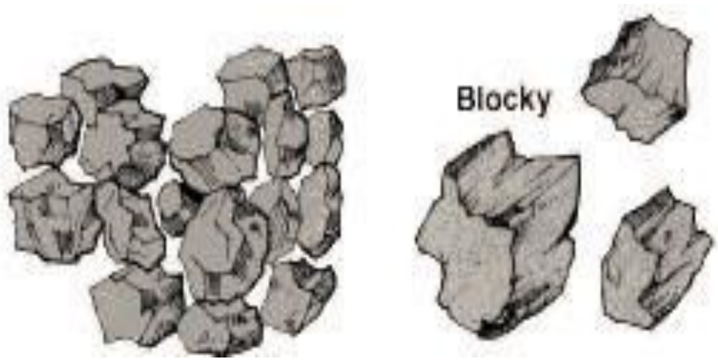
Platy structure

Are characterized by thin horizontal peds or plates, may be found in both surface and subsurface horizons. In most instances the plates have developed as a result of soil forming processes. However, unlike other structure types, platy structure may also be inherited from soil parent materials, especially those laid down by water or ice. In some cases compaction of clayey soils by heavy machines can create platy structure.



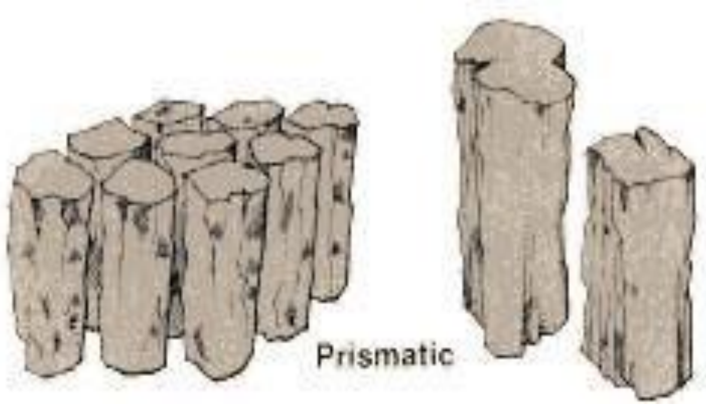
Blocky structures

Peds are irregular, roughly cube-like and range from about 5-50mm across. The individual blocks are not shaped independently, but are molded by the shapes of the surrounding blocks. When the edges of the blocks are sharp and the rectangular faces distinct, the subtype is designated as *angular blocky*. When some rounding has occurred, the peds are referred to as *sub- angular blocky*. These types are usually found in B- horizons, where they promote drainage aeration, and root penetration.



Columnar and prismatic structure

These are characterized by vertically oriented prisms of pillar like peds that vary in height among different soils and may have a diameter of 150mm or more. The columnar structure which has pillars with distinct rounded tops is mainly found in sub-soils high in sodium. When the tops of the prisms are relatively angular and flat horizontally, the structure is designated as prismatic. Both prisms like structures are often associated with swelling types of clay. Prismatic structure commonly occurs in subsurface horizons in arid and semiarid regions and, when well developed, provides a very striking feature of the profile. In humid regions, prismatic structures sometimes occur in poorly drained soils and in fragipans.



Granular

Granular structures consist of spheroidal aggregates that may be separated from each other in a loosely packed arrangement. They typically ranged from less than 1 to as large as 10mm in diameter. In reference to this type of structure, the term aggregates used more commonly than ped. Granular structure characterizes many surface soils (usually A horizons), particularly those high in organic matter. Consequently, this is the principal type of soil structure affected by management. Granular aggregates are especially prominent in grass land soils and in soils that have been worked by earth worms.

3.1.2 Description of soil structure in the field

In describing soil structure, soil scientist need to note not only the type (shape) of the structural ped present, but also the relative size (fine, medium, coarse) and degree of development or distinctness of the ped (grades such as strong, moderate or weak). Generally the structure of a soil is easier to observe when the soil is relatively dry. When wet, structural peds may swell and press closer together making the individual peds less well defined. Observation can be subjective but a well aggregated soil is felt with the hands and fingers. If a slight force is applied to the ped and it crumbles easily, it is described as a weak or poor structure. Meanwhile, if a greater force is used between the fingers and the ped/aggregate and it takes a little time to disintegrate, it is then described as moderately structured. Large forces used on a ped that is between the fore finger and index finger or within the palm of the hands, and the ped withstand the force and did not crumble, then it is described as well-aggregated. These are more desirable for a soil to withstand the forces of water erosion and tillage equipment under crop production.

3.3 Surface area of soil minerals

The specific surface area of soils and soil minerals is typically expressed as surface area per unit mass of solid (in units of square meters per kilogram; m^2/kg or cm^2/g). The specific surface area of soils and soil constituents can range from less than 1×10^3 m^2 kg.

Specific surface area of a soil sample is combined surface area of all the particles in the sample, as determined by some experimental technique and expressed per unit mass of the sample, mostly in m^2 g^{-1}. As its definition implies, term “specific surface area” is an operational concept. Specific surface area can be determined by calculation and depends on shape of soil particle. For example, if spherical (r = radius and ρ = density of particle)

Surface area (a) = $4\pi r^2$ (Equation 1)
Mass (m) = $\rho V = \rho[4\pi r^3/3]$ (Equation 2)

Sample question

Given a silt particle with a diameter of 0.002mm, calculate the specific surface area of the particle. Assume a particle density of 2.6 g/cm^3

Solution:

Diameter of particle =0.002 mm = 0.0002 cm

Therefore, radius of particle =0.0002 cm divided by 2= 0.0001cm Thus, $3/(2.6 \text{ g cm}^{-3} \times 0.0001 \text{ cm}) = 11538.5 \text{ cm}^2/\text{g}$ or $11.5 \times 10^4 \text{ cm}^2/\text{g}$
Table 2 gives the specific surface are of mineral soil primary particles and shows the surface area of soil particles to increase with decreasing particle size. Thus clay particles have higher surface area than all the soil separates. Surface area of soil affects its physical and chemical properties and is largely determined by amount of clay present in soil.

Sample exercise

Use the sample question above to calculate the specific surface area of a clay particle. Table 2: Surface area of soil particles

Particle	Effective diameter (cm)	Mass (g)	Area (cm^2)	Specific surface area ($cm^2\ g^{-1}$)
Gravel	2×10^{-1}	1.13×10^{-2}	1.3×10^{-1}	11.1
Sand	5×10^{-3}	1.77×10^{-7}	7.9×10^{-5}	444.4
Silt	2×10^{-4}	1.13×10^{-4}	1.3×10^{-7}	11.1×10^{4}
Clay	2×10^{-4}	8.48×10^{-15}	6.3×10^{-8}	7.4×10^{6}

3.4 Physical composition of soil

Soil is composed of three major components which are solid, water and air and they exist in different proportions at different times. Although the solid fraction may remain the same, the proportion of water and air in the pore spaces depends on the prevailing conditions. A representative cultivated loam soil contains approximately 50% solid particles (sand, silt, clay and organic matter), 25% air and the rest 25% water (Figure 2). 50% of the soil consists of the solid fraction which contains the rock minerals and biological matter or organic matter (approximately 5%).

Some basic relationship exists between the different soil components which is very important in Soil Physics.

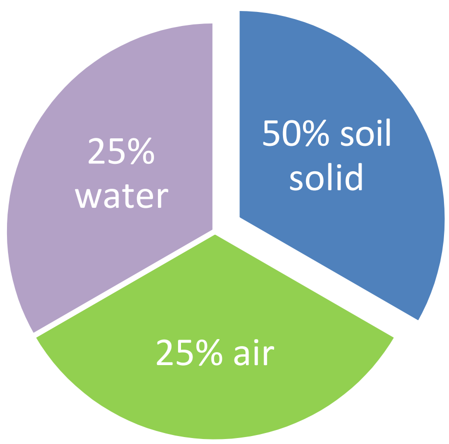
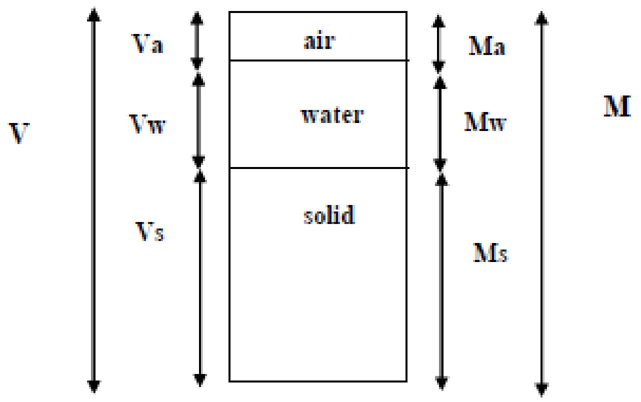


Figure 2: Physical composition of soils



Some basic relationships between soil compositions

$$V = Va + Vw + Vs$$

Va= Volume of air; Vw= Volume of water; Vs = Volume of solid; V=total volume of soil

$$M = Ma + Mw + Ms$$

Ma= mass of air; Mw= mass of water; Ms= mass of solid; M = total mass of soil

Bulk density (ρd) is expressed as the mass of dry soil per unit total soil volume i.e.

$$\rho d = \frac{Ms}{V}$$

Particle density (ρp) is expressed as

$$\rho p = \frac{Ms}{Vs}$$

and is approximately 2.65 g cm^{-3} for most mineral soils

Total porosity in percent (F) relates to bulk density and particle density as

$$F = 1 - \frac{\rho d}{\rho p}\ X\ 100$$

Volumetric water content (Θv) $\Theta v = \frac{Vw}{V}$ given as v/v

Gravimetric water content (Θg) is expressed as $\Theta g = \frac{Mw}{M}$ given as g/g

Both moisture contents are related as

$$\Theta v = \Theta g \times \rho d$$

Note that a wet soil has all the voids or pore spaces filled with water. A soil core is used to collect undisturbed soil sample. A soil core is a concentric ring that is inserted into the soil to remove a known volume of soil.

Sample Question
An undisturbed soil core is 10 cm in diameter and 10 cm in length. The wet soil mass is 1320 g. After oven drying the core, the dry soil mass is 1100 g. The mineral density of the soil is 2.6 g cm^{-3}.
Calculate:

a. Dry soil bulk density b. Water content on a mass basis c. Water content on a volume basis d. Total porosity

Solution
a) Dry bulk density (Bd) = Ms/V Mass of wet soil (M)= 1320g
Mass of dry soil (Ms)= 1100g Height of core = 10cm
Diameter of core=10cm; radius=d/2 = 10/2 = 5cm density of water =1g cm^{-3}
But
Mw=wet soil mass – dry soil mass Mw= 1320g - 1100g =220g
$V=\pi r^2 h$
V= 3.142 x (5^2) x 10 = 785.75cm^3
Thus Bd = 1100/(3.143 x 25 x 10) =1.40g cm^{-3}
b) Water content on a mass basis

$$\theta g = Mw/Ms$$

$$\theta g = \frac{220g}{1100g} = 0.2 \quad \text{or} \quad 20\%$$

c) $\theta v = \frac{Vw}{V}$

$$\theta v = \frac{220cm^3}{785.75cm^3}$$

$= 0.28$ or 28%

d) $F = 1 - \frac{\rho d}{\rho p} X\ 100$

Substituting the values of bulk density and particle density.

$$F = 1 - \frac{1.4}{2.6} X\ 100$$

F=46%

4.0 CONCLUSION

Soil structure describes the manner in which soil particles are aggregated. Some soil exhibit a single grained structural condition in which particles are not aggregated. However, most soils exhibit some type of aggregation and are composed of peds.

5.0 SUMMARY

In this unit, we have learnt that:

- Soil structure is the arrangement of soil particles into distinct units called peds or aggregates.
- Many types or shapes of peds occur in the soil, often within different horizons of a particular soil profile.
- A well aggregated soil can withstand the forces of water erosion and tillage activities.
- Soil aggregates can be simply described on the field by applying pressure on the ped between the fore finger and the index finger or within the palm.

6.0 TUTOR-MARKED ASSIGNMENT

- Define soil texture, structure and specific surface area of minerals.
- Describe the various types of soil structure.
- List 4 textural classes
- How do you describe the soil structure on the field?
- An undisturbed soil core has a diameter of 10 cm and is10 cm in length. The wet soil mass is 1350 g. After oven drying the core, the dry soil mass is 1140 g. The mineral density of the soil is 2.65 g cm^{-3}.
- Calculate: (a) Dry soil bulk density (b). Water content on a mass basis (c). Water content on a volume basis (d). Total porosity

7.0 REFERENCES/ FURTHER READINGS

Brady, N. C. and Weil, R. R. (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey.

Six, J., Elliott, E. T. and Paustian, K. (2000). Soil structure and organic matter: II A normalized stability index and the effect of mineralogy. *Soil Science Society of America Journal,* 64:1042- 1049.

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press.

UNIT 2 SPATIAL VARIABILITY OF SOIL PROPERTIES

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Spatial variability of soil properties.
3.1.1 Small scale soil variability
3.1.1 Medium scale soil variability
3.1.1 Large scale soil variability
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

One area of great concern in Soil Science is variability of soil properties within the soil system. Anyone who works intimately with soil soon realizes that soils are anything but uniform. Soil properties are variable at all spatial and time scales. At spatial space, soil can vary within few centimeters to meters within the same soil series and area. In this Unit, we will consider soil variations occurring across distances having geographic meaning for land management from few meters to several kilometers.

2.0 OBJECTIVES

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

- Know that variations exist among soil properties with respect to space.
- The various scales at which soil variability exist.

3.0 MAIN CONTENT

3.1 Spatial variability of soil properties

This refers to the variations that exist among soil properties with respect to space. Factors responsible for the spatial variability of soil properties at large scale (regional differences) are those that influence soil formation and these include: climate, parent material, organisms, topography and time. However, small scale soil variability may result from past soil management practices. This is because soil has physical properties that are dynamic with time as influenced by management practices such as tillage and addition of organic matter. These variations may exist as altered forms of the previous form of the particular soil property in question.

3.1.1 Small scale soil variability

Soil properties are likely to change markedly across small distances. At this scale, variations most often relate to small changes in topography and thickness of parent material layer or to effects of macro or microorganisms (e.g the effect of individual trees or past human management). The small scale variability may be difficult to measure and not readily apparent to the casual observer. In some cases, the height or vigor of vegetation reflects the subsurface variability of soil properties, i.e whether the soil is fertile or less fertile, or whether the soil is deep or roots are restricted by the presence of hard pan or impermeable layer. In other cases, the changes in soil properties are detected by analyzing soil samples taken from many evenly spaced auger points made throughout the plot of land in question.

3.1.1 Medium scale soil variability

For many soil properties, variability at this scale is related primarily to differences in a particular soil forming factor, such as soil topography or parent material. If one understand the influence of these soil forming factors in a landscape, it is often possible to define set of individual soils that tend to occur together in sequence across the land. Identifying one member of the set makes it possible to predict soil properties in the landscape position occupied by other members of the set.

3.1.1 Large scale soil variability

At a very large scale, soil patterns are principally the result of climate and vegetation patterns and secondary related to parent material differences. Although, it is often useful to general regional soil characteristics, it must be remembered that much localized variation exist within each regional group. These are variations that occur in distances of kilometers.

4.0 CONCLUSION

Soil properties (physical, chemical or biological) are variable at all scales and these variations may be attributed to past management practices or differences in a particular soil forming factors (parent material, relief, time etc). The extent to which each factor was exploited determines the scale of the variability within a soil.

5.0 SUMMARY

In this unit, we have learnt that:

- Soil properties vary in space from a few meters to kilometers. Spatial variability of soil properties at large scale is influenced by soil forming factors while at small scale, variability may result from past/previous soil management practices carried out on it.

6.0 TUTOR-MARKED ASSIGNMENT

- What do you understand by soil variability?
- Explain the various scales at which soil spatial variability exist.
- What causes variability of soil at the different scales?

7.0 REFERENCES/ FURTHER READINGS

Brady, N. C. and Weil, R. R (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey.

MODULE 2

Unit 1 Soil water
Unit 2 Flow of water in saturated and unsaturated soils and Darcy's laws
Unit 3 Flow of water in heterogeneous layered medium
Unit 4 Diffusivity
Unit 5 Soil moisture retention characteristics
Unit 6 Hysteresis

UNIT 1 SOIL WATER

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Definition of soil water
3.1.1 Properties of water
3.1.2 Soil water content
3.1.2 Measurement of soil water content
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

We are all familiar with water. We drink it, wash with it, and swim in it. But water in the soil is something quite different from water in a drinking glass. Water is a vital component of every living thing. Therefore all living things in the soil like plants roots, soil organisms and human require water. A wide range of physical, chemical and biological processes are promoted by water. Hence, the hydrosphere (water world) has a very strong influence on the pedosphere (world of soil). Soil is a major reservoirs of fresh water and it account for more than what is obtainable in rivers and streams. In the soil water is intimately associated with soil particles and
this interaction between water and soil solid changes the behavior of both. Water causes soil particles to swell and shrink, to adhere to each other, and to form structural aggregates. Water participate in innumerable chemical reactions that release or tie up nutrient in the soil, create acidity or alkalinity, and wear down minerals so that their constituent elements eventually contributes to the saltiness of the ocean or the soil itself.

2.0 OBJECTIVES

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

- Define soil water.
- State the properties of water.
- Describe ways of expressing soil water content.
- Describe the various methods of measuring soil water content.
- Roles of water in the soil

3.0 MAIN CONTENT

3.1 Definition of soil water

Soil water in a descriptive term would be called soil solution because it contains solute. Unlike the bulk water in rivers and lakes, soil water is expressed with respect to its occurrence in soil porous media and it has free energy status and potential that makes it different in characteristics from that of free water. For example, the soil water potential is considered with respect to free water body as its reference state. Diffusion coefficient of soil water also differ from that of water in a free state. Soil water is not free because of the presence of solutes and its association with the soil solid matrix that makes it have energy states.

3.1.1 Properties of water

The ability of water to influence so many soil processes is determined primarily by the structure of the water molecule. This structure also is responsible for the fact that water is mainly present as a liquid, not gas, at temperature found on the earth. Water is a simple compound, its individual molecules containing one oxygen atom and two hydrogen atoms. The elements are bonded together covalently, each hydrogen atom sharing it single electron with oxygen. The properties that influences or control its relation with soil are:

Polarity

This is the most important as far as physical behavior of water is concerned. Water exhibits polarity due to the structural arrangement of atoms within the molecule. The atoms are not symmetrically arranged in the water molecule. Instead of a linear arrangement (H...O…H), the hydrogen atoms are attached to the oxygen atoms on a V-shaped arrangement at an angle of 105°. The charges became unevenly distributed. Hence the side on which the hydrogen is located tends to be electropositive and the opposite side tends to be electronegative Figure 3.

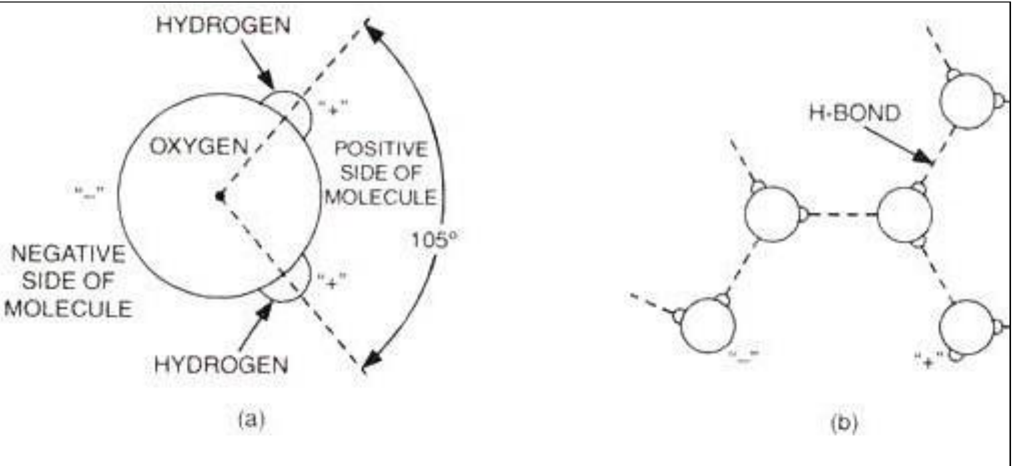


Figure 3 (a) Showing the V-shaped arrangement of hydrogen and oxygen atoms in water
molecule giving it the polar structure (b) Showing the two hydrogen bonds to an oxygen atom

Hydrogen bonding

This type of bond accounts for the polymerization of water due to attraction of water molecules themselves to each other. A hydrogen atom of one water molecule is attracted to the oxygen end of a neighboring water molecule. Thereby bond between the forming a low-energy bond between the two molecules. The importance of hydrogen bonding with respect to water include high boiling point, high specific heat and high viscosity of water compound compared to other hydrogen-containing compounds.

Surface tension

This property is commonly evident at liquid-air interfaces as a result from the greater attraction of water molecules for each other than for the air above. The net effect is an inward force at the surface that causes water to behave as if its surface were covered with a stretch elastic membrane. Because of the relatively high attraction of water molecules to each other, water has a high surface tension. Surface tension is an important factor in the phenomenon of capillarity, which determines how water moves and is retained in the soil.

Cohesion versus adhesion

Hydrogen bonding accounts for two basic forces responsible for water retention and movement in soils. The attraction of water molecules for each other is termed cohesion and the attraction of water molecules for solid surfaces is termed adhesion. By adhesion, some water molecules are held rigidly at the surfaces of soil solids. By cohesion other water molecules farther removed from the solid surfaces. Cohesion and adhesion also make possible the property of plasticity possessed by clays.

Hydration

Polarity also explains why water molecules are attracted to electro-statically charged ions and to colloidal surfaces and also encouraged the dissolution of salt in water since the ionic components have greater attraction for water molecules than for each other.

3.1.2 Soil water content

This is the amount of water present in a given quantity of soil. It is expressed basically in three
(3) ways. These are:

By weight or mass basis (ϴg)

This is the mass of water associated with a given mass of soil that is mass of water by mass of soil. This is usually expressed as gravimetric water/ moisture content (ϴg). It can be expressed in percentage as given in Equation 3:

$$\Theta g = \frac{\text{Mass of water (g)}}{\text{Mass of oven dry soil (g)}} x\ 100 \qquad \text{(Equation 3)}$$

By volume basis (ϴv)

This is the volume of water associated with a given volume of soil that is mass of water by mass of soil. This is usually referred to as volumetric water/ moisture content (ϴv). It can be expressed in percentage as given in Equation 4:

$$\Theta v = \frac{\text{Volume of water (g)}}{\text{Volume of soil (g)}} x\ 100 \qquad \text{(Equation 4)}$$

ϴv= Volume of water (cm^3) / Volume of soil (cm^3)

Conversion of (ϴg) to (ϴv)

Can be written simply as given in Equation 5

$\Theta v = \Theta g * \rho b$ (Equation 5)

By depth basis (ϴh)

Soil water is also expressed in depth basis particularly when amount of water storage is considered. It is denoted by ϴh and usually expressed in length per depth.

$\Theta h = \Theta v * h$

Where Θv = volumetric water content and h = Depth of soil Since
$\Theta v = \Theta g * \rho b$
Therefore, it is written as given in Equation 6
$\Theta v = \Theta g * \rho b * h$ (Equation 6)

3.1.2 Measurement of Soil Water Content

Soil water content can be measured both in field and laboratory using the following methods which may be destructive or non-destructive methods.

***Gravimetric method*:**

This is the direct and standard method of measuring soil water content by which all indirect methods are calibrated. It is a destructive method of measuring soil water content on the field. A sample of moist soil collected with an auger from a certain soil depth and is weighed, and then dried in an oven at a temperature of 105°C for 24 hours, and finally weighed again. The weight loss represents the soil water. The soil moisture is calculated as given in equation 3 to express it in gravimetric terms or as Equation 5 to express it volumetrically.

Caution must be taken so that water is not loss through evaporation if results need to be accurate. The gravimetric method is a destructive method and cannot be automated, thereby making it poorly suited to monitoring changes in soil moisture over several points and time. Several indirect methods are nondestructive, easily automated, and very useful in the field.

Neutron scattering

This is a radiation method and a neutron scattering probe is used which is lowered into the soil via a previously installed access tube, the probe contains a source of fast neutron and a detector for slow neutrons. When fast neutron collide with hydrogen atoms (most of which are part of water molecules), the neutrons slow down and scatter. The number of slow neutrons counted by a detector as counts (for the collisions). Counts are converted to corresponding volumetric soil water contents. This method entails the use of radio-active nuclear atoms and the use is exposed to radiation hazards. Although it is reliable, the method is expensive and requires an experienced technician to handle the probe.

Electromagnetic methods

A widely used electromagnetic method used is time-domain reflectometry (TDR), which measures two parameters: (1) time it takes for an electric impulse to travel down two or three parallel metal transmission rods buried in the soil, and (2) the degree of dissipation of the impulse as it impacts with the soil at the end of the lines. The transit time is related to the soil's apparent dielectric constant, which in turn is proportional to the amount of water in the soil. The

TDR instrument incorporates sophisticated electronics and computer software capable of measuring and interpreting voltage changes over precise pico-seconds time intervals. The instrument is inexpensive and can be used to in most soil types to obtain accurate readings for the entire range of soil water contents.

Capacitance method

In this a capacitance sensor is used to determine the dielectric constant of the soil of the soil by measuring the rate of change of voltage along a thin metal rod embedded in the soil. Because water has a far greater dielectric constant than does mineral soils or air, variations in measured dielectric constant are mainly due to variations in volumetric water content of the soil. Capacitance sensors are less expensive than does the neutron or TDR probes and do not use hazardous radiations as does the neutron probe.
Similarly, there are wide range of simple hand-held moisture meters such as the PMS-hand held meter and Theta Probe that give estimates of soil water in gravimetric or volumetric terms directly, as non-destructive methods of soil water determination. Most often, these are used for pot experiments or at shallow soil measurement depths.

4.0 CONCLUSION

The characteristics and behavior of soil water are very complex. As we have gained more knowledge, however, it has become apparent that soil water is governed by relatively simple, basic physical processes. Soil water is usually expressed in mass, volume or depth basis and remains a very important parameter in several applications on soil water hydrology and irrigation water management.

5.0 SUMMARY

In this unit, we have learnt that:

- Soil water is intimately associated with soil particles and this interaction between water and soil solid changes the behavior of both.
- The ability of water to influence so many soil processes is determined primarily by the structure of the water molecule.
- Soil water content can be measured using direct and indirect methods that could be destructive or nondestructive.
- Soil water is expressed in volumetric or gravimetric basis in soil water applications.

6.0 TUTOR-MARKED ASSIGNMENT

- Define soil water.
- State the properties of water.
- Describe ways of expressing soil water content.
- Describe the non-destructive methods of measuring soil water content.

7.0 REFERENCES/ FURTHER READINGS

Brady.N, C. and Weil, R. R (2008).The nature and properties of soil. Prentice HallUpper Saddle River, New Jersey.

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press.

UNIT 2 FLOW OF WATER IN SATURATED AND UNSATURATED SOILS AND DARCY'S LAWS

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Flow of water in saturated soils
3.2 Flow of water in unsaturated soils
3.3 Darcy's law
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

Movement of water in the soil can occur in liquid or vapor form and can be saturated or unsaturated flow through the soil's porous media. The soil porous media results from the arrangement of soil particles with the cementing agents where large, medium and small pores are formed. Biopores may also be present as a result of the burrowing activities of soil fauna such as earthworms, other types of worms, insects etc. In all cases, water flow on what is called a driving force. If water moves from points A to B, then the force moving the water is said to be the driving force. In all cases, water flow in response to energy gradients, with water moving from a zone of higher to one of lower energy or potential.

2.0 OBJECTIVES

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

- Explain flow of water in saturated soils and unsaturated soils
- State Darcy's law
- Know the principle governing the flow of water in soils.

3.0 MAIN CONTENT

3.1 Flow of water in saturated soils

This type of flow occurs when soil is saturated that is all soil pores (large and small) are filled with water. This type of flow mostly takes place at lower horizons of poorly drained soils, or immediately after heavy rain or irrigation when the pores in the upper soil zones are often filled entirely with water. The flow occurs as a result of differences in hydrostatic pressure head. Saturated flow occurs not only downward the profile. The hydraulic force can also cause horizontal and even upward flow, as occurs when ground water swells up under a stream. The rate of such flow is not quite as rapid and given much focus, since the force of gravity does not assist horizontal flow and hinders upward flow. Water moved downward much more rapidly in sandy loam than in clay loam. On the other hand, horizontal movement was much more evident in clay loam.

3.2 Flow of water in unsaturated soils

This occurs when the soil pores are partially filled with air. This is the most common type of flow for agricultural purposes. Most of the time, water movement takes place when upland soils are unsaturated, that is when the pores are not completely filled with water. In unsaturated soils, the water content and the tightness with which water is held (water potential can be highly variable). This influences the rate and the direction of water movement and also makes it more difficult to measure the flow of water. Here also, the driving force for unsaturated water flow is the differences in water potential. This time however, the difference in matric potential, not gravity, is the primary driving force. This matric potential gradient is the difference in the matric potential of the moist soil areas and nearby drier areas into which water is moving.

3.3 Darcy's law

The quantity of water per unit time (Q/t) that flows through a column of saturated soil can be expressed by Darcy's law, as given in Equation 7: Darcy's law is a generalized relationship for flow in a porous media. It shows the volumetric flow rate as a function of the flow area, elevation, fluid pressure and a proportionality constant. It may be stated in several forms depending on the flow condition. Thus, Darcy's Law states that the velocity of flow of a liquid through a porous medium is proportional to the force causing the flow and equal to the hydraulic conductivity of the medium.

$$\frac{Q}{t} = \frac{\mathrm{AKsat}\,\Delta \mathrm{h}}{L} \qquad \text{(Equation 7)}$$

Where, A is the cross-sectional area of the column through which the water flows, Ksat is the saturated hydraulic conductivity, ΔΨ is the change in water potential between the ends of the column (that is *hin- hout*) and L is the length of the column (Figure 4).

For a given column, the rate flow is determined by the ease with which the soil transmits water (Ksat) and the amount of force driving the water, namely the water potential gradient (Δh/L). By analogy, think of pumping water through a garden hose, with Ksat representing the size of the hose (water flows more readily through a larger hose) and Δh/L representing the size of the pump that drives the water through the hose.

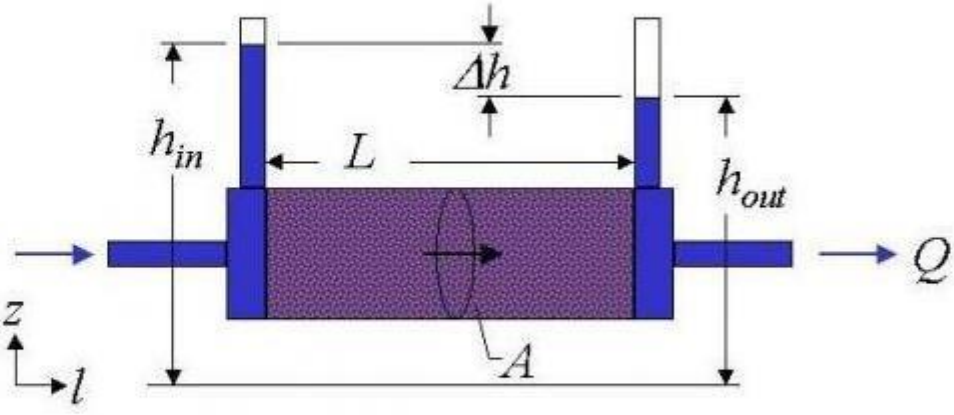


Figure 4: Showing a one-dimensional flow soil column

The units in which Ksat is measured are length/time, typically cm/s or cm/h. The Ksat is an important property that helps to determine how well a soil material will perform in such uses as irrigated cropland, sanitary landfill cover material, waste water storage lagoon lining and septic tank drain.

Both saturated and unsaturated flows in soil can be measured in the field or in the laboratory or with the use of simulation models to estimate the flow.

Darcy's flux
The Darcy's flux (q; cm/s) is defined as
Where q = Q /A (Equation 8)

But q=KΔh/L(Equation 9)

Example 1

A confined aquifer has a source of recharge. K for the aquifer is 50m/day, and n is 0.2. The piezometric head in two wells 1000m apart is 55m and 50m respectively, from a common datum. The average thickness (L) of the aquifer is 30m, and the average width (W) of aquifer is 5km.
Assuming no dispersion or diffusion, calculate
- The rate of flow through the aquifer
- The average time of travel from the head of the aquifer to a point 4 km downstream

Solution
Cross sectional area (L*W) 30(5)(1000m) = 15 x 10^4 m^2 Hydraulic gradient = (55-50)/1000 = 5 x 10^{-3}
Rate of flow for K= 50m/day Q = (50m/day)(75 x 10^1 m^2) = 37, 500m^3/day Darcy's flux q=Q/A (37500m^3/day)/(15 x 10^4 m^2) =

0.25 m/day Seepage velocity Vs = q/n 0.25/0.2 = 1.25 m/day
Time of travel 4 km downstream = T = 4(1000m) /1.25m/day
= 3200 days or 8.77 years

*This example shows that water moves very slowly underground

4.0 CONCLUSION

Two types of water movement within the soil are recognized and in all cases water flows in respond to energy gradients, with water moving from a zone of higher potential to a to one of lower water potential. Saturated flow takes place when soil pores are completely filled with water while unsaturated flow occurs when the larger pores in the soil are filled with air leaving only the smaller pores to hold and transmit water.

5.0 SUMMARY

In this unit we have learnt that:

- Water movement can occur in liquid or gaseous form
- Water moves under saturated and unsaturated soil condition.
- Water flow in soils is governed by a driving force.
- Water moves from a zone of higher potential to a to one of lower water potential

6.0 TUTOR-MARKED ASSIGNMENT

- Explain flow of water in saturated soils and unsaturated soils
- State Darcy’s law
- What is the principle that governs the flow of water in soil?
- What is the nature of the characteristic soil pores during unsaturated flow?
- A confined aquifer has a source of recharge. K for the aquifer is 50m/day, and n is 0.2. The piezometric head in two wells 1000m apart is 60m and 55m respectively, from a common datum. The average thickness (L) of the aquifer is 30m, and the average width (W) of aquifer is 5km. Assuming no dispersion or diffusion, calculate
  - The rate of flow through the aquifer
  - The average time of travel from the head of the aquifer to a point 4 km downstream

7.0 REFERENCES/ FURTHER READINGS

Brady.N, C. and Weil, R. R (2008).The nature and properties of soil. Prentice HallUpper Saddle River, New Jersey.

Manning, J.C. (1997) Applied Principles of Hydrology. Prentice Hall, third edition, 276p.

UNIT 3 FLOW OF WATER IN HETEROGENEOUS LAYERED MEDIUM

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Flow of water in a single column
3.2 Flow of water in heterogeneous layered medium
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

Frequently a soil is employed as a filter, and in preparing a good filter, knowledge of permeability of homogeneous and heterogeneous media is very essential. A medium is homogeneous if the permeability is constant from point to point over medium while it is heterogeneous if permeability changes from point to point in the medium. The permeability is the most important physical property of porous medium, which is a measure of the ability of a material to transmit fluid through it. The application of Darcy’s law enables hydraulic conductivity to be determined. The permeability can be determined or computed from hydraulic conductivity. There is a very strong statistical correlation between porosity and rate of fluid flow in saturated porous media. These suggest that porosity of a material has a great influence on hydraulic conductivity and permeability. Also, the size distribution and percentage of gravel and coarse fraction present are some of the factors that are responsible for variability in hydraulic conductivity.

2.0 OBJECTIVES

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

- Explain the flow of water in a single and heterogeneous layered medium.
- Know how flow of water in a heterogeneous layered medium differ from that of a homogenous one.

3.0 MAIN CONTENT

3.1 Flow of water in heterogeneous layered medium

A homogenous soil layer hardly occurs in nature. In calculation of water flow in soils, there is over simplification of the reality with the assumption of the soil as a homogeneous unit to avoid the accompanying complications of real-time problems. For the Darcy’s law to be applicable, assumptions that the flow is laminar flow as well as the uniformity of pores and hydraulic conductivity is maintained. Thus, the entire soil layer is assumed to be one homogeneous block with similar characteristics within itself. However, soil is a heterogeneous mix up of layers with varied properties and that makes the next section very important to real-life situation.

3.2 Flow of water in heterogeneous layered medium

If layers of beds of porous media of different porosity are considered and it is assumed that each layer is homogeneous and isotropic, then each layer is however, characterized by a different hydraulic conductivity rendering the sequence as a whole heterogeneous. It was found that for horizontal flow, the most permeable unit dominates the system. For vertical flow the least permeable unit dominates the system. Under the same hydraulic gradient, horizontal flow is faster than vertical flow. The rate, magnitude and direction of seepage of water flow in porous media are vital tools in seepage and drainage control in soils. These can be determined by Darcy's law of laminar flow of fluids in porous media. When water flows from a soil of low permeability into a soil of higher permeability, less area is required to accommodate the same quantity of water and lower gradients are needed. If the flow is from high permeability into lower permeability, steeper (or higher) gradient are required and a relatively more area is needed to accommodate the flow. However, fluid flow in homogeneous porous media is generally faster than that of heterogeneous media of similar geometry and grain packing. Thus, layered heterogeneous medium is more appropriate as a protective filter for seepage control.

4.0 CONCLUSION

Soil is heterogeneous in nature and exhibit different flow properties at each point. Permeability from point to point over a homogeneous layered medium is constant while that of heterogeneous layered medium changes from point to point.

5.0 SUMMARY

In this unit, we have learnt that:

- Water flow in homogeneous porous media is generally faster than that of heterogeneous media of similar geometry and grain packing.
- When water flows from a soil of low permeability into a soil of higher permeability, less area is required to accommodate the same quantity of water and lower gradients are needed.

6.0 TUTOR-MARKED ASSIGNMENT

- Differentiate between the flows of water in a homogeneous porous media and that of a heterogeneous layered media.

7.0 REFERENCES/ FURTHER READINGS

Brady, N. C. and Weil, R. R (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey.

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press.

UNIT 4 DIFFUSIVITY

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Diffusivity
3.2 Importance of diffusivity
3.3 Factors affecting diffusivity
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

Diffusion explains the movement of molecules from a region of higher concentration to one of lower concentration. In this unit, we will discuss on how fast or slow the movement of molecules occurs across the concentration gradient.

2.0 OBJECTIVES

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

- Define diffusivity.
- Know the factors affecting diffusivity.
- Know importance of diffusivity in soil processes.

3.0 MAIN CONTENT

3.1 Diffusivity

Diffusivity is a rate of diffusion, a measure of the rate at which particles or heat or fluids can spread. Diffusivity is how easily a particular solute will move in a particular solvent for a particular gradient in concentration. It is also known as diffusion coefficient and is proportionality constant between the molar flux due to molecular diffusion and the gradient in the concentration of the species (or the driving force for diffusion). Diffusivity is encountered in Fick's law which states that:

$$J = -D\frac{dc}{dx} \qquad \text{(Equation 10)}$$

Where

- J = diffusion flux, of which the dimension is amount of substance per unit area per unit time, so it is expressed in such units as mol m^{-2} s^{-1}. J measures the amount of substance that will flow through a unit area during a unit time interval.

- D = diffusion coefficient or diffusivity. Its dimension is area per unit time, so typical units for expressing it would be m^2/s.
- C = (for ideal mixtures) = concentration, of which the dimension is amount of substance per unit volume. It might be expressed in units of mol/m^3.
- x = position, the dimension of which is length. It might thus be expressed in the unit m.

In heat transfer analysis, diffusivity is called thermal diffusivity and is the rate of transfer of heat of a material from the hot side to the cold side - a measure of how quickly a material can absorb heat from its surroundings. However, diffusivity is measured differently for different mediums. In gases, diffusion progresses at a rate of about 5 cm/ min; in liquids, its rate is about 0.05 cm/min; in solids, its rate may be only about 0.00001 cm/min.

For example, if a few crystals of a colored material like copper sulfate are placed at the bottom of a tall bottle filled with water, the color will slowly spread through the bottle. At first the color will be concentrated in the bottom of the bottle. After a day it will penetrate upward a few centimeters. After several years the solution will appear homogeneous. The process responsible for the movement of the colored material is molecular diffusion that often called simply diffusion, which is the thermal motion of all (liquid or gas) particles at temperatures above absolute zero.

3.2 Importance of diffusivity

The slow rate of diffusion is responsible for its importance. In many cases, diffusion occurs sequentially with other phenomena. When it is the slowest step in the sequence, it limits the overall rate of the process. For example, diffusion often limits the efficiency of commercial distillations and the rate of industrial reactions using porous catalysts. It limits the speed with which acid and base react and the speed with which the human intestine absorbs nutrients. The result of diffusion is a gradual mixing of material. In a conductive transient heat transfer process it determines how fast the temperature change inside the body. The meaning can easily be explained with an analogy. Cooling a body is similar to emptying a water tank. If it is higher, then less time is required for the heat to penetrate into the solid. Its significance is also seen for fire protection.

3.3 Factors affecting diffusivity

There are several factors that affect the rate of molecular diffusion especially with respect to the liquid and gas media. Factors that affect the rate of diffusion are:

Temperature
Diffusivity is proportional to absolute temperature i.e. the higher the temperature the faster the rate of diffusion.

Viscosity of the fluid
Diffusivity is inversely proportional to fluid dynamic viscosity, that is to say, the more the viscosity of fluid, the slower the rate at which it diffuses.

Solution concentration and size (mass) of particles
Diffusivity is dependent on solution concentration and weight or size of molecules. The diffusivity of the methane decreases as the loading of the bigger, slower-moving co-adsorbed molecules is increased.

Agitation
In gases and liquids, the rates of these diffusion processes can often be accelerated by agitation. For example, the copper sulfate in the tall bottle can be completely mixed in a few minutes if the solution is stirred. This accelerated mixing is not due to diffusion alone, but to the combination of diffusion and stirring.

Random molecular motions
Diffusion still depends on random molecular motions that take place over smaller distances. The agitation or stirring is not a molecular process, but a macroscopic process that moves portions of the fluid over much larger distances. After this macroscopic motion, diffusion mixes newly adjacent portions of the fluid.

4.0 CONCLUSION
Diffusivity is measured differently for different mediums. The value of diffusivity can be determined from Fick's law. The rate of diffusion in a fluid medium is affected by factors such as temperature, viscousity, agitation, solution concentration and mass of particles and random molecular motion. It is important in industrial chemical processes as well as in biological/human systems.

5.0 SUMMARY
In this unit, we have learnt that:

- Diffusivity is a measure of the rate at which particles or heat or fluids can spread in a medium.
- In heat transfer analysis, is termed thermal diffusivity and is a measure of how quickly a material can absorb heat from its surroundings.
- Diffusivity is dependent on temperature, viscosity of fluid, concentration of solute and random molecular motions.

6.0 TUTOR-MARKED ASSIGNMENT

- Define the term diffusivity
- State Fick's law.
- How does diffusion differ from diffusivity?

7.0 REFERENCES/ FURTHER READINGS

Grathwohl, P. (1998). Diffusion in natural porous media: Contaminant transport, sorption / desorption and dissolution kinetics. Kluwer Academic.

Hirschfelder, J.; Curtiss, C. F.; Bird, R. B. (1954). Molecular theory of gases and liquids. New York: Wiley.

Smith, W. F. (2004). Foundations of materials, science and engineering (3rd ed.). McGraw-Hill. Welty, J. R.; Wicks, C. E.; Wilson, R. E.; and Rorrer, G. (2001). Fundamentals of momentum, heat and mass transfer. Wiley.

UNIT 5 SOIL MOISTURE RETENTION CHARACTERISTICS

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Soil moisture retention versus soil suction
3.1.1 Soil moisture retention curve
3.1.2 Factors affecting soil moisture characteristic curve
3.2 Soil water regimes
3.2 1. Field capacity
3.2 2. Permanent wilting point
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

From the molecular structure of water, there exist two basic forces which are responsible for the retention and movement of water in the soil. These forces are due to the effect of hydrogen bond and these forces are adhesion and cohesion. In this unit, we will discuss the relationship between soil suction and water content. This is very important phenomenon to know the soil water regime that exists for proper water management plans.

2.0 OBJECTIVES

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

- Know the relationship between soil moisture retention and soil suction.
- Describe soil moisture retention curve.
- State and explain factors affecting soil moisture characteristic curve.
- Soil moisture regimes that are important in crop production.

3.0 MAIN CONTENT

3.1 Soil suction versus soil moisture retention

Soil suction is the negative pressure or force that pools and holds water in the soil. It is a dynamic soil property and it maximum value is zero. It could be expressed in the same unit as pressure i.e. Pascal (Pa), bar, cm etc. However, if we consider a saturated soil placed in a suction pumping system, as the pump is started, suction created by the pump will try to extract water from the soil sample. At first, the macro pores will empty their water and as suction strength is increased, smaller pores will empty their water gradually. If the suction strength is tabulated against soil moisture content, we will observe an inverse relationship between the soil suction and the water content of the soil.

3.1.1 Soil moisture retention curve (SMRC)

This is the fundamental relationship between soil suction and soil water content presented graphically by a curve. The relationship expressed graphically is sometimes called soil water retention curve or soil water characteristic curve. This curve is very useful in irrigation water management and to know the amount of water available for plant to use (Refer to Figure 1).

3.1.2 Factors affecting soil moisture characteristic curve

The type and shape of the curve may depend on basic soil properties including texture and structure, and other factors such as swelling of clay, entrapment and persistence of air bubbles in the soil.

Effect of soil texture

In a sandy soil, the proportion of macro pores is more than the micro pores; hence, it is easier to remove water from a sandy than a clayey soil where micro pores dominate. If a loam soil moisture characteristic curve is drawn, a sandy SMRC will be below it.

Effect of soil structure

Consider two soils with similar pores and characteristics, except that one is well aggregated and the other is compacted. The SMRC will be similar from the low to the intermediate suction. The curve of the compacted soil falls below that of the well aggregated soil at low suction. At high suction, the curve of the compacted soil falls above that of the well aggregated soil.

3.2 Soil water regimes

When a soil is saturated, and all the pores are filled with water, the water will gradually drain away and leave the soil at a wet to moist regime. With further drying and unsaturation, the soil becomes drier and water becomes less available for plant to use, and the matric potential is further increased. Further drying reveals a soil that the water molecules are strongly held by the surface of the soil and even embedded within the soil matrix structure. At this stage, water cannot be extracted from within the soil matrix. These explanation shows the different regimes that soil water assumes. However, soil water exists under two main regimes of water availability as given below.

3.2.1 Field Capacity (FC)

Moisture content at field capacity represents soil water held at 33kPa (0.3 bars) matric potential and which is water available for plant use. It occurs when free drainage ceases in a soil that was initially saturated (e.g water lost to gravity after a rain or irrigation event). In the Laboratory, field capacity is determined using a pressure plate apparatus whose pressure gauge is set at 33kPa pressure when a saturated soil is placed on the extraction porous placed in the metallic air-tight chamber. When water flowing out of the chamber ceases, the soil's matric potential is equivalent to the set pressure and is at field capacity. Weight of the moist soil is taken and oven dried to know the moisture content.

In FC, the property is significantly influenced by aggregation, structural porosity, and soil organic matter content. The influence of soil texture on FC and PWP is given in Figure 5.

3.2.1 Permanent Wilting Point (PWP)

Moisture content at permanent wilting point represent soil water that is unavailable for plant use and indicates a drying soil. It is soil moisture held at 15 bar or 1500kPa matric potential. This is the lower limit of the moisture content of soil at which forces of cohesion and adhesion holding moisture in soil far exceed the pull that plant roots can exert to extract moisture from the soil. It is a unique moisture content that a soil attains beyond which soil moisture is no longer available to plants. This is the moisture content at which plant leaves wilt permanently and do not regain turgidity even when placed in an atmosphere with a relative humidity of 100%. The PWP is the moisture content at which even the retention pores have been depleted of their moisture content. The residue moisture content in soil at the PWP is of little use to plants.

Similar to field moisture capacity, moisture content at PWP also differs widely among soils. The PWP is higher in soils with higher clay content. It is higher with 2:1 type than 1:1 type clay minerals, and with expanding-lattice and more surface area than those with fixed-lattice and low surface area. In contrast to FC, the PWP is primarily influenced by the amount and nature of clay content.

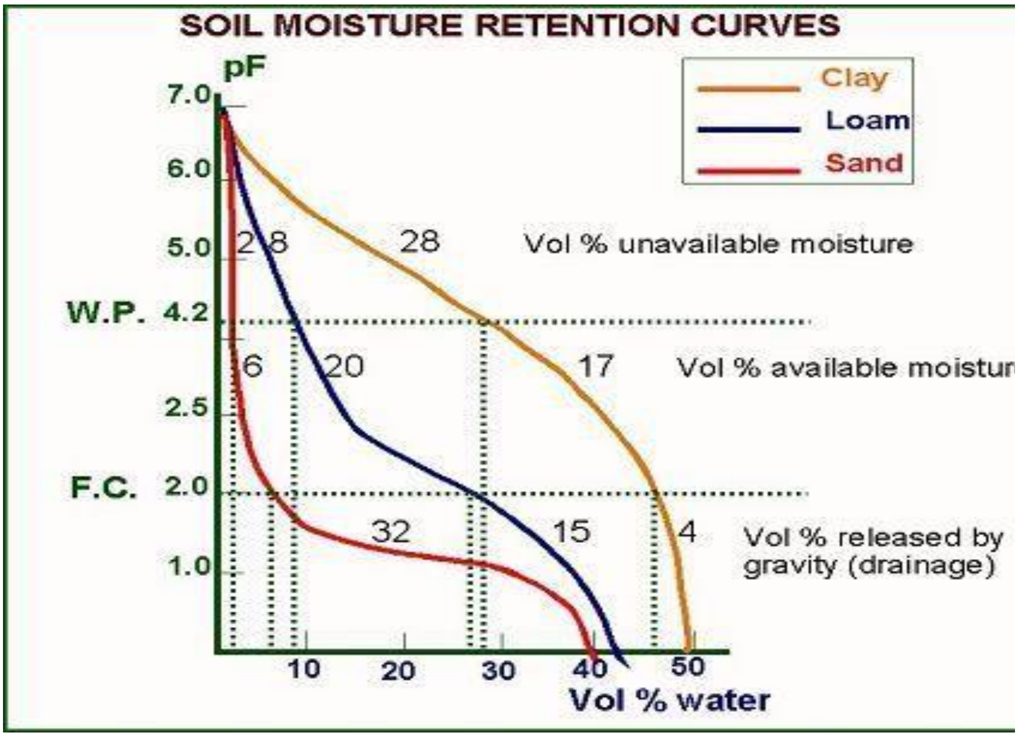


Figure 5: Soil moisture characteristic curve showing field capacity (F.C) and permanent wilting point (W.P) of three variable soil textures.
Photo source. Anonymous 2019

Both terms are applicable to determination of plant available water for proper irrigation scheduling/quantification. Field capacity and PWP are also used in several applications relevant to soil water models for watershed management, planning and design

4.0 CONCLUSION

The graphical relationship is between soil suction and soil water content is called soil water retention curve (SWRC) and shape of the curve depend on several factors including basic soil properties such as texture and structure. Soil water regimes is used to refer to the state of soil water for water availability for plant use. Field capacity water regime ensures water availability to plants while water is unavailable for plant use at permanent wilting point.

5.0 SUMMARY

In this unit, we have learnt that:

- The relationship is between soil suction and soil water content can be presented graphically and referred to as the soil moisture retention curve (SMRC).
- The SMRC of an aggregated soil differ from that of compacted soil
- Also the SMRC of a loam soil differ from that of a sandy due to the variations in their pore size distributions.
- Field capacity and permanent wilting point define water

availability or plant use.

6.0 TUTOR-MARKED ASSIGNMENT

- Describe soil moisture retention curve (SMRC).
- State and explain factors affecting SMRC.
- Give the differences in the two main water regimes discussed.

7.0 REFERENCES/ FURTHER READINGS

Brady.N, C. and Weil, R. R (2008).The nature and properties of soil. Prentice HallUpper Saddle River, New Jersey.

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press.

UNIT 6 HYSTERISIS

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Hysteresis
3.1.1 Reasons for hysteresis
3.1.2. Importance of Hysteresis
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

We are familiar with the relationship between soil suction and soil moisture content from the previous unit. In this unit we will see how SMRC of the same soil differ when the relationship between soil suction and soil moisture content is determined in two different ways that is to say, by wetting an initially dry soil or by drying a wet soil.

2.0 OBJECTIVES

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

- Explain what happen during sorption and desorption of the same soil
- Know the causes of hysteresis.

3.0 MAIN CONTENT

3.1 Hysteresis

The relationship between soil water content and soil suction, determined as soil dries out, will differ from the relationship measured as the same soil is rewetted. These yield two continuous curves which are generally not identical. The soil moisture content at any given suction is greater in desorption (drying) curve than in sorption (wetting) curve. Hence the equilibrium moisture content and the state of water depend on the direction of the process. This phenomenon is known as hysteresis.

3.1.1 Causes of hysteresis

Hysteresis is caused by a number of factors which include:

Non-uniformity of soil pores

Some of the soil macro pores may be surrounded by micro pores thereby creating a bottle neck effect. In this condition, the macro pores will not lose water until suction is high enough to empty water from the surrounding micro pores.

Presence of entrapped air
As soils are wetted, some of the some of the smaller pores are bypassed, leaving entrapped air that prevents water penetration. This entrapped air further decreases the water content of the nearly wetted soil.

Swelling and shrinking of clay
When the soil is dominated by swelling and shrinking clays, on wetting, the soil swell, and shrink in drying which brings about changes in soil structure. This will further affect the pore size in the soil which causes variation in equilibrium moisture content during wetting and drying.

3.2 Importance of Hysteresis

Hysteresis is an important phenomenon in the processes that affect soil water uptake by plants. This is because it is occurring in the soil/root interface as water is continually removed from the soil by the root and supplied to the root surface. This conxcept exist in a typical soil-plant systems where water is supplied as irrigation water or via precipitation to a dryer soil, which is a re- wetting aspect and the pores are filled with water. This explains the sorption phenomenon. When the root takes up this water, the soil gradually dries out and explains the desorption aspect. Hence, entrapped air effect may cause the water content-soil potential curves to differ at both wetting (irrigation/precipitation) and desorption (drying and root water uptake).

4.0 CONCLUSION

Hysteresis is a phenomenon where by the sorption and desorption curve of the same soil do not coincide, i.e. they are not identical and this may be caused by several factors within the soil. This phenomenon is important is water supply to the soil and root water uptake in a soil-plant systems. The concept is what exist in under crop production systems and part of soil-plant-water relations.

5.0 SUMMARY

In this unit, we have learnt that:

- SMRC of the same soil varies with depending on method of determination.
- Non-uniformity of soil pores, presence of entrapped air as well as swelling and shrinking of clays are factors responsible for hysteresis.
- Hysteresis is important in water management under crop production.

6.0 TUTOR-MARKED ASSIGNMENT

- Discuss the term hysteresis
- Explain what happen during sorption and desorption of the same soil.

- How is hysteresis important?

7.0 REFERENCES/ FURTHER READINGS

Brady, N. C. and Weil, R. R (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey.
Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.
Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press.

MODULE 3

Unit 1 Field water cycle
Unit 2 Drainage
Unit 3 Ground water drainage

UNIT 1 FIELD WATER CYCLE

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 The hydrologic cycle
3.2 Water balance equation
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

The hydrologic cycle upon which all life depends is very simple in principle. However, the processes occurring in the cycle will be discussed in this unit.

2.0 OBJECTIVES

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

- Describe the processes involved in hydrologic cycle.
- Know the various components of the water balance equation.

3.0 MAIN CONTENT

3.1The hydrologic cycle

This is the cycling of water from the earth's surface to the atmosphere and back again driven by solar energy. About one-third of the solar energy that reaches the earth is absorbed by water, stimulating evaporation-the conversion of water into water vapor. The water vapor moves up into the atmosphere, eventually forming clouds that move from one region of the globe to another. Within an average of about 10 days, pressure and temperature differences in the atmosphere cause the water vapor to condense into liquid droplets or solid particles which return to the earth as rain or other forms of precipitation. Some of the water falling on land runs off the surface of soil, and some infiltrates the soil and drains into the ground water. Both the surface runoff and ground water seepage enter streams and rivers that in turn flow into oceans (Figure 6).

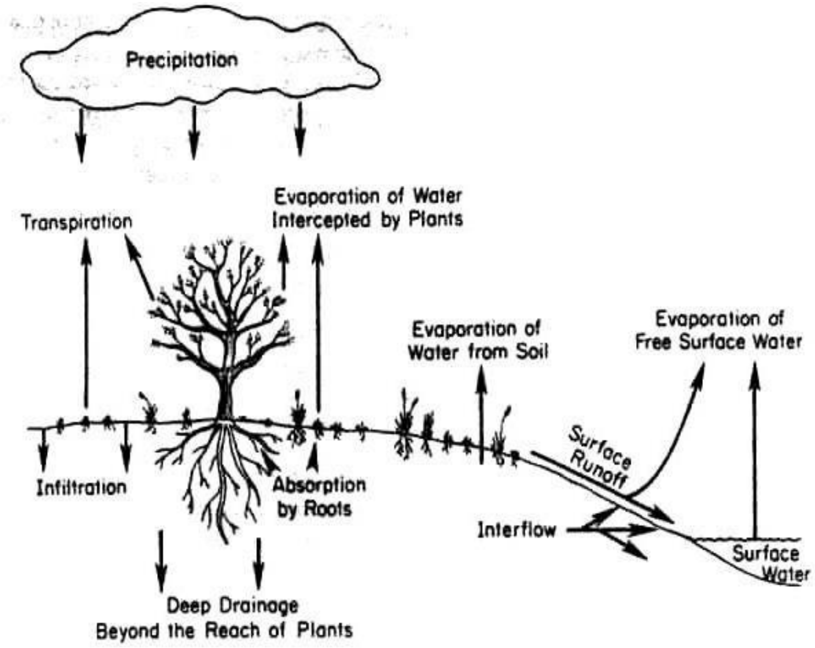


Figure 6. An overview of the hydrologic cycle

3.2 Water balance equation

It is often useful to consider the components of the hydrologic cycle as they apply to a given watershed. All the precipitation falling on the watershed is either stored in soil, return to the atmosphere or discharged from the watershed surface to subsurface flow (runoff and deep drainage). Water is return to the atmosphere either by evaporation from land surfaces (vaporization of soil water) or, after plant uptake and use, by vaporization from the stomata on the surface of leaves (a process termed transpiration). Together, these two pathways of evaporative loss to the atmosphere are called evapotranspiration (ET). Water that deeply drained through the soil may end up in ground water reservoirs and eventually join stream flows, and where it can be evaporated back to the atmosphere.

The disposition of water in watershed is often expressed by water balance equation, which in its simplest form as given in Equation 7:

$P = ET + SS + D$ (Equation 11)

Where P = Precipitation, ET = evapotranspiration, SS = Soil storage, and D = Discharge

This concept show that water is not lost but conserved in different parts of the systems (soil, water, and atmosphere) and is referred to as the Water Balance Equation.

4.0 CONCLUSION

The hydrologic cycle encompasses all movement of water on or near the earth's surfaces. It is driven by solar energy, which evaporates water from the ocean, the soil, and vegetation. The water cycled into the atmosphere, returning elsewhere to the soil and the oceans in rain and snow.

The soil is an essential component of the hydrologic cycle. It receives precipitation from the atmosphere, rejecting some of it, which is then forced to runoff into streams and rivers and absorbing the remainder, which then moves downward to be either transmitted to the ground water, taken up and later transpired by plants, or evaporated directly from soil surfaces and returned to the atmosphere.

5.0 SUMMARY

In this unit, we have learnt that:

- Hydrologic cycle is driven by solar energy, which evaporates water from the ocean, the soil, and vegetation.
- All movements of water on or near the earth's surfaces are components of hydrologic cycle.

6.0 TUTOR-MARKED ASSIGNMENT

- Describe the processes involved in hydrologic cycle.
- State water balance equation and define all the terms.

7.0 REFERENCES/ FURTHER READING

Brady, N. C. and Weil, R. R (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey, USA.

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, USA. 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press, USA.

UNIT 2 SOIL PLANT ATMOSPHERE CONTINUUM (SPAC)

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Soil plant atmosphere continuum system
3.1.1 Points of resistance to water flow in the SPAC system
3.1.2 Evapotranspiration (ET) and potential evapotranspiration (PET)
3.1.2.1. Factors affecting PET
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

We earlier considered the nature and movement of water in soil. In this unit, we will see how those characteristics apply to the management of water as it cycles between the soil, vegetation and atmosphere.

2.0 OBJECTIVES

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

- Explain the soil plant atmosphere continuum (SPAC)
- Differentiate between evapotranspiration (ET) and potential evapotranspiration (PET) in a SPAC system.

3.0 MAIN CONTENT

3.1 Soil plant atmosphere continuum system

The flow of water through the soil plant atmosphere continuum (SPAC) is a major component of the overall hydrologic cycle. SPAC describe the movement of water from soil to plants to the atmosphere and back to the soil again. Water behavior through the continuum is subject to the same energy relations as water potential. The moisture potential of soil is -50kPa, dropping to - 70kPa in the root, declining still further as it moves upward in the stem and in to the leaf- atmosphere interface, from whence it moves into the atmosphere, where the moisture potential is -20,000kPa. Over 98% of the water absorbed by roots of plants is transpired as water vapor over the course of the growing season.

3.1.1 Points of resistance to water flow in the SPAC system

Water encounters major resistance to its movement as it crosses the root soil-water interface and again as it crosses the leaf cell-atmosphere interface. This means that two primary factors determined whether plants are well supplied:

1. The rate at which water is supplied by the soil to the absorbing roots.
2. The rate at which water is transpired from the plant leaves.

3.1.2 Evapotranspiration (ET) and potential evapotranspiration (PET)

It is quite difficult to determine how much of water loss occurred directly from the soil (by evaporation, E) and how much occurred from leaf surfaces after plant uptake (by transpiration, T) in the SPAC system. Therefore information is commonly available on evapotranspiration (ET), the combined loss from the two processes. From the stand point of plant productivity, the evaporation component of ET may be viewed as a "waste" of water. However, at least some of the transpiration components are essential for plant growth, providing the water that plant needs for cooling, nutrient transport, photosynthesis, and tugor maintenance. The potential evapotranspiration (PET) tells us how fast water vapor would be loss from a densely populated plant- soil system if water content were continuously maintained at an optimal level. The PET is largely determined by the vapor gradient between a wet soil, leaf or body of water and the atmosphere.

In practice PET can be most easily estimated by applying a correction factor to the amount of water evaporated from an open pan of water of standard design (a class A evaporation Pan). Is given by PET = 0.65* pan evaporation.

The values of PET range from more than1500mm per year, in hot arid areas to less than 40mm in very cold regions.

3.1.2.1. Factors affecting ET and PET

Factors affecting ET and PET are:

Effect of soil moisture

In most cases, the upper 15 to 20 cm of soil provides most of the water for surface evaporation, unless a shallow water table exists. In a classical soil-plant systems, transpiration will occur together with evaporation and the higher the soil moisture, the greater the ET of the system. In the presence of a shallow water table, the upward capillary movement of water is very limited and the surface soil soon dries out, leading to further evaporative loss. PET is affected by a dense vegetative cover and the presence of adequate soil moisture such that it decreases if the water available is decreased.

Plant water stress

For dense vegetation growing in soils well supplied with water, ET nearly equal PET. When soil water content is less than optimal, the plant will not be able to withdraw water from the soil fast enough to satisfy PET. If water evaporate from the leaves faster than it enters the root, plant will loss turgor pressure and eventually wilt.

4.0 CONCLUSION

The behavior and movement of water in soil and plants are governed by the same set of principles: water moves in response to differences in energy level, moving from higher to lower water potential. These principles can be used to manage water more effectively and to increase efficiency of its use.

5.0 SUMMARY

In this unit, we have learnt:

- The concept of SPAC
- That water moves from region of higher to lower water potential in SPAC system
- That moisture potential decline as it moves upward from the soil to the root through the plant and into the atmosphere.
- About the factors that affect ET and PET are soil moisture and plant water stress

6.0 TUTOR-MARKED ASSIGNMENT

- Explain the soil plant atmosphere continuum (SPAC)
- Differentiate between evapotranspiration (ET) and potential evapotranspiration (PET) in a SPAC system.
- Explain the principle that governs the movement of water in the SPAC system.

7.0 REFERENCES/ FURTHER READINGS

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, USA. 494 pages.

Kirkham, M.B. (2005). Principles of Soil and Plant Water Relations. First Edition, Elsevier Academic Press, USA.

Brady, N, C. and Weil, R. R (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey, USA

Campbell, G.S. and Norman, J.H. (1998). Introduction to Environmental Biophysics. Second Edition. Springe-Verlag, New York, Inc. USA

UNIT 3 DRAINAGE AND GROUND WATER DRAINAGE

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main content
3.1 Drainage
3.1.1 Surface drainage
3.1.2 Subsurface/ ground water drainage
3.2 Benefits of artificial drainage
3.3 Detrimental effects of artificial drainage
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/ Further Readings

1.0 INTRODUCTION

Water-saturated, poorly aerated soil conditions are essential to the normal functioning of wetland ecosystems and to the survival of many wetland plant species. However, for most other land uses, these conditions are a distinct detriment. Water-saturated soils make the production of most upland crops and forest species difficult, if not impossible. In wet land soil, farm equipment used for planting, tillage or harvest operations may bog down. Most crop species grow best in well drained soils since their roots require adequate oxygen for respiration. Furthermore, a high water table early in the growing season will confine the plant root to shallow layer particularly aerated soil. The resulting root system can lead to water stress later in the year, when the weather turns dry and water table drops rapidly. For these and other reasons, artificial drainage systems have been widely used to remove excess (gravitational) water and lower the water table in poorly drained soils.

2.0 OBJECTIVES

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

- Know the meaning of drainage.
- Understand the various types of drainage systems.
- Know the benefits and detrimental effects of artificial drainage.

3.0 MAIN CONTENT

3.1 Drainage

Drainage is the removal of excess water from soil to prevent water logging and eliminate excess salt. Land drainage is practiced in selected areas in almost every climatic region, but most widely used to enhance the agricultural productivity of clayey alluvial and lacustrine soils.

3.1.1 Surface drainage

This type of drainage is extensively used where the landscape is nearly level and soils are fine textured with slow internal drainage (percolation). It purpose is to remove water from land before it infiltrate the soil.

Types of surface drainage

Surface drainage ditches

Most surface drainage systems hasten the surface runoff of water by construction of shallow ditches with gentle slope that do not interfere with equipment traffic. If there is some slope, ditches are usually oriented across the slope and across the direction of planting and cultivation, thereby permitting the interception of water as it runs off down the slope. These ditches are made at low cost with simple equipments.

Land smoothing

Small ridges are cut down and depressions are filled in using precision, laser-guided field- leveling equipment. The resulting land configuration permit excess water to move at a controlled rate over the soil surface to the outlet and then on to a natural drainage channel. Land smoothing is also commonly used to prepare a field for flood irrigation.

3.1.2 Subsurface / ground water drainage

The purpose of subsurface drainage system is to remove the ground water from within the soil and subsequently lower the water table. They require channels such as deep ditches, underground pipes or "mole" tunnels into which water can flow. Internal drainage occurs only when the pathway for drainage is located below the level of the water table.

Types of Subsurface / ground water drainage

Deep open-ditch drainage

If a ditch is excavated to a depth below the water table, water will seep from the saturated soil, where it is under positive pressure, into the ditch, where its potential will be essentially zero. However, the ditches, being 1m or more deep, present barriers to farm equipment. Therefore, deep ditch drainage is generally practical only for sandy soil in which the ditches may be spaced quite far apart.

Buried perforated pipes (Drain Tiles)

A network of perforated plastic pipes can be laid underground using specialized equipments. Water moves into the pipe through the perforations. The pipe should be laid with the perforated side down. This allows water to flow up into the pipe but protect against soil falling into and clogging the pipe.

Mole drainage

A mole drain system can be created by pulling a pointed shank followed by attached bullet- shaped plug steel about 7 to 10 cm in diameter through the soil at the desired depth. The compressed wall channel thus formed provides a pathway for the removal of excess water, similar to buried pipe. Mole drain is quite inexpensive to install, but is efficient only in fine- textured soils in which the channel is likely to remain open for number of years.

3.2 Benefits of artificial drainage

- Increase bearing strength and improve soil workability which allow more timely field operations and greater access to vehicular and foot traffic.
- Enhanced root depth, growth and productivity of most upland plant due to improved oxygen supply and in acid soil lessen toxicity of manganese and iron.
- More rapid soil warming resulting in earlier maturing crops
- Less level of methane and nitrogen gases that cause global environmental damage.

3.3 Detrimental effects of artificial drainage

- Loss of wildlife habitat, especially water fowl breeding and overwintering site.
- Reduction in nutrient assimilation and other biochemical functions of wetlands.
- Increase leaching of nitrates and other contaminants to ground water.
- Increase frequency and severity of flooding due to loss of runoff and water retention capacity.
- Accelerated loss of organic matter, leading to subsidence of certain soils.

4.0 CONCLUSION

Extreme soil wetness, characterized by surface ponding and saturated condition is a natural and necessary condition for wetland ecosystems. However, for most other land uses, extreme wetness is detrimental. Drainage systems have therefore been developed to hasten the removal of excess water from soil and lower water table so that upland plants can grow without aeration stress, and the soil can better bear the weight of vehicular and foot traffic.

5.0 SUMMARY

In this unit, we have learnt that:

- Artificial drainage systems have been widely used to remove excess water and lower the water table in poorly drained soils.
- Artificial drainage has both beneficial and detrimental effects.
- It is possible to drain underground water artificially

6.0 TUTOR-MARKED ASSIGNMENT

- Explain the various types of drainage
- Mention the benefits and detrimental effects of artificial drainage.

7.0 REFERENCES/ FURTHER READINGS

Daniel Hillel (2003). Introduction to Environmental Soil Physics. First Edition. Elsevier Academic Press, 494 pages.
Brady, N. C. and Weil, R. R (2008).The nature and properties of soil. Prentice Hall Upper Saddle River, New Jersey.