COURSE GUIDE

SLM 302
SOIL FERTILITY AND PLANT NUTRITION
(3 UNITS)

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INTRODUCTION

Soil fertility and plant nutrition is a 3 unit-Course. Each unit has specific objectives which are included at the beginning of the unit. As a way of background information about the course, we all know that Crops need nutrients, just like human beings. A fertile soil will contain all the major nutrients for basic plant nutrition (e.g., nitrogen, phosphorus, and potassium); as well as other nutrients needed in smaller quantities (e.g., calcium, magnesium, sulfur, iron, zinc, copper, boron, molybdenum, nickel). Usually, a fertile soil will also have some organic matter that improves soil structure, soil moisture retention, and also nutrient retention, and a *pH* between 6 and 7. Unfortunately, many soils do not have adequate levels of all the necessary plant nutrients, or conditions in the soil are unfavorable for plant uptake of certain nutrients.

Soil scientists that focus on soil fertility are interested in managing nutrients to improve crop production. They focus on using commercial fertilizers, manures, waste products, and composts to add nutrients and organic matter to the soil. Sometime they also add chemicals that change the pH to a more optimum level for nutrient availability to plants. Soil fertility experts must also be careful to ensure that practices are environmentally sustainable. Inappropriate management of nutrients can lead to contamination of lakes, rivers, streams, and groundwater. In addition, adding amendments to the soil is expensive and cuts into the profitability of farming operations, not to mention that toxic levels of nutrients can be as bad as or worse than too little nutrients for the plants. This course material therefore seek to provide the students all they need to know about soil fertility and plant nutrition.

Prerequisites

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

WHAT YOU WILL LEARN IN THIS COURSE

The Course consists of Modules (made up of units) and a course guide. This course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully. It gives you guidance in respect of your Tutor-Marked Assignment in the assignment file. There will be regular online facilitation classes of the course. It is advisable for you to attend these facilitation sessions. The course will prepare you for the challenges you will meet in the field of soil fertility and plant nutrition.

COURSE AIMS

The aim of the course is not complex. The course aims to provide you with an understanding of soil fertility and plant nutrition; it also aims to provide you with solutions to problems with soil fertility and plant nutrition.

COURSE OBJECTIVES

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

Thus, after going through the course, you should be able to:

- explain fertility in tropical soils.
- describe soil organic matter; its properties and maintenance
- explain what liming is and its soil-plant relations
- explain nitrogen, potassium, phosphorus and sulphur contents of soils
- discuss the soil as plant-nutrient medium.
- understand fertilizers and fertilizer management- their manufacture, sources, applications-methods, rates and timing as well as handling and storage.
- explain crop growth and response to soil nutrients; major, secondary and trace elements in crop nutrition.
- describe nutrient absorption, maintenance and loss in soil fertility in extensive and intensive agriculture.
- discuss role of legumes in soil.

WORKING THROUGH THE COURSE

To complete this course, you are required to read each study units, read the textbook and other materials which may be provided by the National Open University of Nigeria. Each unit contains self-assessment exercises and at certain points in the course you would be required to submit assignment for assessment purpose. At the end of the course there is a final examination. The course should take you a total of 17 weeks to complete. Below you will find listed all the components of the course, what you have to do and how you should allocate your time to each unit in order to complete the course on time and successfully. I will advise that you avail yourself the opportunity of attending the tutorial sessions where you have the opportunity of comparing your knowledge with that of other people.

COURSE MATERIAL

The main components of the course are:

1. The Course Guide
2. Study Units
3. References/Further Reading
4. Assignments
5. Presentation Schedule

STUDY UNITS

The study units in this course are as follows:

MODULE 1 TROPICAL SOILS FERTILITY AND ORGANIC MATTER

Unit 1 Soil fertility in the tropics
Unit 2 Tropical land use and soil fertility relation
Unit 3 Soil organic matter
Unit 4 Properties of soil organic matter
Unit 5 Natural factors influencing the amount of organic
Unit 6 Practices that decrease the amount of organic matter

MAIN COURSE

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MODULE 1 TROPICAL SOIL FERTILITY AND SOIL ORGANIC MATTER

UNIT 1 SOIL FERTILITY IN THE TROPICS

CONTENTS

1.0 INTRODUCTION

Characteristically, tropical soils have been known to be fragile due to the very high extreme weather conditions it faces. Such extremes include rainfall, sunshine and other weather conditions. This situation has led to high rate of leaching, acidity, erosion and most importantly nutrient depletion. These have made our soils to become vulnerable and so delicate (poor) that if we do not improve its fertility status, it cannot continue to support food and fibre production for our increasing population. Therefore, soil is an important natural nutrient medium that supports crop growth and development and good root development to enable the plant complete its crop cycle. It provides also a habitat for soil organisms important in agriculture especially those associated in carbon, nitrogen and phosphorus cycling and oxidation/reduction processes in soil. Hence the fertility status of the tropical soil is essential to enhancing good crop quality and production.

2.0 OBJECTIVES

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

- discuss the tropical soils
- explain tropical soil fertility.

3.0 MAIN CONTENT

3.1 Definition of Soil Fertility

A fertile soil may be defined as that which has the power to supply the right amount of nutrients to the plants and in the right proportion. The fertility of an agricultural soil can also be defined simply as ‘its capacity to produce the crops desired’, emphasising the idea that soil fertility ‘is an outcome of the effects of many kinds of living organisms, and chemical and physical processes acting on the inert parent materials from which soil is made’. Soil fertility is the level or status of a given soil with respect to its ability to supply the needed nutrients for plant growth. In effect, it is the nutrient supplying power of the soil. It is also defined as the quality of nutrients which enables or helps a given soil to make provision of the right nutrients in the right quantity and in the right proportion for growth of a specific plant or crop when all necessary environmental factors such as temperature, water, *pH*, light are adequate / favourable. Soil fertility is the result of the interactions between the biological, chemical and physical properties of soil due to soil type and land use, and the effects of climate. It is related to the potential for the sustainable production of crops and animals and can be assessed and/or described in various ways.

Soil fertility can be viewed as an ecosystem concept integrating the diverse soil functions, including nutrient supply, which promote plant production. Many soil properties interact to impact on crop growth, with both trade-offs and compensating effects. Importantly, economics plays a critical role as farmers will only strive to maintain soil fertility through appropriate practices if it pays the farmer, preferably in the short term. Concerns about soil degradation have highlighted the need to include a much wider range of potential functions of soil alongside plant production within any definition of soil quality and soil fertility is now considered as one aspect of the broader concept of soil quality.

3.2 Factors Affecting Tropical Soil Fertility

It is important to know and fully understand the chemical, biological and physical properties of a soil as well as their relationship in the soil – plant – atmosphere continuum that control nutrient availability. One of the biggest constraints in soil fertility is to develop and implement soil, crop and nutrient management approaches that improve the quality of the soil, water and air. Therefore, the factors that influence tropical soil fertility include those that affect plant growth and development. Such factors include:

- *pH* of soil (soil reaction)
- Climate factor especially temperature and precipitation (moisture)
- Activities of soil micro organisms
- Soil organic matter content
- Nutrient imbalance
- Light energy (Radiant energy)
- Soil type and Soil Structures.

3.3 Key Limitations of Tropical Soils

With increasing knowledge about the extent and distribution of soils in tropical regions, limitations for agricultural production and other purposes could be quantified. It was found that tropical soils are as diverse and varied as those of temperate regions, this makes it difficult to generalize about their distribution and limitations for agriculture and other uses. Some workers (Moormann, 1972; Eswaran *et al.* 1997; Sanchez *et al.*, 1982) have made estimates based on the Fertility Capability Soil Classification System about tropical soils limitations.

3.3.1 Tropical Soil Limitations

i. Mineral stress, defined as nutritional deficiencies or toxicities related to chemical composition or mode of origin, affects about one-fifth of the soils in Africa

ii. That two-thirds of the soils of the humid tropics have low nutrient reserves,

iii. Nearly 60% suffer from Al toxicity and

iv. 38% of the land has soils with high P fixation.

v. based on the FAO–UNESCO maps, that one-quarter of the soils in Africa have medium to low potential

vi. and that more than 50% of the land is fragile and not productive.

SELF-ASSESSMENT EXERCISE

What are the key factors affecting the fertility of tropical soil.

4.0 CONCLUSION

Tropical soils are highly diverse, with some soils having a high production potential. However, there are many areas where the soil resources suffer from serious limitations hindering agricultural production and development. Some soils have a very low chemical fertility, are extremely acid or contain toxic substances, but the exact extent of low-fertility soils and the extent of spare land is, despite advanced mapping techniques, still open for debate.

5.0 SUMMARY

From this unit, you have learnt about the fertility of tropical soils. Some of the key things leant include the following;

- The definitions of soil fertility
- Some factors affecting fertility of tropical soils
- Key limitations of tropical soils

6.0 TUTOR-MARKED ASSIGNMENT

1. Define soil fertility.
2. What are the factors affecting the fertility of tropical soils?
3. Discuss key limitations of tropical soils.

7.0 REFERENCES/FURTHER READING

Alfred E. H. (2003). *Soil fertility decline in the tropics with case studies onplantations.* UK, Trowbridge: Cromwell Press.

Sanchez, P.A. (1976). *Properties and Management of Soils in the Tropics*. New York: John Wiley & Sons.

UNIT 2 TROPICAL LAND USE AND SOIL FERTILITY RELATION

CONTENTS

1.0 INTRODUCTION

Land use is a major factor in tropical soil fertility and plant nutrition. This is because every activity carried out on the soil has either positive or negative impact on the soil's fertility status. Land is being used in tropical regions to grow trees, crops and animals for food, as building sites for houses and roads, or for recreational purposes. Sanchez (1976) distinguished the following land management systems in the tropics: nomadic herding, livestock ranching, shifting cultivation, subsistence tillage, and plantation agriculture. Most land in the tropics is being used by smallholders who farm for subsistence but also may grow some cash crops.

Many soils have been improved since people started cultivation and soil improvements continue in many agricultural areas. Inputs are applied when needed by the crops, losses are minimised and environmental awareness and legislation have created agricultural practices that are ecologically and economically more sustainable.

2.0 OBJECTIVES

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

- discuss different land uses practiced in the tropics
- explain how different land uses affect tropical soil fertility.

3.0 MAIN CONTENT

3.1 Activities that Lead to Changes in Land Use

Obviously, soil fertility is a complex issue consisting of several attributes that interact over time. Measurements require long-term research commitment as well as detailed knowledge about spatial and temporal variability. Most studies about the interaction between land use and soil fertility are on the profile and field scales which makes a direct link with spatial data on land cover change complicated. However, several activities carried out on the land have direct or indirect, positive or negative effect on the soil structural composition of such land which ultimately affects the soil fertility status.

Such activities include;

- cultivation (mechanised, by hand),
- tillage,
- weeding,
- terracing,
- subsoiling,
- deep ploughing,
- manure,
- compost and fertiliser applications,
- liming,
- draining,
- irrigation and empoldering
- also biocides applications on cultivated crops may affect soil properties.

3.1 Types of Land Use

The majority of land use changes are related to agricultural use of the land, including pastures. Agricultural activities change the soil chemical, physical or biological properties. Major types of land use that relates to agriculture include the following;

- Nomadic herding,
- Livestock ranching
- Shifting cultivation
- Subsistence farming
- And plantation agriculture.

3.2.1 Nomadic Herding

Nomadic herding is the practice of keeping and grazing animals on natural pastures. It is common in the arid and semi-arid regions such as certain parts of Saudi Arabia, northern Africa and northern parts of Eurasia. The practice resembles pastoral farming. Nomads move with their animals from one place to another in search of water and pasture for their animals. The types of animals herded vary from one region to another. They include sheep, cattle, camel, goats, donkeys and horses. The activity is a form of subsistence farming meant to feed the family.

3.2.2 Livestock Ranching

Livestock ranching focuses on rearing animals. Unlike nomadic herding, farmers do not move from one place to another in search of pasture and water, but live in settlements. Pasture lands are developed for grazing the animals. Many areas across the globe with large pieces of land with enough grazing areas for animals practice this type of agriculture for commercial reasons. South America, North America and Australia are some regions across the world that intensively practice commercial pastoral farming on large-scale due to low rains received in the areas. The animals in ranches are mainly kept for wool and meat. Dairy farming is also a critical aspect of pastoral farming.

However, the activity is not sustainable because excessive grazing can lead to destruction of natural pastures. Therefore, farmers end up buying feeds for their animals, making the practice costly.

3.2.3 Shifting Cultivation

Shifting cultivation is commonly practiced in the tropics. It involves forest clearance through burning and slashing. The cleared lands is cultivated until its fertility declines, or for three to five years or until native flora and weeds overtake it. When that happens, farmers abandon the land for a fallow period and clear another forest area for cultivation. It is a type of subsistence farming usually done manually. People in the tropical regions such as south-east Asia tend to adopt this type of agricultural activity with a focus on growing grains. However, due to the pressure environmentalists and activists exert to support environment protection from such unsustainable practices, the activity is declining.

3.2.4 Subsistence Farming

Subsistence farming involves growing crops and keeping animals for the sole purpose of feeding the farmer and his family. It involves the use of simple farm tools on small pieces of land. Most subsistence farmers are believed to be poor and thus cannot afford to buy improved seeds and fertilizers. Therefore, they farm on land with low soil fertility or rough terrains.

3.2.5 Plantation Agriculture

Also known as tree crop farming, industrialised agriculture or plantation farming, commercial plantations cover large land areas. Even if practiced on a smaller piece of land, the activity has a high commercial value. It involves the cultivation of tropical crops such as tea, rubber, coffee, coconut, cocoa, grapes, apples, spices, oranges, avocado, mangoes and palm oil. It is commonly practiced in regions with European colonial influence such as Africa, Asia and Latin America. Colonial governments established most of the plantations in their colonies to supply the European markets with tropical crops. It requires high capital to establish with the majority of the crops grown being tree crops. Some plantation farms have processing factories. Various farming techniques are adopted to increase farm yield because the goal of such farms is to make profits.

3.2 How Land Use Affects Soil Fertility

- Land use change always affects soil quality and productivity.
- On-site effects are mostly related to changes in soil organic matter content.
- The most dramatic changes occur directly after a major land use conversion, such as deforestation.
- Mineralisation increases while the change in cover usually induces erosion and other landscape processes.
- Conversion has a large short term (1-5 years) on-site impact on soil properties such as soil organic C and bulk density, whereas land use intensification has longer term (10 to 80 years) effects on soil properties.

SELF-ASSESSMENT EXERCISE

How does tropical land use affect soil fertility and productivity?

4.0 CONCLUSION

Soil fertility is a complex issue consisting of several attributes that interact over time. Measurements require long-term research commitment as well as detailed knowledge about spatial and temporal variability. Most studies about the interaction between land use and soil fertility are on the profile and field scales which makes a direct link with spatial data on land cover change complicated. However, several activities carried out on the land have direct or indirect, positive or negative effect on the soil structural composition of such land which ultimately affects the soil fertility status. Majority of the land uses practiced on our tropical soils are agriculturally related and include the following; Nomadic herding, livestock ranching, shifting cultivation, subsistence tillage, and plantation agriculture. These activities affect soil fertility by changing their quality and productivity.

5.0 SUMMARY

In this unit, you have leant the relationship between tropical land use and soil fertility. You leant the following;

- Some activities that lead to land use changes
- Different land use activities that relates to agriculture
- How land use can affects soil fertility.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss some activities that lead to land use changes.
2. Outline the major agricultural land uses.
3. Explain how land use affect soil fertility.

7.0 REFERENCES/FURTHER READING

Alfred, E. Hartemink. (2010). Land use change in the tropics and its effect on soil fertility World Congress of Soil Science, Soil Solutions for a Changing World 1 – 6 August 2010, Brisbane, Australia.

Sanchez, P.A. (1976). *Properties and Management of Soils in the Tropics*. John Wiley & Sons, New York.

UNIT 3 SOIL ORGANIC MATTER

CONTENTS

1.0 INTRODUCTION

Soil organic matter (SOM) is the organic component of soil, consisting of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter, and stable organic matter (humus). Soil organic matter serves as a reservoir of nutrients for crops, provides soil aggregation, increases nutrient exchange, retains moisture, reduces compaction, reduces surface crusting, and increases water infiltration into soil. Components vary in proportion and have many intermediate stages. Plant residues on the soil surface such as leaves, manure, or crop residue are not considered SOM and are usually removed from soil samples by sieving through a 2 mm wire mesh before analysis.

Soil organic matter content can be estimated in the field and tested in a lab to provide estimates for Nitrogen, Phosphorus and Sulfur mineralised available for crop production and adjust fertilizer recommendations. Soil organic matter impacts the rate of surface applied herbicides along with soil pH necessary to effectively control weeds. Soil organic matter impacts the potential for herbicide carryover for future crops, and amount of lime necessary to raise pH.

2.0 OBJECTIVES

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

- explain what organic matter is
- outline the major sources of organic matter.

3.0 MAIN CONTENT

3.1 What is Soil Organic Matter?

The term "soil organic matter" (SOM) has been used in different ways to describe the organic constituents of soil. Baldock and Skjemstad (1999) defined SOM as "all organic materials found in soils irrespective of origin or state of decomposition". SOM consists of C, H, O, N, P and S. Included are living organic matter (plants, microbial biomass and faunal biomass), dissolved organic matter, particulate organic matter, humus and inert or highly carbonized organic matter. Part of soil organic matter consists of carbohydrates, lipids and proteins that are abundant in fresh plant residues. These are rapidly metabolised, immobilized or decomposed. Organic matter is categorised into aboveground and belowground organic. Aboveground organic matter includes plants and animal residues while the belowground matter comprises of living soil fauna and micro flora, partially decomposed plant and animal.

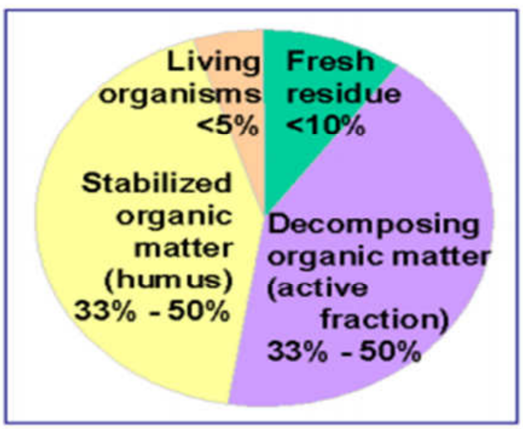

Figure 3.1: Major Soil Organic Matter Components (Source: The Soil Food Web, USDA-NRCS)

3.2 Benefits of Organic Matter to the Soil

- Soil organic matter serves as a reservoir of nutrients for crops,
- provides soil aggregation,
- increases nutrient exchange,
- retains moisture,
- reduces compaction,
- reduces surface crusting,
- and increases water infiltration into soil.

3.3 Sources of Organic Matter

Soil organic matter consists of diverse, heterogenous components. It was reported that living C rarely exceeds 4% of total soil organic C and is present as roots, microorganisms and soil fauna. Non-living C represents the major portion of organic C, consisting of surface litter, root litter, microbial metabolites and humic substances. The living and non-living C component constantly interacts, as do the saprophytic organisms that acquire metabolites from non-living C in the soil and then die.

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1. CROP RESIDUES

Crop residue is divided into two types- field and process residue.

i. **Field residue** is materials which are left in an agricultural field or orchard after the crop has been harvested. This include stalks, stems or leaves and seed pod. The residue can be ploughed directly into the ground or burned first.

ii. **Process residue:** They are materials which are left after the crop is processed into useable resource. It includes husks, seed and root which can be used as soil amendment, fertilizer and in manufacturing. They have high CN ratio with low N content but fairly high Potassium and silica content which help to improve the resistance of crops to disease and lodging. Fibrous materials provide an energy source for soil microorganisms which improve soil physical properties.

2. GREEN MANURE AND COVER CROPS

Green manure can be defined as a practice of ploughing or turning into the soil undecomposed green plant tissues for improving physical structure and soil fertility. The green manure crops supplies organic matter as well as nitrogen, particularly if it is a legume crop.

3. ANIMAL WASTE

Amending soil with animal waste has been old practice. Animal waste can supply nutrients, OM and enriched soil with beneficial organisms. Dung’s comes mostly as undigested material and the urine from the digested material. More than 50% of the organic matter that is present in dung is the form of complex product consists of lignin and protein which are resistant to further decomposition and therefore the nutrients present in dung are released very slowly

4. COMPOST

Compost is any organic material that undergoes decomposition under controlled conditions. Any organic material can be converted to compost, but there are rules regarding what material can and cannot be used. Compared to some uncomposted animals waste, it may have low nutrient levels. Nutrients from compost are often less available to the crop; thus, compost may be more useful for building SOM. Compost causes less water pollution.

Nyamangara *et al.,* (2003) reported that management of soil organic matter by using composted organic waste is the key for sustainable agriculture.

SELF-ASSESSMENT EXERCISE

Explain Soil Organic matter, state the benefits and sources in tropical agriculture

4.0 CONCLUSION

Soil organic matter may be defined as "all organic materials found in soils irrespective of origin or state of decomposition". SOM consists of C, H, O, N, P and S. Soil organic matter (SOM) is the organic component of soil, consisting of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter, and stable organic matter (humus).

5.0 SUMMARY

You have leant about soil organic matter as well as their sources. In this unit, you leant the following;

- That soil organic matter (SOM) is the organic component of soil, consisting of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter, and stable organic matter (humus).
- Benefits of organic matter to the soil includes; organic matter serves as a reservoir of nutrients for crops, provides soil aggregation, increases nutrient exchange, retains moisture, reduces compaction, reduces surface crusting, and increases water infiltration into soil.
- Sources of Organic matter includes; crop residue, green manure, animal waste and compost.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain what you understand as "soil organic matter"
2. What are the benefits of organic matter to the soils?

3. Describe the sources of organic matter to agricultural soils

7.0 REFERENCES/FURTHER READING

Baldock, J. A. & Skjemstad, J. O. (1999). 'Soil organic carbon/soil organic matter.' In, *Soil Analysis: An Interpretation Manual*. (Eds.). K. I. Peverill, L. A. Sparrow, & D. J. Reuter.) pp. 159-170. (CSIRO Publishing: Collingwood.)

Adiaha M. S. (2017) 'The Role of Organic Matter in Tropical Soil Productivity.' *World Scientific News, 86(1), pp.1-66.*

UNIT 4 PROPERTIES OF SOIL ORGANIC MATTER

CONTENTS

1.0 INTRODUCTION

The total amount and partitioning of organic matter in the soil is influenced by soil properties and by the quantity of annual inputs of plant and animal residues to the ecosystem. For example, in a given soil ecosystem, the rate of decomposition and accumulation of soil organic matter is determined by such soil properties as texture, pH, temperature, moisture, aeration, clay mineralogy and soil biological activities. A complication is that soil organic matter in turn influences or modifies many of these same soil properties. Organic matter existing on the soil surface as raw plant residues helps protect the soil from the effect of rainfall, wind and sun. Removal, incorporation or burning of residues exposes the soil to negative climatic impacts, and removal or burning deprives the soil organisms of their primary energy source.

2.0 OBJECTIVES

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

- explain the properties of soil organic matter
- describe how organic matter relates to soil properties.

3.0 MAIN CONTENT

3.1 Properties of Soil Organic Matter

Organic matter within the soil exhibits several properties. From a practical agricultural standpoint, it is important for two main reasons:

(i) as a "revolving nutrient fund"; and
(ii) as an agent to improve soil structure, maintain tilth and minimize erosion.

As a revolving nutrient fund, organic matter serves two main functions:

- As soil organic matter is derived mainly from plant residues, it contains all of the essential plant nutrients. Therefore, accumulated organic matter is a storehouse of plant nutrients.
- The stable organic fraction (humus) adsorbs and holds nutrients in a plant-available form.

Organic matter releases nutrients in a plant-available form upon decomposition. In order to maintain this nutrient cycling system, the rate of organic matter addition from crop residues, manure and any other sources must equal the rate of decomposition, and take into account the rate of uptake by plants and losses by leaching and erosion.

3.2 How Organic Matter Affects Soil Properties

3.2.1 Physical Properties

3.2.1.1 Soil Structure and Aggregate Stability

soil structure stability refers to the resistance of soil to structural rearrangement of pores and particles when exposed to different stresses (e.g. cultivation, trampling/ compaction, and irrigation). Angers and

Carter (1996) noted that the amount of water – stable aggregate (WSA) was often associated with SOC content, and that labile carbon was often positively related to macro-aggregate stability. It was reported that a minimum of 2% SOC was necessary to maintain structural stability. It has also been reported that a threshold of 3-3.5% SOC had to be attained to achieve increase in aggregate stability.

3.2.1.2 Water Holding Capacity

An important indicator of soil physical fertility is the capacity of soil to store and supply water and air for plant growth. It has been found that an increase in water content goes with increasing SOC content that an increase of 1% SOM can add 1.5% additional moisture by volume of FC. Emerson and McGary (2003) showed that per gram of additional carbon at -10 kPa suction, a 50% increase in water content was achieved. They suggest that the organic carbon from exudates (gel) from ectotrophic mycrorhiza would bond soil particles which would result in a change in the size of the pores and a change in water retention at -10 kPa.

3.2.1.3 Soil Colour

Generally, good soil conditions are associated with dark brown colours near the soil surface; which is associated with relatively high organic matter levels, good soil aggregation and high nutrient levels.

3.2.2 Chemical Properties

3.2.2.1 Cation Exchange Capacity (CEC)

A high CEC is regarded as favourable as it contributes to the capacity of soils to retain plant nutrient cations. Functional groups of SOM have been associated with an increase in CEC and an increase in CEC goes with increase in soil organic matter.

3.2.2.2 Buffer Capacity and *pH*

Soil buffering is considered to be an important aspect of soil health, as it assures reasonable stability in soil *pH*. Buffering at intermediate pH value (5-7.5) is mainly governed by functional groups of SOM which act as sink for H+ and OH^-. The importance of SOM to maintain fairly stable *pH* values, despite acidifying factors, has been documented.

3.2.2.3 Adsorption and Complexation

Adsorption of SOM on clay particles is an important mechanism for the protection of SOM from decomposition. Complexation of inorganic materials by SOM have important ramifications for soil fertility as it may increase the availability of P by blocking potential adsorption site of Fe and Al as well as Ca. It was reported that increase concentrations of SOM depress the concentration of heavy metals such as Cupric ions.

3.2.3 Biological Function of SOM

The biological function of SOM are primarily to provide a reservoir of metabolic energy that drives biological process, supply macro- and micro- nutrients and to ensure that both energy and nutrients are stored and released in a sustainable manner. Importantly, biological processes in turn influence both soil chemical and soil structural properties as they greatly affect soil structure and soil redox reactions. Baldock and Nelson (1999) stated that one of the most fundamental function of SOM is the provision of metabolic energy which drives soil biological processes

3.2.4 Soil Resilience

The resilience of a soil is really a measure of the functionality of the whole ecosystem. It is governed by the adequate performance of physical, biological and chemical functions, which in turn is to a large extent determined by the SOM content and its chemical composition.

3.3 Soil Organic Matter and Crop Production

Although there is a considerable variation in the nutrient composition of organic manures depending mainly upon the source, handling and management, the main nutrients supplied are N, P, K, Mg, Ca and a host of micro nutrients. The following were reported about organic matter and crop production;

i. It was reported that nutrient composition of organic manures are N, P, and S as well as micro nutrient elements as B, Cu, Mo, Zn, Mn, Fe and Cl.

ii. Also that an average dressing of 10tonnes ha-1 of farmyard manure would supply about 50 kg N ha-1 and 50 kg K ha-1.

iii. On crop yields, organic fertilizers have been reported to influence crops performance significantly.

iv. Baldock and Nelson (1999) reported that poultry manure application significantly increased soybean yield over NPK fertilizer.

v. With or without the availability of fertilizer, it has been reported that, organic matter management remains a corner stone for successful farming in many areas of the tropics.

SELF-ASSESSMENT EXERCISE

Discuss the physical, chemical and biological characteristics affected by soil organic matter.

4.0 CONCLUSION

Organic matter within the soil exhibits several properties. From a practical agricultural standpoint, as a “revolving nutrient fund”; and as an agent to improve soil structure, maintain tilth and minimise erosion. As soil organic matter is derived mainly from plant residues, it contains all of the essential plant nutrients. Therefore, accumulated organic matter is a storehouse of plant nutrients. The stable organic fraction (humus) adsorbs and holds nutrients in a plant-available form.

5.0 SUMMARY

In this unit, you have leant about the characteristics of soil organic matter as well as the effects of organic matter on soil physical, chemical and biological characteristics.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the properties of soil organic matter.
2. Describe some of the physical, chemical and biological characteristics affected by soil organic matter.
3. What are the roles of organic matter in crop production.

8.0 REFERENCES/FURTHER READING

Angers, D. A. & Carter, M. R. (1996). Aggregation and organic matter storage in cool, humid agricultural soils. In, M. R. Carter, & B. A. Stewart.(Eds). 'Structure and organic matter storage in agricultural soils. physical, chemical and biological characteristics affected by soil organic matter. pp. 193-211. (CRC Press: Boca Raton.)

Baldock, J. A. & Skjemstad, J. O. (1999). Soil organic carbon/soil organic matter. In 'Soil Analysis: an Interpretation Manual. (Eds. K. I. Peverill, L. A. Sparrow, & D. J. Reuter.) pp.159-170. (CSIRO Publishing: Collingwood.)

Emerson, W. W. & McGarry, D. (2003). Organic carbon and soil porosity. *Australian Journal of Soil Research, (*41), pp.107-118.

UNIT 5 NATURAL FACTORS INFLUENCING THE AMOUNT OF ORGANIC MATTER

CONTENTS

1.0 INTRODUCTION

The transformation and movement of materials within soil organic matter pools is a dynamic process influenced by climate, soil type, vegetation and soil organisms. All these factors operate within a hierarchical spatial scale. Soil organisms are responsible for the decay and cycling of both macronutrients and micronutrients, and their activity affects the structure, tilth and productivity of the soil. In natural forest ecosystems without human disturbance, the living and non-living components are in dynamic equilibrium with each other. The litter on the soil surface beneath different canopy layers and high biomass production generally result in high biological activity in the soil and on the soil surface.

The following five mechanisms of natural factors influencing the amount of organic have been distinguished:

- a continuous soil cover of living plants, which together with the soil architecture facilitates the capture and infiltration of rainwater and protects the soil;
- a litter layer of decomposing leaves or residues providing a continuous energy source for macro- and micro-organisms;
- the roots of different plants distributed throughout the soil at different depths permit an effective uptake of nutrients and an active interaction with microorganisms;
- the major period of nutrient release by micro-organisms coincides with the major period of nutrient demand by plants;
- nutrients recycled by deep-rooting plants and soil macrofauna and microfauna.

2.0 OBJECTIVES

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

- explain the mechanisms through which natural factors influence the amount of organic matter.
- describe the environmental and edaphic factors controlling the activities of soil biotas.

3.0 MAIN CONTENT

3.1 Natural Factors Influencing the Amount of Organic Matter

The environmental and edaphic factors that control the activity of soil biota, and thus the balance between accumulation and decomposition of organic matter in the soil, are described below.

3.1.1 Temperature

Several field studies have shown that temperature is a key factor controlling the rate of decomposition of plant residues. Decomposition normally occurs more rapidly in the tropics than in temperate areas. Reaction rates doubled for each increase of 8-9 °C in the mean annual air temperature. The relatively faster rate of decomposition induced by the continuous warmth in the tropics implies that high equilibrium levels of organic matter are difficult to achieve in tropical agro-ecosystems. Hence, large annual rates of organic inputs are needed to maintain an adequate labile soil organic matter pool in cultivated soils. Soils in cooler climates commonly have more organic matter because of slower mineralization (decomposition) rates.

3.1.2 Soil Moisture and Water Saturation

Soil organic matter levels commonly increase as mean annual precipitation increases. Conditions of elevated levels of soil moisture result in greater biomass production, which provides more residues, and thus more potential food for soil biota. On the other hand, periods of water saturation lead to poor aeration. Most soil organisms need oxygen, and thus a reduction of oxygen in the soil leads to a reduction of the mineralisation rate as these organisms become inactive or even die. Some of the transformation processes become anaerobic, which can lead to damage to plant roots caused by waste products or favourable conditions for disease-causing organisms.

3.1.3 Soil Texture

Soil organic matter tends to increase as the clay content increases. This increase depends on two mechanisms. First, bonds between the surface of clay particles and organic matter retard the decomposition process. Second, soils with higher clay content increase the potential for aggregate formation. Macro-aggregates physically protect organic matter molecules from further mineralisation caused by microbial attack. For example, when earthworm casts and the large soil particles they contain are split by the joint action of several factors (climate, plant growth and other organisms), nutrients are released and made available to other components of soil micro-organisms. Under similar climate conditions, the organic matter content in fine textured (clayey) soils is two to four times that of coarse textured (sandy) soils.

3.1.4 Topography

Organic matter accumulation is often favoured at the bottom of hills. There are two reasons for this accumulation: conditions are wetter than at mid- or upper-slope positions, and organic matter is transported to the lowest point in the landscape through runoff and erosion. Similarly, soil organic matter levels are higher on northfacing slopes (in the Northern

Hemisphere) compared with south-facing slopes (and the other way around in the Southern Hemisphere) because temperatures are lower.

3.1.5 Salinity and Acidity

Salinity, toxicity and extremes in soil pH (acid or alkaline) result in poor biomass production and, thus in reduced additions of organic matter to the soil. For example, pH affects humus formation in two ways: decomposition, and biomass production. In strongly acid or highly alkaline soils, the growing conditions for micro-organisms are poor, resulting in low levels of biological oxidation of organic matter. Soil acidity also influences the availability of plant nutrients and thus regulates indirectly biomass production and the available food for soil biota. Fungi are less sensitive than bacteria to acid soil conditions.

3.1.6. Vegetation and Biomass Production

The rate of soil organic matter accumulation depends largely on the quantity and quality of organic matter input. Under tropical conditions, applications of readily degradable materials with low C:N ratios, such as green manure and leguminous cover crops, favour decomposition and a short-term increase in the labile nitrogen pool during the growing season. On the other hand, applications of plant materials with both large C:N ratios and lignin contents such as cereal straw and grasses generally favour nutrient immobilisation, organic matter accumulation and humus formation, with increased potential for improved soil structure development. Root turnover also constitutes an important addition of humus into the soil, and consequently it is important for carbon sequestration. In forests, most organic matter is added as superficial litter. However, in grassland ecosystems, up to two-thirds of organic matter is added through the decay of roots.

SELF-ASSESSMENT EXERCISE

Describe how climate, soil moisture and water saturation, soil texture, topography, salinity and acidity, vegetation and biomass production influence soil organic matter.

5.0 CONCLUSION

The availability, transformation and amount of soil organic matter is a dynamic process influenced by certain factors which may be climate, soil type, vegetation and soil organisms.

5.0 SUMMARY

You have leant the factors influencing the amount of organic matter in the soils. Such factors may include; climate, soil moisture and water saturation, soil texture, topography, salinity and acidity, vegetation and biomass production.

6.0 TUTOR-MARKED ASSIGNMENT

1. Outline the mechanisms of natural factors influencing the amount of soil organic matter.
2. Explain how the following factors; climate, soil moisture and water saturation, soil texture, topography, salinity and acidity, vegetation and biomass production influence soil organic matter.

7.0 REFERENCES/FURTHER READING

Adiaha M. S. (2017). 'The Role of Organic Matter in Tropical Soil Productivity.' *World Scientific News 86(1) (2017) 1-66.*

UNIT 6 PRACTICES THAT DECREASE THE AMOUNT OF ORGANIC MATTER

CONTENTS

1.0 INTRODUCTION

Various types of human activity decrease or increase soil organic matter contents and biological activity. However, increasing the organic matter content of soils or even maintaining good levels requires a sustained effort that includes returning organic materials to soils and rotations with high-residue crops and deep- or dense-rooting crops. It is especially difficult to raise the organic matter content of soils that are well aerated, such as coarse sands, and soils in warm-hot and arid regions because the added materials decompose rapidly. Soil organic matter levels can be maintained with less organic residue in fine textured soils in cold temperate and moist-wet regions with restricted aeration.

2.0 OBJECTIVES

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

- outline some practices that influence the amount of organic matter in the soil
- explain how to avoid practices that will deplete organic matter content of our soils.

3.0 MAIN CONTENT

3.1 Practices that Decrease Soil Organic Matter

Management practices that alter the living and nutrient conditions of soil organisms, such as continuous tillage or burning of vegetation, result in a degradation of their microenvironments. In turn, this results in a reduction of soil biota, both in biomass and diversity. Where there are no longer organisms to decompose soil organic matter and bind soil particles, the soil structure is damaged easily by rain, wind and sun. This can lead to rainwater runoff and soil erosion, removing the potential food for organisms, i.e. the organic matter of the topsoil.

The factors leading to reduction in soil organic matter in an open cycle system can be grouped as factors that result in:

1. a decrease in biomass production;
2. a decrease in organic matter supply;
3. increased decomposition rates.

3.1.1 Decrease in Biomass Production

3.1.1.1Replacement of Perennial Vegetation

A consequence of clearing forest for agriculture is the disappearance of the litter layer, with a consequent reduction in the numbers and variety of soil organisms. While many temperate forest species appear to adapt well to grassland, the effects of deforestation in the tropics appear to be more marked. Studies have shown that as soil biodiversity declines, adapted species may take over from the indigenous species and the composition may change drastically.

3.1.1.2 Replacement of Mixed Vegetation with Monoculture of Crops and Pastures

The simplification of vegetation and the disappearance of the litter layer under grassland and mono-crop production systems lead to a decrease in faunal diversity. Although root systems (especially of grasses) can be extensive and explore vast areas of soil, the root exudates from one single crop will attract only a few different microbial species. This in turn will affect the predator diversity. The more opportunistic pathogen species will be able to acquire space near the crop and cause harm. Continuous cultivation and grazing also leads to compaction of soil layers, which in turn affects the circulation of air. Anaerobic conditions in the soil stimulate the growth of different micro-organisms, resulting in more pathogenic organisms.

3.1.1.3 High Harvest Index

One of the consequences of the green revolution was the replacement of indigenous varieties of species with high-yielding varieties (HYVs). These HYVs often produce more grain and less straw, compared with locally developed varieties; the harvest index of the crop (ratio of grain to total plant mass aboveground) is increased. From a production point of view, this is a logical approach. However, this is less desirable from a conservation point of view. Reduced amounts of crop residues remain after harvest for soil cover and organic matter, or for grazing of livestock (which results in manure). Moreover, where animals graze the residues, even less remains for conservation purposes.

3.1.1.4 Use of Bare Fallow

Traditionally, a fallow period is used after a period of crop production to give the land some “rest” and to regenerate its original state of productivity. Usually, this is necessary in production systems that have drawn down the nutrient supply and altered the soil biota significantly, such as in slash-and-burn systems or conventional tillage systems. Instead of recovering the soil food web, the soil organic matter is degraded further and the lack of cover can result in severe erosion and runoff when the rains start after the dry season.

3.1.2 Decrease in Organic Matter Supply

3.1.2.1 Burning of Natural Vegetation and Crop Residues

Burning destroys the litter layer and so diminishes the amount of organic matter returned to the soil. The organisms that inhabit the surface soil and litter layer are also eliminated. For future decomposition to take place, energy has to be invested first in rebuilding the microbial community before plant nutrients can be released. Similarly, fallow lands and bush are burned before cultivation. This provides a rapid supply of P to stimulate seed germination. However, the associated loss of nutrients, organic matter and soil biological activity has severe long-term consequences.

3.1.2.2 Overgrazing

There is a tendency throughout the world to overstock grazing land above its carrying capacity. Cows, draught animals and small ruminants graze on communal grazing areas and on roadsides, stream banks and other public land. Overgrazing destroys the most palatable and useful species in the plant mixture and reduces the density of the plant cover, thereby increasing the erosion hazard and reducing the nutritive value and the carrying capacity of the land.

3.1.2.2.1 Indicators of Overgrazing

One indicator of overgrazing is that the animals run short of pasture. In some regions of the United States under continuous grazing, overgrazed pastures promote by short-grass species such as bluegrass and will be less than 2-3 inches tall in the grazed areas. In other parts of the world, overgrazed pasture is typically taller than sustainably grazed pasture, with grass heights typically over 1 meter and dominated by unpalatable species such as *Aristida* or *Imperata*. In all cases, palatable tall grasses such as orchard grass are sparse or non-existent. In such cases of overgrazing, soil may be visible between plants in the stand, allowing erosion to occur, though in many circumstances overgrazed pastures have a greater sward cover than sustainably grazed pastures.

3.1.2.2.2 Rotational grazing

Under rotational grazing, overgrazed plants do not have enough time to recover to the proper height between grazing events. The animals resume grazing before the plants have restored carbohydrate reserves and grown back roots lost after the last defoliation. The result is the same as under continuous grazing: in some parts of the United States tall-growing species die and short-growing species that are more subject to drought injury predominate the pasture, while in most other parts of the world tall, drought tolerant, unpalatable species such as *Imperata* or *Aristida* come to dominate. As the sod thins, weeds encroach into the pasture in some parts of the United States, whereas in most other parts of the world overgrazing can promote thick swards of native unpalatable grasses that hamper the spread of weeds.

Another indicator of overgrazing in some parts of North America is that livestock run out of pasture, and hay needs to be fed early in the fall. In contrast, most areas of the world do not experience the same climatic regime as the continental United States and hay feeding is rarely conducted.

Overgrazing is also indicated in livestock performance and condition. Cows having inadequate pasture immediately following their calf's weaning may have poor body condition the following season. This may reduce the health and vigor of cows and calves at calving. Also, cows in poor body condition do not cycle as soon after calving, which can result in delayed breeding and a long calving season. With good cow genetics, nutrition, ideal seasons and controlled breeding 55% to 75% of the calves should come in the first 21 days of the calving season. Poor weaning weights of calves can be caused by insufficient pasture, when cows give less milk and the calves need pasture to maintain weight gain.

3.1.2.3 Removal of Crop Residues

Many farmers remove residues from the field for use as animal feed and bedding or to make compost. Later, these residues return to contribute to soil fertility as manures or composts. However, residues are sometimes removed from the field and not returned. This removal of plant material impoverishes the soil as it is no longer possible to recycle the plant nutrients present in the residues.

3.1.3 Increased Decomposition Rates

3.1.3.1 Tillage Practices

Tillage is one of the major practices that reduces the organic matter level in the soil. Each time the soil is tilled, it is aerated. As the decomposition of organic matter and the liberation of CO_2 are aerobic processes, the oxygen stimulates or speeds up the action of soil microbes, which feed on organic matter.

This means that:

- When ploughed, the residues are incorporated in the soil together with air and come into contact with many micro-organisms, which accelerates the carbon cycle. The decomposition is faster, resulting in the formation of less stable humus and an increased liberation of CO_2 to the atmosphere, and thus a reduction in organic matter.
- The residues on the soil surface slow the carbon cycle because they are exposed to fewer micro-organisms and thus wane more slowly, resulting in the production of humus (which is more stable), and liberating less CO_2 to the atmosphere.

Organic matter production and conservation is affected dramatically by conventional tillage, which not only decreases soil organic matter but also increases the potential for erosion by wind and water. The impact occurs in many ways:

- Ploughing leaves no residues on the soil surface to lessen the impact of rain.
- Ploughing reduces the quantity of food sources for earthworms and disturbs their burrows and living space, hence populations of certain species decrease drastically.
- Tillage by repeated hoeing or discing smoothes the surface and destroys natural soil aggregates and channels that connect the surface with the subsoil, leaving the soil susceptible to erosion.
- The development of a plough pan or hoe pan, a layer of compacted soil resulting from smearing action at the bottom of the plough or hoe, may retard both root penetration and water infiltration.

- Ploughing or discing under dry conditions exacerbates the pulverization of the soil, causing the soil surface to crust more easily, leading to greater water runoff and erosion.
- Increased runoff during rainstorms may also increase the possibility of drought stress later in the season, because water that runs off the field does not infiltrate into the soil to remain available to plants.

In some circumstances, imbalances of certain soil organisms can disrupt soil structure and processes, e.g. certain earthworm species in rice fields or pastures.

3.1.3.2 Drainage

Decomposition of organic matter occurs more slowly in poorly aerated soils, where oxygen is limiting or absent, compared with well-aerated soils. For this reason, organic matter accumulates in wet soil environments. Soil drainage is determined strongly by topography - soils in depressions at the bottom of hills tend to remain wet for extended periods of time because they receive water (and sediments) from upslope. Soils may also have a layer in the subsoil that inhibits drainage, again exacerbating waterlogging and reduction in organic matter decomposition.

3.1.3.3 Fertilizer and Pesticide Use

Initially, the use of fertilizer and pesticides enhances crop development and thus production of biomass (especially important on depleted soils). However, the use of some fertilizers, especially N fertilizers, and pesticides can boost micro-organism activity and thus decomposition of organic matter. The chemicals provide the microorganisms with easy-to-use N components. This is especially important where the C: N ratio of the soil organic matter is high and thus decomposition is slowed by a lack of N.

SELF-ASSESSMENT EXERCISE

How does conventional tillage affect organic matter production and conservation in the tropics?

4.0 CONCLUSION

Various types of human activity decrease or increase soil organic matter contents and biological activity. Certain management practices that alter the living and nutrient conditions of soil organisms, such as continuous tillage or burning of vegetation, result in a degradation of their microenvironments.

5.0 SUMMARY

You have leant that practices that leads to depletion of organic matter anchors on these three major factors;

- a decrease in biomass production
- a decrease in organic matter supply
- increased decomposition rates.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss fully how organic matter depletion may occur due to the following factors;

    - decrease in biomass production;
    - decrease in organic matter supply;
    - increased decomposition rates.

2. Explain how organic matter production and conservation may be affected by conventional tillage.

7.0 REFERENCES/FURTHER READING

Angers, D. A. & Carter, M. R. (1996). Aggregation and organic matter storage in cool, humid agricultural soils. In, M. R. Carter, & B. A. Stewart.(Eds.). 'Structure and organic matter storage in agricultural soils. Boca Raton: CRC Press. pp. 193-211.

Adiaha M. S. (2017). ‘The Role of Organic Matter in Tropical Soil Productivity.’ *World Scientific News 86(1), pp.1-66.*

UNIT 7 PRACTICES THAT INCREASE THE AMOUNT OF ORGANIC MATTER

CONTENTS

1.0 INTRODUCTION

Different approaches are required for different soil and climate conditions. However, the activities will be based on the same principle: increasing biomass production in order to build active organic matter. Active organic matter provides habitat and food for beneficial soil organisms that help build soil structure and porosity, provide nutrients to plants, and improve the water holding capacity of the soil.

2.0 OBJECTIVE

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

explain the practices that increase organic matter content of soils.

3.0 MAIN CONTENT

3.1 Practices that Increase the Amount of Organic Matter

Several cases have demonstrated that it is possible to restore organic matter levels in the soil. Activities that promote the accumulation and supply of organic matter, such as the use of cover crops and refraining from burning, and those that reduce decomposition rates, such as reduced and zero tillage, lead to an increase in the organic matter content in the soil.

The following Practices may increase the organic matter content of soils;

3.1.1 Increased Water Availability for Plants

In dry conditions, water may be provided through irrigation or water harvesting. The increased water availability enhances biomass production, soil biological activity and plant residues and roots that provide organic matter. Numerous water harvesting systems have been developed over the centuries, especially in arid areas. The principle of collecting runoff for crop production is also inherent to many other soil and water conservation technologies that apply the concept of runoff and runon areas at a micro-watershed level, such as negarims, trapezoidal or "eyebrow" bunds and tied ridges.

3.1.2 Balanced Fertilization

Where the supply of nutrients in the soil is ample, crops are more likely to grow well and produce large amounts of biomass. Fertilizers are needed in those cases where nutrients in the soil are lacking and cannot produce healthy crops and sufficient biomass. Most soils in sub-Saharan Africa (SSA) are deficient in P. P is required not only for plant growth but also for N fixation. Unbalanced fertilization, for example mainly with N, may result in more weed competition, higher pest incidence and loss of quality of the product. Unbalanced fertilization eventually leads to unhealthy plants. Therefore, fertilizers should be applied in sufficient quantities and in balanced proportions. The efficiency of fertilizer use will be high where the organic matter content of the soil is also high. When soil organic matter levels are restored, fertilizer can help maintain the revolving fund of nutrients in the soil by increasing crop yields and, consequently, the amount of residues returned to the soil.

3.1.3 Cover Crops

Growing cover crops is one of the best practices for improving organic matter levels and, hence, soil quality. The benefits of growing cover crops include:

- They prevent erosion by anchoring soil and lessening the impact of raindrops.
- They add plant material to the soil for organic matter replenishment.
- Some, e.g. rye, bind excess nutrients in the soil and prevent leaching.
- Some, especially leguminous species, e.g. hairy vetch, fix N in the soil for future use.
- Most provide habitat for beneficial insects and other organisms.
- They moderate soil temperatures and, hence, protect soil organisms.

A range of crops can be used as vegetative cover, e.g. grains, legumes and oil crops. All have the potential to provide great benefit to the soil. However, some crops emphasize certain benefits; a useful consideration when planning a rotation scheme. It is important to start the first years with (cover) crops that cover the surface with a large amount of residues that decompose slowly (because of the high C:N ratio). Grasses and cereals are most appropriate for this stage, also because of their intensive rooting system, which improves the soil structure rapidly.

The term green manure is often used to indicate the same plant species that are used as cover crops. However, green manure refers specifically to a crop in the rotation grown for incorporation of the non-decomposed vegetative matter in the soil. While this practice is used specifically to add organic matter, this is not the most effective use of organic matter (especially in hot climates) for two reasons:

- Mechanical disturbance of the soil should be avoided as much as possible.
- When biomass is incorporated in the soil all at one time, there is a short period of high microbial activity in decomposing the material. This results in the sudden release of a large quantity of nutrients that cannot be captured by the seedlings of the following crop and is thus lost from the system.

3.1.4 Improved Vegetative Stands

In many places, low plant densities limit crop yields. Wide plant spacing is often practised as “a way to return power to the soil” or “to give the soil some rest”, but in reality it is an indicator that the soil is impoverished. Plant spacing is usually determined by farmers in relation to soil fertility and available water or expected rainfall (unless standard recommendations are enforced by extension). This means that plants are often spaced widely on depleted soils in arid and semi-arid regions with a view to ensuring an adequate provision of plant nutrients and water for all plants.

3.1.5 Agroforestry and Alley Cropping

Agroforestry is a collective name for land-use systems where woody perennials (trees, shrubs, palms, etc.) are integrated in the farming system. Alley cropping is an agroforestry system in which crops are grown between rows of planted woody shrubs or trees. These are pruned during the cropping season to provide green manure and to minimise shading of crops.

Alley cropping is an agroforestry practice that places trees within agricultural cropland systems. This system is sometimes called intercropping, especially in tropical areas. It is especially attractive to producers interested in growing multiple crops on the same acreage to improve whole-farm yield. Growing a variety of crops in close proximity to each other can create significant benefits to producers and help them manage risk. Alley cropping systems change over time. As trees and shrubs grow, they influence the light, water, and nutrient regimes in the field. These interactions are what set alley cropping apart from more common mono-cropping systems. Some producers plan alley cropping systems to provide additional functions that support and enhance other aspects of their operation. For example, a livestock producer might grow crops that supply fodder, bedding, or mast crops for their livestock. Other producers may want to produce biomass for on-farm use. Organic producers may choose tree species that fix nitrogen. Like all agroforestry systems, alley cropping systems should be considered as part of the whole farm operation.

3.1.5.1 Design Considerations Alley Cropping

i. The tree and crop species should be suited to the soils, climate, and the site.
ii. Species and spacing should ensure accessibility for timely management activities such as spraying, pruning, or harvesting.
iii. The size of available equipment used for the alley cropping will in part dictate the width of the alleys.
iv. Take into account growth in both height and width of trees and shrubs on either side of the alleys.
v. Optimal tree row orientation depends on the specific alley crop and alley width. Tree rows planted on contours or aligned in a keyline system can help reduce soil erosion.
vi. Managing the light for crops is important. As trees and shrubs grow they will create more shade on the companion crops. To address this change, trees can be thinned or crops can be planted that are more shade-tolerant or have a complementary growing season with the trees.
vii. Some plants, most notably black walnut, smooth brome, and some fescue grasses, produce chemicals that inhibit the growth of other plants. Find out which plants are most susceptible to any allelopathic species under consideration.
viii. Competition for space, water, and nutrients in the soil is also an issue. Try to choose plants that have root structures that are less likely to compete for valuable resources.
ix. Understand the producer's goals for the system. Most producers have other goals beyond optimising or maximising income. Wildlife and water quality are also common interests of producers.

3.1.6 Reforestation and afforestation

Afforestation means the establishment of a forest on land that has not grown trees recently. It can serve two principal soil and water conservation purposes: protection of erosion-prone areas, and revegetation and rehabilitation of degraded land. Afforestation is specifically used to provide protective cover in vulnerable, steep and mountainous areas. Afforestation helps to replenish timber resources and provide fuel-wood and fodder. The establishment of a forest cover under good management is an effective means of increasing organic matter production.

3.1.6.Why Reforestation and Afforestation

Reforestation and afforestation are two of the leading nature-based solutions for tackling the effects of climate change. For commercial foresters and landowners, these two practices are essential to ensuring they can grow wood for wood products and continuously meet demand in a sustainable way. Reforestation is crucial in combating or preventing deforestation or forest degradation, where forests shrink in size or are completely removed. As well as reducing a forest's ability to absorb carbon dioxide (CO_2), deforestation can destroy wildlife habitats and contribute to the likelihood of flooding in certain areas. Afforestation can also help avoid desertification, where fertile land turns into a desert as a result of drought or intensive agriculture.

How Reforestation and Afforestation Limit the Effects of Climate Change

Forests are a natural way of keeping the earth's CO_2 levels in check. The more trees there are, the more CO_2 is captured and converted into oxygen through photosynthesis. By absorbing CO_2, forests help to lower the amount of greenhouse gasses in the atmosphere and reduce the effects of climate change. Reforestation and afforestation help maximize these abilities of forests by increasing the overall amount of forested land on the planet.

The Roles Does Reforestation Play in Commercial Forestry

The global wood products industry depends on sustainable forests to supply the wood needed to make furniture, create construction materials and provide fuel for energy. The supply chain will often start with what's called a 'working forest' – a commercially-run forest which is often privately owned. The landowner will grow a working forest to a certain stage of maturity and then harvest some or all of the trees to sell the wood. Once the wood has been sold for use as lumber, wood products or fuel, the landowner will reforest the areas to regrow the trees.Foresters will typically do this in stages across their land to ensure there are multiple stands of forest at different stages of growth across their land, which ensures there is consistent, sustainable growth at all times.

3.1.7 Regeneration of Natural Vegetation

Regeneration of natural grasslands and forest areas increases biomass production and improves the plant species diversity, resulting in more diverse soil biota and other associated beneficial organisms. Natural regeneration may be more reliable where land is not very productive. In some cases, natural regeneration of a given area may lead to the infestation of plots by weeds. Increasingly, natural vegetation is being recognised for its multipurpose benefits, for example, fuelwood, fibre, biocontrol (e.g. neem) and medicinal species, as well as restoration of soil fertility (*Acacia albida* and other leguminous species) and habitats for various beneficial species (pollinators and natural enemies) as well as wildlife.

3.1.8 Protection from Fire

Burning affects organic matter recycling significantly. Fire destroys almost all organic materials on the land surface except for tree trunks and large branches. In addition, the surface soil is sterilised, loses part of its organic matter, the population of soil microfauna and macrofauna is reduced, and no ready-to-use organic matter is available for rapid restoration of the populations. However, this practice is widely used (e.g. in Africa) in order to enhance pasture regrowth for livestock (using residual P), to control pests and diseases, and even to catch small animals for food.

3.1.9 Crop Residue Management

The most appropriate method for managing crop residues depends on the purpose of the crop residues and the experience and equipment available to the farmer. Where the aim is to maintain mulch over the soil for as long as possible, the biomass is best managed using a knife roller, chain or sledge in order to break it down but not kill it. Where the decomposition process should commence immediately in order to release nutrients, the residues should be slashed or mown and some N applied because dry residues have a high C:N ratio. However, in order to avoid nitrate emission, urea should not be broadcast on the surface but injected where possible.

In systems where crop residues are managed well, they:

- add soil organic matter, which improves the quality of the seedbed and increases the water infiltration and retention capacity of the soil, buffers the pH and facilitates the availability of nutrients;
- sequester (store) C in the soil;
- provide nutrients for soil biological activity and plant uptake;
- capture the rainfall on the surface and thus increase infiltration and the soil moisture content;
- provide a cover to protect the soil from being eroded;
- reduce evaporation and avoid desiccation from the soil surface.

Depending on the nature of the following crop, decisions are made as to whether the residues should be distributed evenly over the field or left intact, e.g. where climbing cover crops (e.g. mucuna) use the maize stalks as a trellis.

An even distribution of residues will help achieve the following:

(i) provides homogenous temperature and humidity conditions at sowing time;
(ii) facilitates even sowing, germination and emergence;
(iii) minimises the development of pests and diseases; and
(iv) reduces the emergence of weeds through allelopathic effects.

3.1.10 Integrated Pest Management

As with balanced fertilization, proper pest and disease management results in healthy crops. Healthy crops produce optimal biomass, which is necessary for organic matter production in the soil. Diversified cropping and mixed crop-livestock systems enhance biological control of pests and diseases through species interactions. Through integrated production and pest management farmers learn how to maintain a healthy environment for their crops. They learn to examine their crops regularly in order to observe ratios of pests to natural enemies (beneficial predators) and cases of damage, and on that basis to make decisions as to whether it is necessary to use natural treatments (using local products such as neem or tobacco) or chemical treatments and the required applications.

3.1.11 Compost

Composting is a technology for recycling organic materials in order to achieve enhanced agricultural production. Biological and chemical processes accelerate the rate of decomposition and transform organic materials into a more stable humus form for application to the soil. Composting proceeds under controlled conditions in compost heaps and pits.

3.1.12 Mulch or Permanent Soil Cover

One way to improve the condition of the soil is to mulch the area requiring amelioration. Mulches are materials placed on the soil surface to protect it against raindrop impact and erosion, and to enhance its fertility. Crop residue mulching is a system of maintaining a protective cover of vegetative residues such as straw, maize stalks, palm fronds and stubble on the soil surface. Mulching adds organic matter to the soil, reduces weed growth, and virtually eliminates erosion during the period when the ground is covered with mulch.

There are two principal mulching systems:

- *in situ* mulching systems - plant residues remain where they fall on the ground;
- cut-and-carry mulching systems - plant residues are brought from elsewhere and used as mulch.

3.1.13 Reduced or Zero Tillage

Repetitive tillage degrades the soil structure and its potential to hold moisture, reduces the amount of organic matter in the soil, breaks up aggregates, and reduces the population of soil fauna such as earthworms that contribute to nutrient cycling and soil structure. Avoiding mechanical soil disturbance implies growing crops without mechanical seedbed preparation or soil disturbance since the harvest of the previous crop. The term zero tillage is used for this practice, synonymously, with terms such as no-till farming, no tillage, direct drilling, and direct seeding.

SELF-ASSESSMENT EXERCISE

What are some of the practices that affect the availability of organic matter in the tropics?

4.0 CONCLUSION

Activities that promote the accumulation and supply of organic matter, such as the use of cover crops and refraining from burning, and those that reduce decomposition rates, such as reduced and zero tillage, lead to an increase in the organic matter content in the soil.

5.0 SUMMARY

In this unit, you have leant some practices that enhance the organic matter content of soils. These practices may include the following;

- Increased water availability, balanced fertilization, cover crops, afforestation and reforestation, improved vegetative stand, integrated pest management, compost, mulching, and zero tillage.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the practices that may increase soil organic matter you studied.
2. Outline the advantages of systems where crop residues are well managed.
3. Enumerate what even distribution of residues in our soils will help achieve.

7.0 REFERENCES/FURTHER READING

Adiaha M. S. (2017). The Role of Organic Matter in Tropical Soil Productivity. *World Scientific News 86(1),pp.1-66.*

Baldock, J. A. & Skjemstad, J. O. (1999). Soil organic carbon/soil organic matter. In 'Soil Analysis: An Interpretation Manual. (Eds

K. I. Peverill, L. A. Sparrow, & D. J. Reuter.) pp. 159-170. (CSIRO Publishing: Collingwood.)

Emerson, W. W. & McGarry, D. (2003). 'Organic carbon and soil porosity.' *Australian Journal of Soil Research* 41, 107-118.

MODULE 2 LIMING AND ITS SOIL PLANT RELATIONSHIP

UNIT 1 LIMING

CONTENTS

1.0 INTRODUCTION

Liming is the application (to soil) of calcium- and magnesium-rich materials in various forms, including marl, chalk, limestone, burnt lime or hydrated lime. In acid soils, these materials react as a base and neutralize soil acidity. This often improves plant growth and increases the activity of soil bacteria, but oversupply may result in harm to plant life.

2.0 OBJECTIVES

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

- discuss what liming is all about
- explain causes of soil acidity.

3.0 MAIN CONTENT

3.1 Liming of Soils

What is liming?

Liming is a traditional procedure in preparing soil for planting. It is the application of calcium- and magnesium-rich materials to soil in various forms, including marl, chalk, limestone, or hydrated lime. Lime used on farm land is also called **agricultural lime**. The primary reason to apply agricultural lime is to **correct the high levels of acidity in the soil**. Acid soils reduce plant growth by inhibiting the intake of major plant nutrients -nitrogen, phosphorus and potassium. Some plants, for example legumes, will not grow in highly acidic soils.

3.2 Causes of Soil Acidity

- Leaching of land caused by high rainfall levels
- Application of modern chemical fertilizers, which are the major contributors of acidified soil
- acidic precipitation in its true sense, that is H^+ ions in precipitation;
- the deposition from the atmosphere of acidifying gases or particles such as sulphur dioxide (SO_2), ammonia (NH_3) and nitric and hydrochloric acids (HNO_3; HCl);
- nutrient uptake by crops and root exudates;
- the mineralisation of organic matter.

1. Leaching of basic cations

Over time, soils also become acidic because calcium and magnesium leach out, because hydrogen is added to soils by decomposition of plant residues and organic matter, or because nitrification of ammonium occurs when fertilizer (UAN solutions, urea, ammonium nitrate, ammonium sulfate, anhydrous ammonia), manure, or plant residues are added to the soil. Lime will neutralise this acidity by dissolving, whereupon it releases a base into the soil solution that reacts with the acidic components, hydrogen and aluminum.

2. Acidic precipitation

'Pure' rain is usually slightly acid, with a pH of between 5 and 5.6 because of the dissolution of carbon dioxide (CO_2) and the dissociation of the resulting carbonic acid (H_2CO_3). A soil exposed to such rain, but no other acidifying inputs and receiving no lime, would attain the same equilibrium pH as that of the rain. There are, however, very strong localized effects because human activity has increased the acidity of precipitation through emissions of acidifying compounds such as

SO_2 and nitrogen oxides (NOx) from industry and motor vehicles, and NH_3 volatilised from manures and fertilizers

3. Acidifying fertilizers and legumes

The most important causes of soil acidification on agricultural land are the application of ammonium-based fertilizers and urea, elemental S fertilizer and the growth of legumes (Bolan & Hedley, 2003). Ammonium salts strongly acidify soils through the process of nitrification.

$$NH^{+}_{4}+2O^{2}=NO^{-}_{3}+2H^{+}+H_2O$$

4. Nutrient uptake by crops and root exudates

Plant growth and nutrient uptake result in some localized acidification around plant roots through the exudation of acids from the roots (Hinsinger *et al*., 2003). Excluding the particular case of legumes, the contribution of this to bulk soil acidification is small (<10%) when compared with N and S fertilizer inputs but it has an important influence on the bioavailability of plant nutrients in the rhizosphere (Marschner, 2012).

5. Mineralization

When microorganisms decompose soil organic matter they produce CO_2, which dissolves in soil water to form H_2CO_3 in the same way as in rain. Thus, soil and root respiration can result in a large concentration of CO_2 in soil air, but because acidic soil solutions hold very little CO_2, the process is unlikely to cause soil pH to decline below 5 (Bolan *et al*., 2003).

Soil with pH below 5.5 and below 70% of saturation requires liming. The best time is when plowing stubble, when there are no crops in the field. **Effect of liming takes on average 6-7 years**.

Agricultural lime has good effects on soil:

- Increases the pH of acidic soil
- Provides a source of calcium and magnesium for plants
- Permits improved water penetration for acidic soils

- Improves the uptake of major plant nutrients (nitrogen, phosphorus, and potassium) of plants growing on acid soils

Most of farming crops require neutral soil, with pH around 6-7, but there are also cultures that need expressly acidic or alkaline soil.

6. Soil pH and Soil Acidity

Soil pH is an indicator of “soil acidity”. A pH of 7.0 is defined as neutral. Values below 7.0 are acidic, and values above 7.0 are basic or alkaline. Small changes in numbers indicate large changes in soil acidity. A soil with a pH of 5 is 10 times more acidic than a soil with a pH of 6 and 100 times more acidic than a soil with a pH of 7. Most plants can grow in slightly acidic soils, so the goal of liming is not to raise the pH to neutral (7.0), but to avoid crop problems related to excessive acidity.

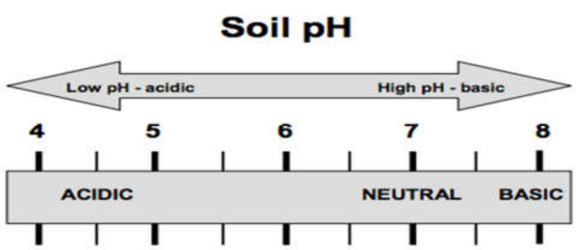


Fig. 1.1 Relationship between soil pH and acidity

Benefits of Proper Lime Use

Proper liming provides a number of benefits:

- Plants develop healthier roots because they are exposed to less potentially toxic aluminum. Better root growth may enhance drought tolerance.

- Lime is a source of calcium (as well as magnesium, if dolomitic limestone is applied).

- Nutrient solubility is improved by a higher pH, so plants have a better nutrient supply. (The optimum pH for most crops is 5.8 to 6.2 when grown on mineral soils in North Carolina.)

- Increased soil CEC occurs, as well as reduced leaching of basic cations, particularly potassium.
- Nodulation of legumes is enhanced, which improves nitrogen fixation.
- Triazine herbicides, such as atrazine and simazine, work better.
- Optimal pH allows the breakdown of some herbicides, preventing damage to rotational crops.
- Some nematicides work better.

SELF-ASSESSMENT EXERCISE

What are the major implications of liming on agricultural soils?

4.0 CONCLUSION

Liming is the application (to soil) of calcium- and magnesium-rich materials in various forms, including marl, chalk, limestone, burnt lime or hydrated lime. "Soil acidity" is the term used to express the quantity of hydrogen (H) and aluminum (Al) cations (positively charged ions) in soils. When levels of hydrogen or aluminum become too high—and the soil becomes too acid—the soil's negatively charged cation exchange capacity (CEC) becomes "clogged" with the positively charged hydrogen and aluminum, and the nutrients needed for plant growth are pushed out. Application of lime neutralizes the acidity due to hydrogen and aluminum.

5.0 SUMMARY

In this unit, you have leant that:

- Liming is the application of calcium and magnesium rich materials which may be in various forms to the soil to reduce acidity.
- You have also leant that some of the causes of acidity may include leaching of basic cations, acid rains, application of acidic fertilizers, mineralisation of organic matter and nutrient uptake by crops as well as exudates of acidic substances from roots of certain plants.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define liming and mention some substances used as lime to the soil
2. Explain the causes of acidity in the soil
3. What are the advantages of lime application to the soil?
4. Explain the relationship between soil pH and soil acidity

7.0 REFERENCES/FURTHER READING

Marschner, P. (Ed.) 2012. Marschner's Mineral Nutrition of Higher Plants.(3rd ed.). Academic Press, London.

Hinsinger, P. , Plassard, C. , Tang, C. & Jaillard, B. (2003). Origins of root-mediated Ph changes in the rhizosphere and their responses to environmental constraints: a review. Plant and Soil, 248, pp.43–59.

Bolan, N.S. Adriano, D.C. & Curtin, D. (2003). Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Advances in Agronomy, 78, pp.215–272.

https://blog.agrivi.com/post/importance-of-liming-for-high-soil-fertility

https://content.ces.ncsu.edu/soil-acidity-and-liming-basic-information-for-farmers-and-gardeners

UNIT 2 LIMING AND SOIL PRODUCTIVITY

CONTENTS

1.0 INTRODUCTION

The most commonly used liming materials are ground limestone, dolomitic ground limestone, chalk, ground chalk, burnt lime and hydrated lime; almost 70% of the material currently used in the UK is ground limestone. For example, 'ground limestone' means 'sedimentary rock consisting largely of calcium carbonate and containing not more than 15% of magnesium expressed as MgO and of which 100% will pass through a sieve of 5 mm, not less than 95% will pass through a sieve of 3.35 mm and not less than 40% will pass through a 150-micron (150 μm) sieve'. The seller must also declare the neutralizing value (NV) and the amount of material as a percentage by weight that will pass through a 150-micron sieve.

2.0 OBJECTIVES

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

- explain different liming materials
- discuss the quality standards to differentiate liming materials.

3.0 MAIN CONTENT

3.1 Liming Materials

A liming material can bring the pH of a soil to optimum levels for crop production if used properly. Liming materials also provide calcium (Ca) and/or magnesium (Mg) to the soil for plant uptake. Materials that can cause an increase in pH include carbonates, oxides or hydroxides of calcium and magnesium. When looking at liming materials it is often hard to distinguish one material from another. Quality standards used to differentiate liming materials include Total Neutralising Value (TNV), Calcium Carbonate Equivalence (CCE), Fineness, and Effective Neutralising Value (ENV).

3.2 Quality standards used to differentiate liming materials

i. Total Neutralising Value (TNV)

This is the percentage of the material that can neutralise acid expressed as the calcium carbonate equivalence (CCE) of the product.

ii. Calcium Carbonate Equivalence (CCE)

This standard compares the liming material to pure calcium carbonate ($CaCO_3$). Some materials such as hydrated lime and burned lime will have a CCE higher than 100%. Pure magnesium carbonate ($MgCO_3$) will neutralise about 1.2 times more acidity than $CaCO_3$ so dolomitic limestone will have a higher CCE than calcitic limestone.

iii. Fineness

The rate of reaction of a liming material is determined by the particle sizes of the material; 100% of lime particles passing a 100-mesh screen will react within the 1st year while only 60% of the liming materials passing a 20-mesh sieve (but held on 100 mesh sieve) will react within a year of application. Material that does not pass the 20 mesh sieve is not expected to react within a 1 year following application.

iv. Effective Neutralising Value (ENV)

The ENV is the fraction of the material's CCE that will react with soil acidity in the first year of application. The ENV is calculated by multiplying a liming material's CCE and its fineness. As an example: a liming material with CCE of 90% and a fineness of 0.86 has an ENV of 90*0.86= 77.4.

3.3 Commonly Used Lime Materials

The Neutralisation Values (NV) of the material defines the amount of acidity that it will neutralise and is based on a reaction with HCl in a laboratory. Typical NVs of the three most commonly used materials are as follows:

1. Limestone ($CaCO_3$), NV = 50–55% depending on the geological strata;
2. Dolomitic limestone ($CaMg(CO_3)_2$, usually 42% $CaCO_3$ and 53% $MgCO_3$), NV = 56%;
3. Chalk ($CaCO_3$), more readily broken down and absorbed into the soil solution than limestone, NV = 48–54%.

However, the effectiveness of a liming material also depends on its reactivity, effectively its rate of dissolution, which depends on particle size and hardness. For example, the difference between 'ground' and 'screened' limestone is the amount that will pass through a 150-micron sieve: that is screened limestone is a coarser material and so it reacts more slowly.

Throughout Europe, each country has its own specifications for liming materials but the European Union has proposed harmonising regulations. EC Regulation 463/2013 adds liming materials to the European Fertiliser Regulations so that they can be sold as 'EC Fertiliser Liming Materials', in which case sales documentation must state the parent rock type (e.g. Chalk), the grade of product, the NV and the Ca^{2+} and/or Mg^{2+} content.

3.4 Other Acid-Neutralising Materials

A number of 'waste products' are available that neutralise acidity: sugar factory lime, basic slag, wood ash, coal combustion products such as fly ash and bottom ash, calcium humates and fulvates from oxidised brown coal and by-products of the paper and pulp industry (e.g. Bolan *et al.*, 2003; Gagnon *et al.*, 2014). The NVs of some of these, compared with lime-based products, are shown in Table 1. Sugar Factory (or Spent) Lime is a by-product of sugar beet purification. It also contains some nutrients, approximately 3–5 kg N, 7–10 kg 'available' P_2O_5, 5–7 kg MgO and 4–6 kg SO_3 per tonne of lime and has a fine particle size, so is fast-acting.

Table 2. 1: The Neutralising value of various liming materials expressed as a weight percentage of pure lime ($CaCO_3$) adapted from Bolan *et al.* (2003)

Liming Material	**Chemical formula**	**Neutralizing value**
Burnt lime	CaO	179.0
Slaked lime	$Ca(OH)_2$	136.0
Dolomitic lime	$CaMg(CO_3)_2$	109.0
Lime	*$CaCO_3$*	100.0
Basic slag	$CaSiO_3$	86.0
Phosphogypsum	$CaSO_4.2H_2O$	0.3
Mined gypsum	$CaSO_4.2H_2O$	12.4
Flue gas desuphurised gypsum	$CaSO_4.2H_2O$	0.1
Coal fly ash		variable

*Italicised text shows lime as the reference against which other acid neutralising materials are compared

3.5 Positive Effects of Liming on Soil Properties

- Liming increases Ca^{2+} concentrations and ionic strength in the soil solution, causing clay flocculation and thus an improvement in soil structure and hydraulic conductivity (Haynes & Naidu, 1998).

- Liming also increases earthworm activity and therefore macroporosity (Bolan *et al.*, 2003).

- Because of the beneficial influence of lime on soil structure, there has been much research on the use of lime and other acid-neutralizing materials for improving degraded soils, especially in arid and semi-arid countries, for example Kirkham *et al.* (2007).

- Bennett *et al.* (2014) found that lime applied at 5 t/ha was still improving aggregate stability, hydraulic conductivity, vegetation cover, total C and N and soil respiration 12 years after application.

- Dolomitic limestone is recommended for soils deficient in Mg^{2+} but using it too frequently can result in Mg^{2+} indices >3 and so poor K^+ availability. In such a situation, farmers should ensure that there is sufficient K^+ available and so no risk of K^+ deficiency in the crops grown.

SELF-ASSESSMENT EXERCISE

1. How would you explain a liming material- and how does it relate to soil productivity?

2. Describe the quality standards used in differentiating liming materials.

4.0 CONCLUSION

Liming has strong effect on soil productivity as it helps to reduce the acidity of the soils. The acidity is mostly due to the deposits of hydrogen and aluminum in agricultural soils. Application of lime neutralises the acidity due to hydrogen and aluminum. When levels of hydrogen or aluminum become too high—and the soil becomes too acid—the soil's negatively charged cation exchange capacity (CEC) becomes "clogged" with the positively charged hydrogen and aluminum, and the nutrients needed for plant growth are pushed out.

5.0 SUMMARY

Liming material can bring the pH of a soil to optimum levels for crop production when it is properly used. Liming materials also provide calcium (Ca) and/or magnesium (Mg) to the soil for plant uptake. Materials that can cause an increase in pH include carbonates, oxides or hydroxides of calcium and magnesium. When looking at liming materials it is often hard to distinguish one material from another. Quality standards used to differentiate liming materials include Total Neutralizing Value (TNV), Calcium Carbonate Equivalence (CCE), Fineness, and Effective Neutralizing Value (ENV).

6.0 TUTOR-MARKED ASSIGNMENT

1. What is a liming material and how does it relate to soil productivity.
2. Discuss the quality standards used in differentiating liming materials.
3. What are the positive effects of liming on soil properties?
4. In a tabular form, state the liming materials you know indicating their chemical formula and neutralising values.

7.0 REFERENCES/FURTHER READING

Bennett, J.McL , Greene, R.S.B. , Murphy, B.W. , Hocking, P. & Tongway, D. 2014. Influence of lime and gypsum on long-term rehabilitation of a Red Sodosol, in a semi-arid environment of New South Wales. Soil Research, 52, 120–128.

Bolan, N.S., Adriano, D.C. & Curtin, D. 2003. Soil acidification and liming interactions with nutrient and heavy metal transformation and bioavailability. Advances in Agronomy, 78, 215–272.

Gagnon, B. , Robichaud, A. , Ziadi, N. & Karam, A. 2014. Repeated annual paper mill and alkaline residuals application affects soil metal fractions. Journal of Environmental Quality, 43, 517–527.

Haynes, R.J. & Naidu, R. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. Nutrient Cycling in Agroecosystems, 51, 123–137.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5032897/

MODULE 3 SOIL PLANT NUTRIENTS ELEMENTS

UNIT 1 NITROGEN CONTENT OF SOILS

CONTENTS

1.0 INTRODUCTION

Nitrogen (N) is the most abundant element in the atmosphere and is usually the most limiting crop nutrient. Nitrogen cycles through soil in various processes and forms. Some processes are necessary to convert N into forms which plants can use. Some processes can lead to N losses such as leaching or volatilisation. Nitrogen is added to soil naturally from N fixation by soil bacteria and legumes and through atmospheric deposition in rainfall. Additional N is typically supplied to the crop by fertilizers, manure, or other organic materials. Soil nitrate-N is an excellent indicator of N-cycling in soils, whether carryover nitrogen was used by the previous crop and whether additional nitrogen is needed.

2.0 OBJECTIVES

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

- discuss Nitrogen content of soils and
- explain factors affecting its availability to plants.

3.0 MAIN CONTENT

3.1 Nitrogen Content of Soils

Improved agricultural methods and better crop varieties are demanding more and more of this element. Soils alone seldom can meet the increased demand because they were never well supplied with nitrogen or because they have lost much of their original supply during 50 to 100 years of cultivation. Nitrogen is of special importance because plants need it in rather large amounts, it is fairly expensive to supply, and it is easily lost from the soil. A major factor in successful farming is the farmer's ability to manage nitrogen efficiently.

3.2 Losses of Nitrogen from Soil-Plant System

Apart from nitrate (NO_3 – N) and ammonium ($NH4^+$ -N) which are plant utilizable forms of nitrogen in the soil, other forms of inorganic N such as nitrogen dioxide (NO2), nitric oxide (NO) ammonia (NH3), nitrous oxide N 20 and nitrogen gas (N2) do exist having been transformed from organic fractions. However, these other forms usually escape to the atmosphere in gaseous forms completely away from the soil-plant system. They are regarded as nitrogen losses and are usually the products of **denitrification** and **volatilisation.**

Other losses are through **crop removal** or by harvest, **erosional losses** and **liquid leaching losses.** Certain portions of nitrogen (NH4 – N and simple amino compounds) are held on negatively charged sites in the soil in the interlayer spaces of 2:1 clay minerals and are also unavailable to crops but cannot be regarded as losses since they can still be released for plant use under certain soil conditions.

3.3 Inherent Factors Affecting Soil Nitrogen

- Inherent factors such as soil drainage, soil texture, and slope steepness impact N-transport and N transformation processes that limit availability to crops or lead to losses.
- Inherent factors such as rainfall and temperature; and site conditions such as moisture, soil aeration (oxygen levels), and salt content (electrical conductivity/EC) affect rate of N mineralisation from organic matter decomposition, nitrogen cycling, and nitrogen losses through leaching, runoff, or denitrification.
- Organic matter decomposes releasing N more quickly in warm humid climates and slower in cool dry climates. This N release is also quicker in well aerated soils and much slower on wet saturated soils.

3.3.1 How leaching affects soil Nitrogen

Nitrogen can readily leach out of the root zone in nitrate-N form. The potential for leaching is dependent on soil texture (percentage of sand, silt, and clay) and soil water content. Water moves more quickly through large pore spaces in a sandy soil than it does through small pores in a clayey soil and water holding capacity is much lower in sandy soils, making them especially vulnerable. Soils that have poor drainage and are ponded or saturated with water causes denitrification to occur resulting in loss of N as a gas which can result in emission of potent greenhouse gases, yield reduction and increased N fertilizer expense.

3.4 Nitrogen Management

Management factors, such as N-rate, N source, N placement method, timing of application, irrigation management, residue management, crop type, etc. all can affect how efficiently N is used by crops and amount of N losses. Nitrogen management on sandy soils is important because of high potential for leaching losses. Selecting appropriate N rate is the primary management consideration. However, nitrogen source, timing N application close to plant uptake, and method of application such as injecting N to avoid losses are also important. Management measures that increase organic matter and avoid compaction are also important to stabilize crop N supply, increase aeration, and to limit N losses due to denitrification occurring in saturated soils.

3.4.1 Nitrogen Supply to Soils

Nitrogen rates should be based on amount needed to optimize yield based on agronomic economic and environmental considerations. When planning N-fertilizer or manure application rates appropriate N-credits should be accounted for including; soil test residual nitrate-N, soil organic matter mineralisation, legume credits, manure or other organic amendments, irrigation water nitrate-N, residue decomposition and natural N sources. Time N fertilisation to provide adequate amounts of N when plants are actively growing and using N rapidly. Losses of applied N from fertilizer can be reduced by delaying application until the crop has emerged (side dressing). Split N applications, where some N is applied prior to crop emergence and the balance after emergence can increase crop N-use efficiency. Fertilizer source is important to increase N recovery by crops, avoid N-loss from volatisation and be matched to the type of placement method to reduce losses and maximise recovery by crops. Anhydrous ammonia is usually the least expensive N source, but this material must be handled safely, and must be injected/knifed in with ideal soil moisture conditions. Urea and urea containing materials should be injected to reduce loss from ammonia volatilization. Surface applied urea N fertilizers, should not be applied during warm humid conditions, or on wet residues because of high potential for N losses from volatisation. Manure or organic amendments can be an effective N-fertilizer. However, care must be taken to apply manure uniformly at a known rate, and account for mineralisation rate. Placement of N-fertilizer can be accomplished by several methods.

3.4.2 Methods of N Application

Typical methods include:

- Side dress applications after crop emergence,
- Knifed application placing a band of fertilizer below the soil surface,
- broadcast applications that uniformly distribute N, and
- Through sprinkler irrigation systems.

Each placement method has its advantages, and must be matched to type of fertilizer or manure that will be applied. Irrigation scheduling is important. The goal is to supply enough water to optimise yield while avoiding excess irrigation which can increase costs and leach N below the root zone.

3.4.3 Keys to Managing N in Most Efficient Manner include these Strategies:

1) Apply recommended rate based on realistic yield

2) Time N application just before peak crop demand

3) Select an ammonium containing fertilizer which provides greater N recovery by crops

4) Inject N if possible to avoid ammonia or volatisation losses

5) Use N-inhibitors when N is applied outside of growing season

6) Credit all sources of N

7) Irrigate wisely

8) Monitor crop nitrogen needs by scouting

9) Regular soil testing for nitrate (including deep samples), and soil salt content (EC)

3.3.4 Symptom of N Deficiency in Crops

Yellow coloration in a “V” shaped pattern is symptomatic of nitrogen deficiency. This pattern progresses from leaf end to leaf collar and from lower to upper leaves. Lower leaves often die when nitrogen deficiency is severe.

3.4 Biological Nitrogen Fixation

Biological nitrogen fixation is the conversion of dinitrogen (N2) in soil air into combined forms useable by the plants and effected by microorganisms. Some groups of microbes live freely in the soil where they are able to convert N2 into body tissue nitrogen form and when they die and decompose, the combined nitrogen is released for plant use.

These groups of free living N-fixers are known as **Non-symbiotic nitrogen fixing microorganisms.** In the tropics ***Azotob**acter* and *Bjeirinckia* species are known to be free-living microbes that fix N2 under aerobic well aerated soils of pH 6.0. *Clostridium spp.* Are free-living bacteria that fix N2 under anaerobic conditions in soil. Other-living soil micro-organisms that fix nitrogen are blue -green algae and *Azospiriullum* in the rhizosphere of certain plants. The range of fixed N by these group of non-symbiotic microbes is between 2-25 kg/ha/year.

In **symbiotic fixation,** bacterial and *actinomycetes* effect the formation of **root nodules** (abnormal root growth) in both legume and non-legume plants and then inhabit those nodules where they fix nitrogen. The host plant supplies the bacteria with carbohydrate as source of energy, and the bacteria supplies the plant with fixed nitrogen compounds.in effect, both the plant and the microorganism have a mutually beneficial association known as *symbiosis.* There are various species of Rhizobium bacteria that inhabit different plant species such as *R. trifolic* which inhabit clovers, *R. japonicum* for *Glycine max* (soyabeans) and *R. Phaseoli* which associates with *Phaseolus vulgaris* (dry beans). Appropriate Rhizobia cultures are used to inoculate the soil for a particular crop to nodulate for the fixation of nitrogen.

3.5 Nitrogen Cycle

Besides nitrogen (N2) gas within soil pore space, nitrogen is found in both organic and inorganic forms in soil. Organic forms occur in soil organic matter which consists of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter, and stable organic matter. Predominate inorganic forms of N in soils are ammonium (NH4) and nitrate (NO3), which are both useable by plants. The nitrogen cycle (Fig. 3) illustrates reactions that various inorganic and organic N compounds undergo in soil. The nitrogen cycle typically begins with nitrogen in its simplest stable form, dinitrogen (N2) in air, and follows it through the processes of fixation, mineralisation, nitrification, leaching, plant assimilation, ammonia volatilisation, denitrification, and immobilisation.

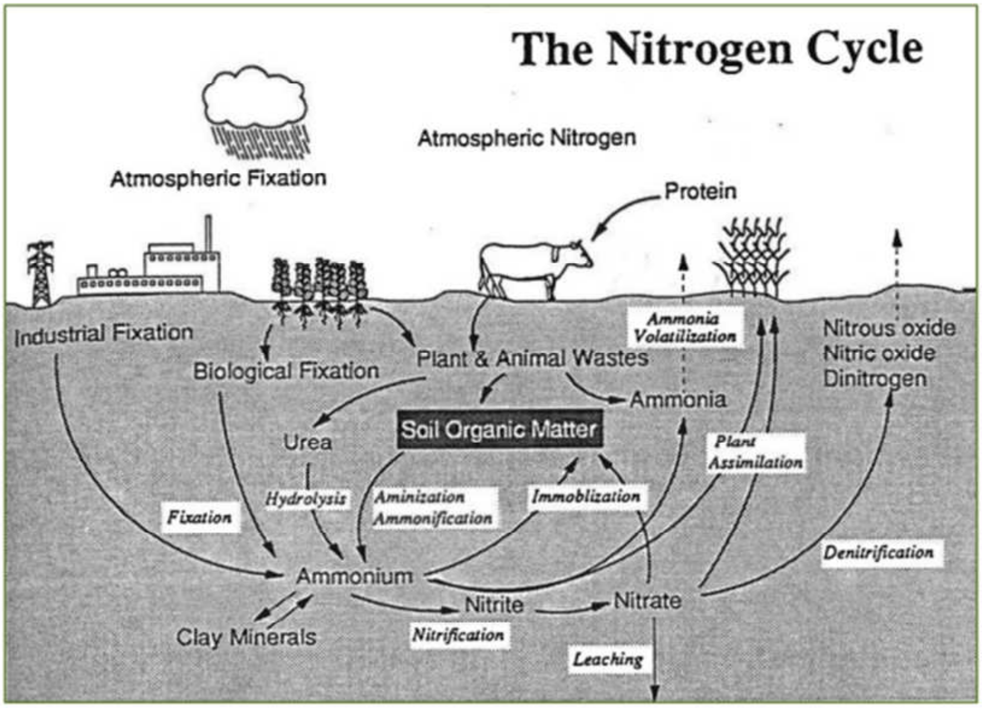


Fig 1. 1: Nitrogen Cycle

SELF-ASSESSMENT EXERCISE

1. Explain the nitrogen content of soils.
2. What are the inherent characteristics affecting soil nitrogen?
3. What are the keys to managing N in most efficient way in the tropical soils?

4.0 CONCLUSION

You have learnt that Nitrogen (N) is the most abundant element in the atmosphere and is usually the most limiting crop nutrient. Nitrogen cycles through soil in various processes and forms. Some processes can lead to N losses such as leaching or volatilisation. Nitrogen is added to soil naturally from N fixation by soil bacteria and legumes and through atmospheric deposition in rainfall.

5.0 SUMMARY

An abundant supply of the essential nitrogen compounds is required in each plant cell for a good rate of reproduction, growth, and respiration. Even the green leaf pigment chlorophyll, which enables plants to use the energy of sunlight to form sugars, starches, and fats from carbon dioxide and water, is a nitrogenous compound.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the nitrogen content of soils.
2. Outline the inherent factors affecting soil nitrogen.
3. Explain how nitrogen can be supplied to the soil.
4. Outline methods of nitrogen application to the soil.
5. What are the keys to managing N in most efficient way.
6. Use diagram to explain nitrogen cycle.

7.0 REFERENCES/FURTHER READING

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053274.pdf

UNIT 2 POTASSIUM CONTENT OF SOILS

CONTENTS

1.0 INTRODUCTION

Soil potassium (K) directly affects crop yield since K is responsible for the maintenance of osmotic pressure and cell size, which in turn influences photosynthesis and the energy production along with stomatal opening and carbon dioxide supply. Except nitrogen, K is a mineral nutrient plants require in largest amounts. Potassium is assimilated in relatively large quantities by the growing crop as the yield and quality are closely related to soil K (Tisdale, *et al* 1993). Plants require soil K for ATP production, translocation of sugars, starch production in grains, nitrogen fixation in legumes and protein synthesis.

2.0 OBJECTIVES

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

- explain the potassium content of soils
- discuss the importance of K in crop's nutritional requirements.

3.0 MAIN CONTENT

3.1 Potassium Content of Soils

The concentration and availability of K in the soil is primarily controlled by inorganic processes. Though K does not pose the potential environmental concerns that nitrogen and phosphorus do; an understanding of K cycling and availability is important for the management of profitable long-term cropping systems. Soil K has, however, not been given much attention by researchers as it deserves in the tropics. Possibly this neglect in K research could be due to the general assumption that most tropical soils contain adequate amounts of K to sustain crop growth. Whilst this assumption could be true, losses of K are basically incurred through leaching in drainage waters, crop removal, continuous cropping and utilisation by living organisms.

3.2 Forms of Soil K

Based on availability to plants, K can be categorised into three major forms:

- Relatively unavailable K; this is contained within the crystalline structure of micas, feldspars and clay minerals. Plants cannot use the K in these insoluble forms and therefore mineral weathering must take place. Because feldspars and micas are resistant to weathering they release only small quantities of K during a single cropping season.

- Slowly available (fixed) K; this form of K is trapped between the layers or plates of certain kinds of clay minerals as illite, vermiculite and chlorite. Potassium held in this manner cannot be used much by plants during a single growing season. However, the supply of fixed K largely determines the soil’s ability to supply K over extended periods of time.

- Readily available K; is that which is dissolved in soil water or held on the surface of clay particles. Plants absorb dissolved K readily, and as soon as the concentration in the soil solution drops, more is released into the solution from the exchangeable forms. Potassium in the soil solution, which represents a very small fraction of total soil K, is an important indicator of K availability.

Generally, 90 to 98 percent of the total K in soils is in the relatively unavailable form, 1 to 10 percent in the slowly available form and about 0.1 to 2 percent in the readily available form.

3.3 Sources of K in Soils

Clay minerals are the most important sources of soil K excluding that from fertilizers. They hold the bulk of mobile K and release it when the concentration of the soil solution falls due to uptake by plants or to an increase in soil moisture. It has also been observed that over 95 percent of the K in tropical soils is contained in primary and secondary minerals. Potash feldspars, muscovite and biotite are generally considered the original sources of K in soils. At equal clay content, the K concentration of soil solution depends on the nature of the clay minerals.

i. Kaolinitic clay minerals have no inter-lattice binding sites for K and a low cation exchange capacity. They do not hold non-exchangeable K and therefore behave similarly to sand and soil organic matter, as far as K dynamics are concerned.

ii. Illitic clay minerals, vermiculite and chlorite adsorb K selectively. According to Olaitan and Lombin (1984) illites form the most important clay mineral that contains K.
iii. The selectivity of montmorillonitic clay minerals (smectite) for K is lower than that of illitic but greater than that of kaolinitic clay minerals.

iv. Allophanes contain very small amounts of K.

3.4 Relationships between K Forms and other Soil Properties

- It has been reported that there is greater exchangeable K availability to plants in soils of coarse texture than on fine texture. Thus, replacement of a given amount of exchangeable bases will cause release of more K ions from sandy soils than from clayey soils with equal exchangeable K content.

- It has also been found that K fixation by samples of many soils of Finland increased with clay content indicating that soils with higher clay content are likely to contain more non-exchangeable K. Sands are often made up of almost entirely of quartz and therefore contain very small amounts of K minerals.

- Organic matter has no strong affinity for absorbing K. However, it has been argued that the CEC of organic matter increases with pH and that at higher pH levels organic matter may be able to serve better as a source of plant available K.

- The effect of soil pH on the availability of soil K is still a debatable issue. York et al (1953) noted that the fixation of fertilizer K takes place more readily in neutral than in acid soils and liming an acid soil increases its ability to fix K.

- It has also been reported that even though liming decreases K susceptibility to leaching, it might also reduce solution K to levels where plants suffer deficiencies.

3.5 Factors Affecting Availability and Fixation of Potassium Soils

Nature of Soil Colloids

The dominant clay species in a soil determines the extent to which added fertilizer K could be fixed. Soils in which 1:1-type clays, such as Kaolinite, are dominant fix very little K. On the other hand, soils in which 2:1-type clays, such as vermiculite, montmorrilonite and fine grained mica (illite), are dominant readily fix K in large amounts. The 2:1 clays have larger negative charge from isomorphous substitution of A13+ for Si4+ in their silical tetrahedral layer thereby strongly binding the K+ ions.

Alternate Wetting and Drying

Alternate wetting and drying and freezing and thawing has been reported to contribute to fixation of K into non-exchangeable form as well as its ultimate release to the soil solution. During wetting, the 2:1 expanding clay minerals increase their interlayer spaces and K+ ions could easily move into the spaces. On drying, the expanded layers collapse to entrap the K+ ions between the interlayer spaces, thereby preventing the release of the potassium. The same mechanism is believed to occur during freezing and thawing.

Influence of Lime

Application of lime usually results in an increase in K-fixation and thus conserved against leaching losses. Nevertheless, in soils where the negative charge is pH-dependent, liming can greatly reduce the level of K in the soil solution. High calcium levels in the soil solution also reduce potassium uptake by the plant.

Frequency of Application

Frequent light applications of K are found to be superior to heavier ones. Frequent light applications are recommended to avoid luxury consumption, leaching losses and fixation of excess potassium.

Crop Removal

Crop removal of K is higher than all other nutrient elements except nitrogen. Annual losses by crop removal could be as high as 200kg ha-1 of K especially in leguminious crops such as soya bean and cowpea.

The percent recovery of K from fertilizer – K by crops on most soils is about 70% but if the clay content is up to 27%, especially illite clay, recovery is only about 30%.

Presence of other Nutrient Elements

Potassium is supplied as cation K^+ and it is readily available to crops. However, there is competition between NH^{+4} and K^+ uptake and between Ca^{2+} and K^+ as in calcareous soils where uptake of K may be suppressed.

3.6 Potassium Deficiency and Toxicity Symptoms

On an annual basis, agricultural crops remove between 100-300kg K ha^{-1}. The amount taken up annually by a good cereal crop yielding 5 to 10t ha^{-1} grain is between 200-300kg K ha^{-1} while a good crop of potato could also be up to 300kg K ha^{-1}. Potassium uptake by grass could be very much higher than the figures quoted for common arable crops.

Although the total amount of potassium in soil may be several times larger than uptake, the potassium may not be present in the soil in the available form to meet crop requirement. This is because amount available for crop uptake depends on the concentration at the root surface and its replenishment. Potassium in its form taken up by plant, that is K+, is a mobile element easily translocated to the younger parts of the plants whenever there is a short fall in the amount taken up by the crop.

Therefore, deficiency symptoms first manifest on the older plant parts. There is yellowing along the margin from leaf tips or apex of older leaves. Necrotic area along leaf margins is characteristic of K-deficiency symptom in dicotyledon plants. There is also browning of tips of leaves down to the base. Acute shortfall in K-supply leads to stunted growth, poor root development and reduction in the production of fruits and grains. Fertilizer K is normally added to correct K deficiencies. Deficiencies occur in soils that are low in micas, soils that are low in clay (few exchange sites) and acid soils of pH 4.0 – 6.0 due to leaching by high rainfall.

Excess potassium has been found to induce the deficiency of magnesium (Mg) and cobalt (Co). Excess application of K-fertilizer generally leads to deficiency of other cations such as Mg- deficiency in oil palm referred to as **orange frond.** This condition is called **ion antagonism** in plants. At the end of the growing season, some K is passed back to the soil through the roots. Potassium moves up the plant as salt by passive means in water solution through the xylem vessels and moves down as organic K through the phloem.

SELF-ASSESSMENT EXERCISE

1. Highlight the availability of K in the soil.
2. Discuss how K relates with other soil properties.
3. Explain the factors affecting availability and fixation of K in the soil.

4.0 CONCLUSION

The concentration and availability of K in the soil is primarily controlled by inorganic processes. Except nitrogen, K is a mineral nutrient plants require in largest amounts. Potassium is assimilated in relatively large quantities by the growing crop as the yield and quality are closely related to soil K. Clay minerals are the most important sources of soil K excluding that from fertilizers.

5.0 SUMMARY

You have leant that:

- K is the next largest nutrient element after nitrogen needed by crops for their growth and development.
- Soil potassium (K) directly affects crop yield since K is responsible for the maintenance of osmotic pressure and cell size, which in turn influences photosynthesis and the energy production along with stomatal opening and carbon dioxide supply.
- The forms in which K is available in the soil are; relatively unavailable K, slowly available and readily available.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the K content of soils.
2. What are the sources of K in the soil?
3. Highlight the availability of K in the soil.
4. Explain the relationship between K and other soil properties.
5. Discuss the factors affecting availability and fixation of K in the soil

7.0 REFERENCES/FURTHER READING

Victor Afari-Sefa, Peter K. Kwakye, Daniel Okae-Anti1, A. Ziblim Imoro, Mercy Nyamiah. (2004). Potassium Availability in Soils–Forms and Spatial Distribution. *The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy.* https://www.researchgate.net/publication/228591331

UNIT 3 PHOSPHORUS CONTENT OF SOILS

CONTENTS

1.0 INTRODUCTION

Phosphorus constitutes about 0.2 percent of a plant's dry weight, where it is primarily a component of tissue molecules such as nucleic acids, phospholipids, and adenosine triphosphate (ATP). After nitrogen (N), phosphorus (P) is the second most limiting nutrient. It can reduce plant growth and development and potentially limit crop yield. However, excess phosphorus in soil can be detrimental to the environment because it can enter freshwater bodies through surface runoff and can cause algal bloom reducing water quality.

Improved phosphorus management can create profitable crop production systems while reducing negative impacts on the environment. The objective of this document is to understand phosphorus forms, transformation, and cycling in the soil. Phosphorus cycle is unique and different from the nitrogen cycle because phosphorus does not exist in a gaseous form. This document provides basic information on the various forms of phosphorus present in the soil and the processes that affect phosphorus availability for crop production.

2.0 OBJECTIVES

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

- highlight forms of phosphorus in the soil
- explain phosphorus cycle and transformation in the soil
- state factors influencing availability of P in the soil.

3.0 MAIN CONTENT

3.1 Phosphorus Forms Present in the Soil

Soil phosphorus is found in two forms, namely organic and inorganic. These two forms together make up the total soil phosphorus. Although total soil phosphorus is generally high, with concentrations ranging from 200 to 6,000 pounds per acre, 80 percent of this phosphorus is immobile and not available for uptake by the plant.

Approximately 30 to 65 percent of total soil phosphorus is in organic forms, which are not plant available, while the remaining 35 to 70 percent is in inorganic forms. Organic forms of phosphorus include dead plant/animal residues and soil micro-organisms. Soil micro-organisms play a key role in processing and transforming these organic forms of phosphorus into plant available forms. The inorganic phosphorus forms can be classified to exist in three different pools:

- **Plant-available (soil solution) phosphorus:** This pool is comprised of inorganic phosphorus dissolved in water/soil solution that is readily available for plant uptake.
- **Sorbed phosphorus:** This phosphorus pool is comprised of inorganic phosphorus attached to clay surfaces, iron (Fe), aluminum (Al), and calcium (Ca) oxides in soil. The phosphorus in this pool is released slowly for plant uptake.
- **Mineral phosphorus:** This phosphorus pool is comprised of primary and secondary phosphate minerals present in soil.

Examples of primary phosphorus minerals include apatite, strengite, and variscite. The secondary phosphorus minerals include calcium (Ca), iron (Fe), and aluminum (Al) phosphates. The release of phosphorus from this pool is extremely slow and occurs when the mineral weathers and dissolves in soil water.

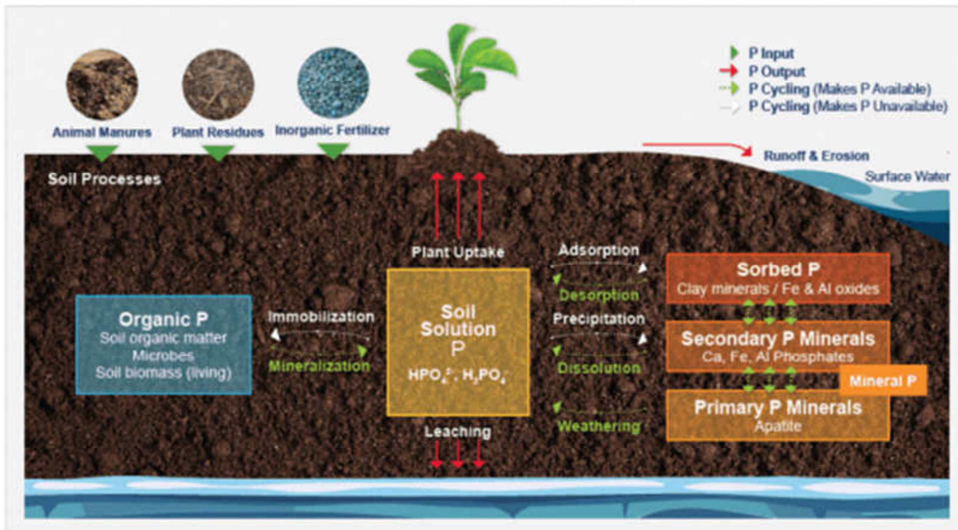


Fig. 3.1: Soil phosphorus cycle. This figure illustrates the sources of phosphorous inputs in the soil, pathways through which phosphorus becomes available/ unavailable for plant uptake, and phosphorus outputs/ loss pathways.

3.2 Phosphorus Cycling and Transformation in the Soil

Once phosphorus enters the soil through chemical fertilizers (inorganic source), manure, biosolids, or dead plant or animal debris (organic sources), it cycles between several soil pools via processes such as mineralisation, immobilisation, adsorption, precipitation, desorption, weathering, and dissolution. Following are explanations of these processes:

3.2.1 Mineralisation and Immobilisation

Mineralisation is a process through which organic phosphorus in soil is converted into inorganic phosphorus with the help of soil microbes. Immobilisation, on the other hand, is the reverse of mineralisation. During immobilisation, inorganic phosphorus forms are converted back to organic forms and are absorbed into the living cells of soil microbes. Immobilisation typically occurs when crop residues are incorporated in the soil. As crop residues decompose, more phosphorus becomes available in the soil solution through mineralisation. Since mineralisation and immobilisation processes are biological processes, they are highly influenced by soil moisture, temperature, pH, organic carbon to organic phosphorus ratio of crop residues, microbial population, etc.

3.2.2 Adsorption and Desorption

Adsorption is a process in which phosphorus present in soil solution is attached/bound to the surface of soil particles. The phosphorus binding takes place on clay surfaces or the iron (Fe) and aluminum (Al) oxides and hydroxides present in soil. Adsorption is a fast process and reversible in nature, meaning that adsorbed phosphorus can be released into soil solution via a process known as desorption and will be available for plant uptake.

Soils containing greater concentrations of iron and aluminum oxides have greater potential to adsorb phosphorus than soils with relatively low iron and aluminum oxides. Another soil property that favors phosphorus adsorption is the clay content. Soils with greater clay content have higher adsorption capacity than coarse textured sandy soils.

3.2.3 Weathering, Precipitation, and Dissolution

Soil contains minerals that are rich in phosphorus. These minerals are classified into primary and secondary minerals. Minerals break down over time (a process referred to as weathering) and release phosphorus in the soil solution for plant uptake. Primary minerals such as apatite are very stable and resistant to weathering. Hence, phosphorus is released very slowly compared to secondary phosphorus minerals such as calcium, iron, or aluminum phosphates.

Precipitation on the other hand is a process by which metal ions such as Al^{3+} and Fe^{3+} (these ions are dominant in acidic soils) and Ca^{2+} (dominant in calcareous soils) react with phosphate ions present in the soil solution to form minerals such as Al-, Fe-, or Ca-phosphates. Precipitation is a slow process and involves a permanent change into metal phosphates. These metal phosphates can release phosphorus in soil solution upon dissolution, but the release rate is very slow. Dissolution is a form of weathering when the phosphate minerals dissolve and release phosphate back into the soil solution.

3.2.4 Phosphorus Loss

Phosphorus is removed from soil by (a) crop/plant uptake, (b) runoff and erosion, and (c) leaching (figure 4). Surface runoff is the major pathway for phosphorus loss from soils. Runoff water carries away both soluble (dissolved) phosphorus and particulate (eroded soil particles) phosphorus from soil surface. Leaching is the loss of soluble phosphorus from sub-surface soil as water percolates vertically down the soil profile. In general, phosphorus loss by leaching is minimal compared to surface runoff.

3.3 Factors Influencing Phosphorus Availability in the Soil

While the processes such as weathering, dissolution, mineralisation, and desorption increase phosphorus availability in the soil for plant uptake, processes such as immobilisation, adsorption, precipitation, runoff, and erosion decrease the phosphorus availability.

In addition, phosphorus availability in soil solution is influenced by the following factors:

- **Organic Matter.** Organic matter is an important factor in controlling phosphorus availability. With the addition of organic matter, availability of phosphorus increases. This is due to the following reasons:
    - Mineralisation of organic matter releases plant-available forms of phosphorus into soils.
    - Organic molecules will compete with phosphate adsorbed to soil surfaces and will reduce phosphorus retention. This process will increase availability of phosphorus.
- **Clay Content.** Soils with higher clay content have high phosphorus retention capacity because clay particles have

very large surface area per unit volume, which can adsorb phosphorus easily.

- **Soil Mineralogy.** The mineral composition of the soil influences the phosphorus adsorption capacity. For example, soils with a high content of Al3+ and Fe3+also tend to have the greatest phosphorus adsorption capacity.
- **Soil pH.** Optimum soil pH between 6 and 7 will result in maximum phosphorus availability. At low pH (acidic soils), soils have greater amounts of aluminum and iron, which form very strong bonds with phosphate. At high pH when calcium is the dominant cation, phosphate tends to precipitate with calcium.
- **Other factors.** Temperature, moisture, and soil aeration can affect the rate of P mineralisation from organic matter decomposition. For example, in warm, humid climates organic matter decomposes faster compared to cool dry climates.

3.4 Phosphorus Deficiency and Toxicity

Since P is a mobile element, deficiency symptoms first show up in older leaves of plants. The deficiency symptoms may appear as:

- Stunted overall growth of whole plant compared to normal plants.
- Dark green colour, dark red to purple discolouration of stems, and, at times, dull green.
- Protein synthesis is impaired, vegetative growth is depressed.
- P-deficient plants have limited root system and thin stems. In cereals, tillering is affected.
- There is a deposition of starch in roots.
- Stems of annual plants have reddish green colour because of formation of anthocyamins.
- Leaves are tinged with brownish colour and fall off prematurely.
- Phosphorus contents of P-deficient plants are usually low (0.1% P).

When cereal and herbage are supplied with P, their P-content may go up to about 0.3 to 0.4%. Phosphorus toxicity is not common, but when it occurs it leads to reduced growth due to retardation of up-take and translocation of micro-nutrients including zinc, iron and copper.

3.5 P-Management Strategies

Four major P-management strategies are:

1. Lime acid soils to increase soil pH to between 6.5 and 7.0;

2. Apply small amounts of P fertilizer frequently rather than large amounts at one time;

3. Reduce P tie-up by banding/injecting P fertilizer or liquid manure; and

4. Place P fertilizers near crop row or in furrow where roots are most active.

SELF-ASSESSMENT EXERCISE

1. Discuss phosphorus contents, forms and transformations in soils
2. Highlight the factors affecting the P content and availability in the soil

5.0 CONCLUSION

Various components of phosphorus cycle in soil can be correlated with the types of money in your bank. Just as money can be separated into categories—savings or checking accounts, the checks you carry for use as needed, and the cash you keep with you—phosphorus in soil can also be categorised to exist in three different accounts/pools.

6.0 SUMMARY

You have leant that; soil phosphorus is found in two forms, namely organic and inorganic. These two forms together make up the total soil phosphorus. The inorganic P can be classified to exist in the following forms;

- Plant-available (soil solution) phosphorus
- Sorbed phosphorus
- Mineral phosphorus

Factors Influencing Phosphorus Availability in the Soil

- Organic matter
- Clay content
- Soil mineralogy
- Soil pH and
- Other factors

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss phosphorus content of soils.
2. Explain the cycle and transformation of P in the soil.
3. Highlight the factors affecting P availability in the soil.

7.0 REFERENCES/FURTHER READING

Brady, M.C. & Ray, R. Weil. (1999). *The Nature and Properties of Soils, (*12th ed.). New Jersey: Prentice-Hall.

Agbede O.O. (1986). Simultaneous Extraction of Phosphorus and Sulphur in Soils by the Anion Exchange Resin Methods. *Soil Sci. Soc. Nigeria 14th Ann. Conf.* (Ed. V.O. Chude) Makurdi, pp 68-71.

https://www.aces.edu/blog/topics/crop-production/understanding-phosphorus-forms-and-their-cycling-in-the-soil/?cn-reloaded=1

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053254.pdf

UNIT 4 SULPHUR CONTENT OF SOILS

CONTENTS

1.0 INTRODUCTION

Soil sulphur occurs in both organic and inorganic forms. About 50 – 70% of the total S in top soil is in organic matter implying high S in soils with high organic matter content. Total S content in soils is about 0.005 to 0.1% depending on the soil type. Organic S occurs as organic sulphates and carbon sulphides. It could occur in absorbable sulphates – SO_4^{2}- and as elemental sulphur, S, in some soils. Most S in soils comes from parent materials, the S containing minerals such as FeS, CuS, NiS which could be oxidized by Micro-organisms to form water soluble sulphates: FeS + 20_2 S-oxidizing Fe3+ + SO_4.

2.0 OBJECTIVES

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

- describe the forms of sulphur in the soil
- explain the functions of suphur in the soil.

3.0 MAIN CONTENT

3.1 Forms and Functions of Sulphur

Like phosphate, sulphur is taken up by plants as the sulphate form, SO4 Sulphur concentration in plant tissue is about 0.05% forming the –SH and the –S-S groups in plant cells. There is high requirement for S by such crops as soya bean, cotton, tobacco, legume (for manufacture of protein), cabbage family mustard, onion and pepper which has hot taste due to S-containing compounds such as glucosides.

3.1.1 Amount and Functions of Sulphur in Plants

The major functions of sulphur in plant could be summarised as follows: Sulphur forms structural components of plants through three amino acids containing sulphur – crysteine, methionine and crystine-by the disulphide bonds. There is serious human malnutrition whenever these amino acids are deficient. Sulphur is important in the metabollic processes. It is involved in fatty acid synthesis, forms constituents of vitamins biotin, thianire and glucosides whose characteristic taste is found in onion and pepper. The mustard produced from sulphur in plants contains allylisothio-cyanate CH2 = CH CH2CNS which has high flavour as in onion and mustard oil. Sulphur is required for nochelation of leguminous plant by Rhizobium, the nitrogen fixing bacteria. Sulphur also increases oil content of oil producing plants such as groundnut, oil palm and soyabean. Sulphur functions in proteins: in coenzymes for carbohydrates and lipid metabolisms.

3.2 Deficiency Symptom

Deficiency symptoms of S occurs as a general yellowing of entire plants; and this characteristic yellowing may be difficult to distinguish from severe nitrogen deficiency. Plants are usually small and spindly. Nodulation of the roots of legumes is reduced. Absence of S may also delay maturity of fruits and seeds and reduce the quality of protein in plants. Sulphur-deficiency is prevalent in the tropics compared to the temperate regions due to parent materials, high leaching rates and low level of atmospheric sulphur-bearing air. Excess S has been found to lead to accumulation of NO^{-3} in plants and also the reduction in the absorption and utilization of molybdenum, Mo, by plants.

Some small amount of sulphate is held on positively charged sites of soil colloids. FeS and CuS are referred to as primary minerals which have not been weathered. Sulphur is also found in secondary minerals. Often found along with $CaCO_3$ and Ca SO_4 in arid or semi-arid soils. There are few S-deficient soils in the world. In normal agricultural soils,
S is added in many ways.

3.3 Acid Rain

Rainfall dissolves the sulphur oxides SO2 evolved during the burning of wood, coal, fuel oil or from range and forest fires. Rainwater combines with sulphur oxide to form sulphuric acid making the soil to be acidic. Natural gas has high level of SO2 which is usually dissolved in rain water as follows:

$$SO_2 + H_2O \longrightarrow H_2SO_3 + O \longrightarrow H_2SO_4$$

This is referred to as **Acid Rainfall** which is produced in large amounts especially in oil-prospecting areas causing acidification of lakes and rivers. During the dry seasons, dry deposition of SO2 may occur on leaves and soil surfaces. Soils generally are becoming S-deficient due to reduced use of S-containing agricultural inputs but are also still receiving their S from atmosphere.

SELF-ASSESSMENT EXERCISE

1. Discuss the Sulphur content of soil.
2. Describe the forms and functions of sulphur in the soil.
3. What are the deficiency symptoms of sulphur in plants?

4.0 CONCLUSION

Soil sulphur occurs in both organic and inorganic forms. Total S content in soils is about 0.005 to 0.1% depending on the soil type. Organic S occurs as organic sulphates and carbon sulphides. Most S in soils comes from parent materials, the S containing minerals such as FeS, CuS, NiS which could be oxidised by microorganisms to form water soluble sulphates.

5.0 SUMMARY

You have leant that;

- like phosphate, sulphur is taken up by plants as the sulphate form,
- SO4 Sulphur concentration in plant tissue is about 0.05% forming the –SH and the –S-S groups in plant cells.

The major functions of sulphur in plant could be summarised as follows:

- Sulphur forms structural components of plants through three amino acids containing sulphur – crysteine, methionine and crystine-by the disulphide bonds.
- Deficiency symptoms of S occurs as a general yellowing of entire plants; and this characteristic yellowing may be difficult to distinguish from severe nitrogen deficiency.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the Sulphur content of soil
2. What are the forms and functions of sulphur in the soil
3. What are the deficiency symptoms of sulphur in plants
4. Fully describe acid rain

7.0 REFERENCES/FURTHER READING

Zane, F., Lund, & Lyoyd W. Murdock. (1978). *Sulphur in Agriculture.* Vol. 2.Washington, D.C: The Sulphur Institute.

MODULE 4 FERTILIZER AND FERTILIZER MANAGEMENT

UNIT 1 SOURCES OF FERTILIZERS

CONTENTS

1.0 INTRODUCTION

A fertilizer is artificially prepared manure with a variable concentration of plant food. Fertilizers are mostly inorganic preparations although some like urea are organic compounds. A good farmer knows the importance of a good fertilizer. Recognizing which fertilizer best fits the needs of your specific plants will help you to maximize your productivity and output. Become a fertilizing expert as you learn about the different options and nutrients that can impact your crops. Fertilizers can be purchased in dry (granular) or liquid form. Dry fertilizers are applied using a broadcast spreader, a planter or drill.

When two or more fertilizer sources are mixed, some degree of particle size uniformity of each of the individual sources is essential for uniform placement of the nutrients in the mixture. With the proper equipment, liquid fertilizers are easy to handle. Chemical compatibility of different liquid fertilizers is important when materials are mixed to prevent precipitation in the mixing tank. Two major sources of fertilizers are the organic and inorganic sources giving rise to organic and inorganic fertilizers.

2.0 OBJECTIVES

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

- outline the different sources of fertilizers
- discuss the advantage and disadvantage of each of the sources.

3.0 MAIN CONTENT

3.1 Sources of Fertilizers (Organic and Inorganic)

Organic fertilizers are made from natural and organic materials—mainly manure, compost, or other animal and plant products. These fertilizers are a great source of nutrients, though there isn't a measurable amount of any specific nutrients—some bags will print estimates. Organic fertilizers tend to work slowly and over the long-term. It can help to build up your soil over time. One of the best benefits of organic fertilizers is that is can be made at home. Using your own compost can help grow your garden. Inorganic fertilizers are made of up chemical components that contain necessary nutrients, hence may be referred to as chemical or synthetic fertilizers. If you're looking to give your garden a quick boost, this is likely the best option for you. For successful short-term growth, determine what nutrient your plant needs and use an inorganic fertilizer with nutrient.

3.2 Organic Fertilizers

It is necessary to clarify that organic fertilizers, in some countries, are those fertilizers that can be used in organic farming, and are derived from animal matter, animal excreta, human excreta and vegetable matter, according to some international standards. European Commissions working groups gave a more generic definition of organic fertilizers as those whose nutrients are contained in organic materials of animal, vegetable or other natural organic origin constituted by compounds/materials, in which the main nutrients are chemically linked or are part of these organic matrices. The nutrients contained in organic fertilizers must be transformed in the soil by microorganisms before they are assimilated by the plants. Their incorporation into the crops is, however, more gradual than those of inorganic or mineral fertilizers.

3.2.1 Importance of organic fertilizers in agriculture

Organic fertilizer, when available, can and should be part and parcel of soil fertility management strategies. Organic fertilizer alone will, however, not be sufficient to support the sustained high levels of production and productivity necessary to feed Africa's rapidly growing population. This is due to space–time variability in production and utilization. Application of organic fertilizers, as a component of sustainable agriculture apart from soil mineral provision, contribute to soil quality by improving the chemistry, biological and structural levels of soil. These shape the general agricultural soils‟ health. Its nutrients are also gradually released and reused. Because it is based, mostly on locally sourced materials with little or no dependence on external inputs, it is one of the eco-friendly infrastructures for sustainable rural development.

3.2.2 Advantages of using organic fertilizers

There is an array of advantages in using organic fertilizers for crops production. Some examples of such advantages are as stated below:

1. **Improves soil Structure**
   Because of the organic matter present in organic fertilizer, soil structure is improved and as a result, the soil water and nutrients holding capacity increases.
2. **More microorganisms activity**
   Organic fertilizer, is rich in organic matter, which assists microbes to favourably perform decomposition activity. Organic fertilizer also contains carbon as part of its chemical structure; and it is the C, along with N, P and K that nourishes microorganisms and enables them to make nutrients available for plants in a naturally occurring biological process.

3. **More environmentally Friendly**
   Chemical fertilizers run off into waterways thereby harming aquatic life and water quality. Organic fertilizers, on the other hand, do not run off as easily, even if at all, and are associated with soil structure. According to the Organic Trade Association, organic fertilizers also increase species biodiversity by up to 30 % compared with artificial fertilizers.

4. **Reduce Fertilizers and Pesticides**

   Although organic fertilizers can be costlier than synthetic, depending on certain factors and conditions, it can reduce the need for pesticides and the overall N, P and K requirements. This is due to reductions; organic fertilizer can be cost neutral and sometimes a cost savings.

5. **Plant Damage Threat Avoided**

   Some synthetic fertilizers can cause plant damage to leaves and roots, due to their burning effects. This is a situation less likely with organic fertilizers.

3.2.3 Disadvantages of using organic fertilizers

1. Not all Products are Created Equally

Not all products are created equally and many organic products produce inconsistent results. Make sure you are selecting a product that is industry vetted by reviewing any university studies or case studies.

2. Low Nutrient Levels

The level of nutrients present in organic fertilizer is usually low. Additionally, the nutrients are often complex in organic chemical structure. Using an organic fertilizer is, therefore a process, not an event.

3. Making compost may be a Complicated Procedure

While one can produce one's own compost, it's sometimes a messy and complicated process that may lead to an inconsistent product and end-result. Another disadvantage is that, when organic matter decomposition is rapid, more nutrients are released but release of soil organic matter, on the other hand, is favoured by a slow decomposition process. Decomposition of organic matter, therefore, operates with moisture and temperature. These two vital factors can, however, not be controlled and hence nutrient may be released when the plants do not need them.

4. Potentially pathogenic

In addition, an organic fertilizer or incomplete/badly formed compost can leave some types of pathogens in organic matter. The pathogens can later enter water or food chains, thereby causing environmental and health problems.

3.3 Inorganic Fertilizers

Inorganic fertilizers are available in the form of **single fertilizers, incomplete fertilizers** and **complete fertilizers.** Single element fertilizers contain only one fertilizer element. Examples are ammonium sulphate (N2), Urea (N), super phosphate (P205), Mariate of potash (K2O).

Incomplete fertilizers contain two fertilizer elements; a typical example is Ammonium Phosphate (N + P205). **Compound fertilizers** containing three elements are designated **complete fertilizers.** Ammonium phosphate which has an analysis of 11-45-0 is also called a compound two element fertilizer while an example of a complete fertilizer is compound 15-15-15.

The use of inorganic fertilizer is one of the crucial land management practices that has reduced nutrient problem in cropland and considerably increased soil fertility and consequent crop yields over the past century. Chemical P fertilizer production was also enhanced along with the P acid. On the one hand, as a crucial constituent of the *green revolution*, the histrionic increase in fertilizer production and application has markedly contributed in global rise in agricultural productivity and, hence, reduced hunger. Disproportionate use of inorganic fertilizer, on the other hand, is proven to be causing a number of environmental and ecological menaces, within and outside of farmlands, as eutrophication of water bodies, air pollution, soil acidification and degradation, reduction in crop yield, and attenuation of food and energy production sustainability from agricultural fields. Increase in world total fertilizer use is derived from both cropland expansion and elevated fertilizer application rate per unit cropping area.

3.3.1 Advantages of using Inorganic fertilizers

There are various advantages of inorganic fertilizers to crop plants. Some examples of such benefits are given below for reference purpose, as follows:

1. Support to crop growth

Generally, chemical fertilizers contain the primary plant nutrients (N, P and K) in specifically predetermined ratios tailored towards specific growth needs of specific crop plants. These fertilizer's nutrients allow crops to grow even in depleted soils, as the basic nutritional requirements of the crop plants are met.

2. Provision of a predictable and efficient nutrients' source

Manufactured fertilizers contain a predictable ratio of N, P and K. These nutrients are dissolved in the soil water before quickly reaching plants'' cells, where they are required. The nutrients consistency allow for efficient production of crop products.

3. Allow crops to grow faster and bigger

Crops are capable of growing faster and bigger, due to the nutrients being applied to them through fertilizer application, than those crops living in infertile and/or unproductive soils.

4. Allow for an increased harvest

A quick and efficient production increases harvest yields thereby making food relatively more available and, hence even, affordable through a reduced cost of production.

5. Their nature of easy transport

Chemical fertilizers are easier to transport than such organic soil amendments as animal manure. They are also cheap to produce, and hence cheap to purchase, depending of course upon the country.

3.3.2 Disadvantages of Using Inorganic Fertilizers

1. Possible burning effect

Synthetic fertilizers are composed of high amounts of acidic chemicals and can, therefore, have negative impact on soil quality and burning effect on crop plants and can even affect human skin negatively.

2. Fertilizers are potential pollutants

Nitrogenous fertilizers, through surface runoff from farmlands can enter into water bodies after rains, thereby causing toxic algal blooms in such water bodies as rivers, lakes, ponds, *et cetera* due eutrophication. Chemical fertilizers, depending on type and concentration, usually contain toxins that can be destructive to the soil, especially under poor management system. The chemicals can also be poisonous to humans, wildlife and aquatic lives. Fertilizers can also leach through soil into groundwater, making it very harmful to the surrounding environment.

3. Results in depleted soils

Synthetic fertilizers typically only supply N, P and K, but do not supply most other nutrients to the soil. Consequently, the soil that is continuously used for growing crops with given chemical fertilizers is being depleted, over time, and the food crops may also be nutritionally deficient. This explains why, over the last century, some soils in many parts of the world, become so depleted that many food items became significantly deficient in many such vital nutrients as Mg, as the soil is mostly not been replenished any nutrient other than the N, P and K.

1. **Interfering with natural soil ecology**

In addition to the role of heavy tillage practice of agriculture in disrupting the delicately balanced soil ecosystem, consistent application of chemical fertilizers to crops can also retard the growth of many beneficial soil organisms and even kill others. Without a healthy soil ecology having appropriate texture and structure, soil moisture will not be well retained and this will lead to a reduced resilience to drought. Crop health will also be at stake as unhealthy soil always leads to plants to be more exposed to more pests and diseases.

2. **Chemical fertilizers are like steroids for plants**

Fertilizers provide plant-available nutrients for crops‟ growth; as a consequence, however, the crops can over grow to an extent that their roots cannot sustain. This can result in weaker plants that are further more vulnerable on their own to pests and diseases organisms.

SELF-ASSESSMENT EXERCISE

1. Explain the sources, advantages and the disadvantages of organic and inorganic fertilizers

4.0 CONCLUSION

Organic fertilizers are made from natural and organic materials—mainly manure, compost, or other animal and plant products. Organic fertilizers tend to work slowly and over the long-term. It can help to build up your soil over time. One of the best benefits of organic fertilizers is that is can be made at home using compost. Inorganic fertilizers are made of up chemical components that contain necessary nutrients, hence may be referred to as chemical or synthetic fertilizers. Inorganic fertilizers work faster because it is already in a mineralized for which make it easy for plants to pick it up.

5.0 SUMMARY

Organic fertilizers are those fertilizers that can be used in organic farming, and are derived from animal matter, animal excreta, human excreta and vegetable matter, according to some international standards. Inorganic fertilizers are made of up chemical components that contain necessary nutrients, hence may be referred to as chemical or synthetic fertilizers.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the two main sources of fertilizers.
2. Discuss the advantages and the disadvantages of organic and inorganic fertilizers.

7.0 REFERENCES/FURTHER READING

Bumb, B. & Baanante, C.A. (1996). The Role of Fertilizer in Sustaining Food Security and Protecting the Environment to 2020. USA: International Food Policy Research Institute. Fertilizers and their Use. Agricultural Extension Service. 23 pp. USA: The University of Tennessee.

Food and Agriculture Organisation of the United Nations /International Fertilizer Industry Association FAO/IFA (1999). *Fertilizer Strategies*. Rome: FAO.

Lu, C. & Tian, H. (2017). Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: shifted hot spots and nutrient imbalance. *Earth Syst. Sci. Data,* 9: pp.181–192. doi:10.5194/essd-9-181-2017.

UNIT 2 FERTILIZER APPLICATIONS

CONTENTS

1.0 INTRODUCTION

Proper fertilization is important for crop yield and quality. For the greatest fertilizer nutrient use efficiency, it is important to select the right source, the right method, the right timing, and the right rate of application (the 4Rs framework). The amount and timing of nutrient uptake depend on various factors including variety, planting date crop rotation, soil and weather condition. Timing and quantity should be chosen in such a way that as much as possible of the nutrients is used by plant. Nutrient should be applied, as near to the time the crop needs them to ensure optimum crop use efficiency and to minimize the potential of environmental pollution. This is particularly important for mobile nutrient such as nitrogen, which can leach out of the soil profile if not taken by roots. In this unit, fertilizer sources, application methods, and timing are discussed.

2.0 OBJECTIVES

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

- explain the different fertilizer application methods
- discuss proper fertilizer rates of application
- outline the actual timing of fertilizer application.

3.0 MAIN CONTENT

3.1 Application Methods

There are several factors to consider when choosing fertilizer application methods. Considerations include: the particular mixture of nutrients needed, the crop, timing of application, available equipment, and planting/tillage practices. Application methods include starter application (banded or popup/furrow), broadcasting, topdressing, sidedressing, or foliar feeding. A description of each of these application methods and their pros and cons for use are described in Table 2.1.

Table 2.1: Application method descriptions as well as the pros and cons of using each application method.

Application methods	Description	Characteristics
Band Placement	Small amounts of liquid or granular fertilizer is applied in furrows 1-2 inches below and 2-3 inches to the side of seed placement	- Liquid or dry fertilizer - Nutrient uptake efficiency is higher than for broadcast application, allowing for lower rates - Runoff risk is low - Equipment is standard on many planters - Fertilizer placement in vicinity of roots may aid root development - Requires precision placement to avoid placement too close to the seed
Furrow/pop-up/starter application	Application method used alone or combined with banded application. Usually applied in low rates placed directly on or around the seed during planting.	- Liquid fertilizers are best suited - Can be applied in combination with banded fertilizer during planting - Only low rates needed - Can only be used in low rates to avoid phyto-toxicity
Broadcast	Spinning of dry granules or spraying of liquid fertilizer onto the soil surface,	- Can be done quickly - Standard equipment used - Depending on the source , it requires rainfall or tillage to

	with or without incorporation of the material	move fertilizers to roots - Could result in poor application uniformity
Top dressing	Spreading or broadcasting of fertilizers in the standing crop, after emergence.	- Fast and easy application of fertilizer - Can result in volatilization losses for urea containing sources - Could cause leaf burn - Could result in poor application uniformity
Side dressing	Broadcast or banded between or alongside growing plants; this method normally refers to N applied when corn is 6-12 inches tall	- N can be applied with a high nutrient use efficiency - Application with drop nozzles can be done faster than injection or knifing - Weather and field conditions can delay or prevent application
Foliar feeding	Application where liquid fertilizer is applied directly to the leaves, nutrients are in highly available form and can be taken up by the plant rapidly	- Easy application - Standard sprayer equipment can be used - Not always practical due to row spacing - Material must be absorbed by leaves before it dries

3.1.1 Placement

Placement refers to applying fertilizers into the soil, but with special reference to the location of the seed or plant. When the fertilizer is placed close to the seed or plant the application is said to be localized. The placement of solid fertilizers can be done with the help of simple implement (e.g. ploughs) and such hand-tools as hoes. Hill or row placement refers to applying the fertilizers either in bands or localized areas near the plants or along the planted row, but often in a definite space relationship to the seed or plant. This method allows for a greater availability of nutrients by reducing losses of P and K through fixation than when fertilizers are mixed with the soil. The greatest hazard of placing fertilizers near the seed is that germination may sometime be hindered or the young plant damaged by an excessive concentration of soluble salts, if the materials are put too close to the seed or plant. Such injury is greatest in dry sandy soils.

Fig. 2.1 Row placement

3.1.2 Broadcasting

The main objectives in broadcasting are to distribute the fertilizer evenly and to incorporate it with part of, or throughout the plough layer. Broadcasting is also employed when applying large quantities of fertilizers that can be easily applied at the time of planting. In broadcasting, the fertilizer is spread over the entire soil areas to be treated, either before the land is ploughed, immediately before planting or while the crop is growing. The latter is usually referred to as side dressing if the crop is in wide rows, and as top-dressing if the crop is in narrow rows or not in rows. Delayed applications of nitrogen are made, commonly as top-dressing; top dressing of P and K are ordinarily made only on pasture that occupies the land for several years.

3.1.3 Top Dressing

It is the broadcasting of fertilizers particularly nitrogenous fertilizers in closely sown crops like paddy and wheat, with the objective of supplying nitrogen in readily available form to growing plants. The main disadvantages of application of fertilizers through broadcasting are:

Nutrients cannot be fully utilized by plant roots as they move laterally over long distances. The weed growth is stimulated all over the field.

Nutrients are fixed in the soil as they come in contact with a large mass of soil.

3.1.4 Side Dressing

It refers to the spread of fertilizer in between the rows and around the plants. The common methods of side-dressing are; Placement of nitrogenous fertilizers by hand in between the rows of crops like maize, sugarcane, cotton etc., to apply additional doses of nitrogen to the growing crops and placement of fertilizers around the trees like mango, apple, grapes, papaya etc.

3.1.5 Fertilizing Tree Crops/Plants

The method of fertilizer application to tree plants is often a compromise between broadcasting and localized placement. Often, the fertilizer is broadcast under the tree to a distance of 30 - 60cm beyond the spread of the branches. On the other hand, when a cover or green manure crop is grown between the trees, a large part of the fertilizer may be applied to this crop. In forest zones and on very sandy soils the fertilizer application may be repeated several times during the season.

3.1.6 Foliar Application of Fertilizer

Liquid fertilizer is applied direct to the foliage of a crop for maximum utilization. This is often advantageous when the soil contains insufficient moisture or when its physical and chemical conditions are otherwise unfavorable. This method is useful in correcting micronutrient deficiencies in tree or orchards, and arable crops.

3.1.7 Application through Irrigation Water (Fertigation)

It refers to the application of water soluble fertilizers through irrigation water. The nutrients are thus carried into the soil in solution.

Generally nitrogenous fertilizers are applied through irrigation water.

Fig. 4.2: Fertigation

3.1.8 Injection into soil

Liquid fertilizers for injection into the soil may be of either pressure or non-pressure types.
Non-pressure solutions may be applied either on the surface or in furrows without appreciable loss of plant nutrients under most conditions.

Anhydrous ammonia must be placed in narrow furrows at a depth of 12-15 cm and covered immediately to prevent loss of ammonia.

3.1.9 Aerial application

In areas where ground application is not practicable, the fertilizer solutions are applied by aircraft particularly in hilly areas, in forest lands, in grass lands or in sugarcane fields etc

3.2 Fertilizer Rate

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

3.3 Timing of Application

Selecting which fertilizer source to use begins with evaluating which nutrients are required for optimal plant growth and at what time during crop growth these nutrients are taken up in the largest amounts. Field crops typically take up most of their nutrient requirements during the rapid vegetative growth phase followed by a decline in nutrient uptake as the plants mature. Because of this non-uniform demand, the highest nutrient use efficiencies can be obtained when application is timed to coincide with the period of greatest nutrient demand. For example, the highest N use efficiencies in corn are typically achieved when a small amount of N is banded as a starter at planting.

This is followed by a side-dress application when the corn is 6-12 inches tall, just prior to the rapid vegetative growth phase of the corn. Side-dressing is especially important for N applications to sandy soils in areas of high rainfall where leaching losses can be high or for soils and weather patterns that favor early season denitrification. For such soils, the use of a nitrification inhibitor can help reduce N loss to the environment and hence increase the N use efficiency of the fertilizer. See Agronomy Fact Sheet #45 (Enhanced-Efficiency Nitrogen Sources) for more information on these products.

SELF-ASSESSMENT EXERCISE

Describe the method of application, rates and proper timing of application of fertilizers you studied

4.0 CONCLUSION

When fertilizers are applied appropriately and in the correct dosage, it will enhance vegetative growth in plants, keep the environment healthy. Leaf canopy protects the soil from the direct impact of raindrops, which could result in soil erosion. The life of microorganisms living beneath the soil and animals is protected. During eutrophication, fertilizer elements are eroded into the rivers and lakes for the nutrition of aquatic life. The ecosystem is maintained and biodiversity rejuvenated.

5.0 SUMMARY

If fertilizer is needed to supplement nutrients already on the farm (manure, cover crops, previous crop residues etc.), it is important to select the right material, and to apply it at the right rate, the right place, and the right time (4Rs). By understanding what each fertilizer offers with respect to nutrient availability, and ease of handling and application, producers are better able to meet the needs of their crops.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe the fertilizer application methods you studied.
2. In a tabular form, show the pros and cons of different fertilizer application methods.
3. Discuss the rates of fertilizer application.
4. Explain the proper timing of fertilizer application.

7.0 REFERENCES/FURTHER READING

Basic Fertilizer Management, Agronomy Fact Sheet Series 75. College of Agriculture and Life Sciences Cornell University. Nutrient Management Spear Program http://nmsp.cals.cornell.edu

Chude, V.O., Olayiwola, S.O., Osho, A.O. & Daudu, C.K. (2012). Fertilizer use and management practices for crops in Nigeria. pp. 230.

UNIT 3 FERTILIZER HANDLING AND STORAGE

CONTENTS

1.0 INTRODUCTION

Fertilizers contain concentrated nutrients that must be stored and managed properly. Fertilizers can cause harm if they reach surface or ground water. Excessive nitrate concentrations in drinking water can cause health risks, especially in young children. Phosphorus can be transported to surface waters and cause algae blooms and eutrophication; resulting in poor water quality. Storing fertilizers separate from other chemicals in dry conditions can minimize these risks. Extra care needs to be given to concentrate stock solutions. Secondary containment should always be used. Untimely application of fertilizer may leads to excessive release from the production system to surface and/or ground water. Potential problems can be minimized through adequate environmental awareness, employee training, and emergency preparedness. Below are guidelines or properly storing and handling greenhouse fertilizers.

2.0 OBJECTIVES

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

- discuss how best fertilizer storage can be carried out
- explain effective ways of handling fertilizers.

3.0 MAIN CONTENT

3.1 Storage of Fertilizers

Greenhouse fertilizer storage areas contain relatively large quantities of concentrated chemicals. Risks in storage areas include release through broken, damaged, or leaking containers; loss of security leading to irresponsible use; accumulation of outdated materials leading to excessive quantity of fertilizer thus unnecessarily raising risk level; and combustion of oxidizing compounds in fertilizer (e.g., nitrates) caused by fire or another disaster event. The least amount of risk involves having a building or area dedicated to fertilizer storage; separated from offices, surface water, neighboring dwellings and bodies of water; separate from pesticides and protected from extreme heat and flooding. The storage area should have an impermeable floor with secondary containment, away from plant material and high traffic areas. Clean-up equipment should be readily available.

3.1.1 Good Fertilizer Storage Practices

1. Containers

Fertilizer should be stored in their original containers unless damaged; labels should be visible and readable; food or beverage containers should never use for storage. Labels should be in plain sight; no containers should come in contact with floor; all containers should be stored upright; aisles should be wide enough to comfortably accommodate workers; containers should not be crowded on shelves or pallets.

a. Partially-used Containers

Paper bags and boxes should be opened with a box cutter or scissors; open containers should be resealed and returned to storage; all open paper bags should be sealed inside another, larger container, sealed and labeled.

b. Damaged Containers

Containers should be checked often for damage; when damaged containers are noticed, contents should be repackaged and labeled or placed in suitable secondary containment which can be sealed and labeled.

2. Containment

There should be no floor drain; the floor should provide containment in the event of a spill; there should be secondary containment routinely used for most open containers; damaged or leaking containers should be repaired and/or replaced as soon as possible; all spilled material should be cleaned up upon discovery; and cleanup materials should be discarded promptly and properly.

3. Fire Prevention and Suppression

Fire detection and alarm system should be present; oxidizers and flammable materials should be stored separately; fire extinguisher should be immediately available; the fire department should be notified at least annually of current inventory.

4. Inventory and Recordkeeping

Inventory should be actively maintained as chemicals are added or removed from storage; containers should be dated when purchased; outdated materials should be removed on a regular basis; inventory should be controlled to prevent the accumulation of excess material that may become difficult to use

5. Lighting

Electrical lighting should allow view into all areas and cabinets within the storage area.

6. Monitoring

There should be monthly inspection of storage for 1) signs of container corrosion or other damage - leaking or damaged containers should be repackaged as appropriate, 2) faulty ventilation, electrical, and fire suppression systems – problems should be reported and corrected.

7. Security

The storage room should be locked and access restricted to trained personnel.

8. Signage

There should be signs posted; warning signs should be used as needed; emergency contact information should be posted.

9. Temperature Control

There should be active mechanical temperature control and no direct sources of heat (sunny windows, steam pipes, furnaces, etc.).

10. Ventilation

Mechanical ventilation should be working and used.

11. Storage and Record Keeping

Fertilizer stock tanks should be labeled with fertilizer formulation and concentration; records should be kept of fertilizer formulation, concentration, date, and location of application; records should be kept of media nutrient analyses.

3.2 Ways of Handling Fertilizers

Storage areas should not contain pesticides, or other greenhouse chemicals; storage areas may contain general greenhouse supplies; there should be no food, drink, tobacco products, or livestock feed present.

- Provide pallets to keep large drums or bags off the floor. Shelves for smaller containers should have a lip to keep the containers from sliding off easily. Steel shelves are easier to clean than wood if a spill occurs.

- If you plan to store large bulk tanks, provide a containment area large enough to confine 125 percent of the contents of the largest bulk container.

- Keep the building or storage area locked and clearly labeled as a fertilizer storage area. Preventing unauthorized use of fertilizers reduces the chance of accidental spills or theft.

- Labels on the windows and doors of the building give firefighters information about fertilizers and other products present during an emergency response to a fire or a spill.

- It is a good idea to keep a separate list of the chemicals and amounts stored. If a fire should occur, consider where the water used to fight the fire will go and where it might collect. For example, a curb around the floor can help confine contaminated water.

- Provide adequate road access for deliveries and use, and in making the storage area secure, also make it accessible, to allow getting fertilizers and other chemicals out in a hurry.

- Never store fertilizers inside a well house or a facility containing an abandoned well.

Sound containers are your first line of defense against a spill or leak. If a container is accidentally ripped open or knocked off a shelf, the spill should be confined to the immediate area and promptly cleaned up. The building should have a solid floor and, for liquid fertilizers, a curb. The containment volume should be large enough to hold the contents of the largest full container.

3.2.1 Activities Involved in Fertilizer Handling

1. Containment of Concentrated Stock

Concentrated stock should be stored near the injector in high density polyethylene or polypropylene containers with extra heavy duty walls; secondary containment should be provided.

2. Disposal

Sufficient planning should be made to eliminate the need for disposal; empty fertilizer containers should be discarded based on latest advice from environmental protection authorities.

3. Precipitate and Residue Disposal

Fertilizer systems should be cleaned. Solids and rinse solution should be composted.

4. Spill Prevention and Preparedness

Opening fertilizer product containers, measuring amounts, and transferring fertilizer to the delivery system involves some level of risk from spills. Secondary containment should be used for fertilizer stock tanks routinely; spill clean-up materials should be used for liquids (e.g., absorbent materials) and solids (e.g., shovel, dust pan, broom and empty and/or buckets) should be available within the general area.

5. Delivery System

The fertigation equipment should be checked monthly for accuracy; containment tanks, back flow preventors and any equipment that holds fertilizer in the dry or liquid form should be inspected; stock tanks should be inspected weekly for deterioration and cracks; the manufacturer recommendations should be followed when calibrating or working on fertilizer injector equipment; stock solution tanks and the areas surrounding fertilizer injectors and concentrated solutions should be kept clean and free of debris.

SELF-ASSESSMENT EXERCISE

Discuss the general handling and storage of fertilizers and highlight the good practices involved in it.

4.0 CONCLUSION

The need for proper storing and handling of fertilizers is very necessary as storing fertilizers separate from other chemicals in dry conditions can minimize certain risks. Such risks include the possibility of fertilizers causing harm if they reach surface or ground water. Also excessive nitrate concentrations in drinking water can cause health risks, especially in young children. Phosphorus can be transported to surface waters and cause algae blooms and eutrophication; resulting in poor water quality. Extra care needs to be given to concentrate stock solutions. When fertilizers are properly stored and handled, the resultant effect is that it is used for the sole purpose of crop improvement and other risks associated with it will be avoided.

5.0 SUMMARY

You have leant that proper handling of fertilizers include activities such as the following:

- Storing fertilizers separate from other chemicals in dry conditions.
- Extra care needs to be given to concentrate stock solutions. Secondary containment should be used.
- Provide pallets to keep large drums or bags off the floor. Shelves for smaller containers should have a lip to keep the containers from sliding off easily.
- Steel shelves are easier to clean than wood if a spill occurs.
- If you plan to store large bulk tanks, provide a containment area large enough to confine 125 percent of the contents of the largest bulk container.
- Keep the storage area locked and clearly labeled as a fertilizer storage area. Preventing unauthorised use of fertilizers reduces the chance of accidental spills or theft.

- Labels on the windows and doors of the building give firefighters information about fertilizers and other products present during an emergency response to a fire or a spill.

- Provide adequate road access for deliveries and use, and in making the storage area secure, also make it accessible, to allow getting fertilizers and other chemicals out in a hurry.

- Never store fertilizers inside a well house or a facility containing an abandoned well.

6.0 TUTOR-MARKED ASSIGNMENT

1. Briefly discuss the storage of fertilizers and highlight the good practices involved in it.

2. Explain fertilizer handling.

3. What are some of the activities involved in good fertilizer handling?

7.0 REFERENCES/FURTHER READING

AEM Tier II Worksheet, Fertilizer Storage & Handling in the Greenhouse, Agriculture Environmental Management (AEM) http://www.agmkt.state.ny.us/SoilWater/aem/forms/Greenshouse%20Fertilizer%20Storage.pdf

*Pesticide and Fertilizer Storage,*United States Environmental ProtectionAgency http://www.epa.gov/oecaagct/ag101/pestfertilizer.html

MODULE 5 CROP GROWTH AND RESPONSE TO SOIL NUTRIENTS

UNIT 1 MAJOR, SECONDARY AND TRACE ELEMENTS IN CROP NUTRITION

CONTENTS

1.0 INTRODUCTION

Plant growth and development depends on nutrients derived from the soil or air, or supplemented through fertilizer. There are eighteen essential elements for plant nutrition, each with their own functions in the plant, levels of requirement, and characteristics. Nutrient requirements generally increase with the growth of plants, and deficiencies or excesses of nutrients can damage plants by slowing or inhibiting growth and reducing yield. Many deficiencies can be recognized by observing plant leaves.

2.0 OBJECTIVES

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

- discuss the major, secondary and trace elements
- outline forms which nutrients are taken in the soil
- explain mobility of nutrients in plants and soil.

3.0 MAIN CONTENT

3.1 The Essential Nutrients

There are eighteen elements, without or with cobalt (Co) and/or nickel (Ni), as listed on Table 2, are identified as essential elements for plant growth, of which nine are required in macro (large) and seven in micro (trace) quantities. Hence, they are traditionally divided into two main groups, macronutrients and micronutrients, according to the quantities required by plants. Carbon and O2 are obtained from the gas CO2 whereas H is obtained from water. As C, O and H are supplied by both air and water, they are therefore, not treated as nutrients by the fertilizer industry. These three elements (C, H and O) are, however, also required in large quantities for the production of such plant constituents as cellulose or starch. The other 13 are called mineral nutrients as they are absorbed in mineral (inorganic) forms. Regardless of the amount required, physiologically, all of them are equally important.

The 13 mineral elements are taken up by plants in specific chemical forms as shown in Table 1.1 (below) regardless of their source. The major aim of fertilizer industry is to provide the primary and secondary nutrients which are required in macro quantities. When chlorophyll of plants is exposed to light, the three elements (C, H and O) are combined in a process of photosynthesis thereby making carbohydrates, with subsequent oxygen being released. The water is, on the hand, brought into the plant by root absorption from the soil system. Carbon dioxide (CO2) enters plant through stomata, small leaf openings. The photosynthesis rate is directly controlled by the water and nutritional status of the plant. Maximum rates are ultimately, however, influenced by the plant genetics.

Table 1.1 Essential plant nutrients and their chemical (elemental) symbol

Nutrients Supplied by Air and Water (Structural)	Primary or Macronutrient	Secondary nutrients	Micronutrients
Carbon (C)	Nitrogen (N)	Calcium	Zinc (Zn)
Hydrogen (H_2)	Phosphorus (P)	Magnesium	Chlorine
Oxygen (O_2)	Potassium (K)	Sulphur	Boron (B)
			Molybdonum
			Zinc (Zn)
			Iron (Fe)
			Manganese (Mn)
			Cobalt (Co)*
			Nikel (Ni)*

*These elements are among those regarded as beneficial, but not essential, by some authors. Others are Se, Si, Na and Al.

3.1.1 The 18 Elements Essential for Plant Nutrition

Carbon, H and O make up to 95 % of plant biomass, and the remaining 5 % is made up of all other elements. The difference in plant concentration, between macronutrients and micronutrients, is very large. The relative contents of N and Mo in plants is in the ratio of 10,000:1. Plants need about 40 times more Mg than Fe. These examples indicate the significant difference between macronutrients and micronutrients.

1. Macronutrients: used in large quantities by the plant

Structural nutrients: C, H, O
Primary nutrients: N, P, K
Secondary nutrients: Ca, Mg, S

2. Micronutrients: used in small quantities by the plant

   Fe, B, Cu, Cl, Mn, Mo, Zn, Co, Ni

3.1 Basic Classifications of Essential Elements

3.2.1 Structural Elements

Plants require eighteen elements found in nature to properly grow and develop. Some of these elements are utilised within the physical plant **structure**, namely **carbon (C), hydrogen (H), and oxygen (O)**. These elements, obtained from the air (CO_2) and water (H_2O), are the basis for carbohydrates such as sugars and starch, which provide the strength of cell walls, stems, and leaves, and are also sources of energy for the plant and organisms that consume the plant.

3.2.2 Macronutrients

Elements used in large quantities by the plant are termed **macronutrients**, which can be further defined as **primary** or **secondary**. The primary nutrients include **nitrogen (N), phosphorus (P), and potassium (K)**. These elements contribute to plant nutrient content, function of plant enzymes and biochemical processes, and integrity of plant cells. Deficiency of these nutrients contributes to reduced plant growth, health, and yield; thus they are the three most important nutrients supplied by fertilizers. The secondary nutrients include **calcium (Ca), magnesium (Mg), and sulfur (S)**.

3.2.3 Micronutrients

The final essential elements are used in small quantities by the plant, but nevertheless are necessary for plant survival. These **micronutrients** include iron (Fe), boron (B), copper (Cu), chlorine (Cl), Manganese (Mn), molybdenum (Mo), zinc (Zn), cobalt (Co), and nickel (Ni).

Table 1.2: Essentiality and concentrations of essential elements in plants

Nutrient (symbol)	**Essentiality established by**	**Typical concentration in plant dry matter**
Macronutrients		
Nitrogen (N)	de Saussure (1804)	1.5 %
Phosphorus (P, P_2O_5[1])	Sprengel (1839)	0.1 – 0.4 %
Potassium (K, K_2O[1])	Sprengel (1839)	1 – 5%
Sulphur (S)	Salm-Horstmann (1851)	0.1– 0.4 %
Calcium (Ca)	Sprengel (1839)	0.2 – 1.0 %
Magnesium (Mg)	Sprengel (1839)	0.1 – 0.4 %
Micronutrients		
Boron (B)	Warington (1923)	6 – 60 µg/g (ppm)
Iron (Fe)	Gris (1943)	50 – 250.µg/g (ppm)
Manganese (Mn)	McHargue (1922)	20 – 500.µg/g (ppm)
Copper (Cu)	Sommer, Lipman (1931)	5 – 20.µg/g (ppm)
Zinc (Zn)	Sommer, Lipman (1931)	21 – 150.µg/g (ppm)
Molybdenum (Mo)	Arnon & Stout (1939)	below 1.µg/g (ppm)
Chlorine (Cl)	Broyer *et al.*, (1954)	0.2 – 2 %

[1] Oxide forms are used in extension and trade, 2ppm = parts per million = mg/kg = µg/g; 10, 000 ppm = 1 percent. Source: Roy *et al*., 2006.

Table 1.3: Showing uptake form and mobility in plants and soil

Nutrients	Macro/micro	Uptake form	Mobility in plants	Mobility in soil
Carbon	Macro	CO_2, H_2CO_3		
Hydrogen	Macro	H^+, OH^-, H_2O		
Oxygen	Macro	O_2		
Nitrogen	Macro	NO_3^-, NH_4^-	Mobile	Mobile as NO3-, immobile as NH4+

Phosphorus	Macro	HPO_4^{2-}, $H_2PO_4^-$	Somewhat mobile	Immobile
Potassium	Macro	K^+	Very mobile	Somewhat mobile
Calcium	Macro	Ca^{2+}	Immobile	Somewhat mobile
Magnesium	Macro	Mg^{2+}	Somewhat mobile	Immobile
Sulphur	Macro	SO_4^-	Mobile	Mobile
Boron	Micro	H_3BO_3. BO_3^+	Immobile	Very mobile
Copper	Micro	Cu^{2+}	Immobile	Immobile
Iron	Micro	Fe^{2+}, Fe^{3+}	Immobile	Immobile
Manganese	Micro	Mn^{2+}	Immobile	Mobile
Zinc	Micro	Zn^{2+}	Immobile	Immobile
Molybdenum	Micro	MoO_4^-	Immobile	Somewhat mobile
Chlorine	Micro	Cl^-	Mobile	Mobile
Cobalt	Micro	Co^{2+}	Immobile	Somewhat mobile
Nickel	Micro	Ni^{2+}	Mobile	Somewhat mobile

3.3 Functions of N, P, and K in the Plants

Nitrogen

Nitrogen availability limits the productivity of most cropping systems in Nigeria and all over the world. It is a component of chlorophyll, so when nitrogen is insufficient, leaves will take on a yellow (chlorotic) appearance down the middle of the leaf. New plant growth will be reduced as well, and may appear red or red-brown. Because of its essential role in amino acids and proteins, deficient plants and grains will have low protein content. Nitrogen excess results in extremely dark green leaves, and promotes vegetative plant growth. This growth, particularly of grains, may exceed the plant's ability to hold itself upright, and increased lodging is observed. Nitrogen is mobile both in the soil and in the plant, which affects its application and management, as discussed later.

Phosphorus

Phosphorus is another essential macronutrient whose deficiency is a major consideration in cropping systems. It is an essential part of the components of DNA and RNA, and is involved in cell membrane function and integrity. It is also a component of the ATP system, the "energy currency" of plants and animals. Phosphorus deficiency is seen as purple or reddish discolorations of plant leaves, and is accompanied by poor growth of the plant and roots, reduced yield and early fruit drop, and delayed maturity. Phosphorus excess can also present problems, though it is not as common. Excess P can induce a zinc deficiency through biochemical interactions. Phosphorus is generally immobile in the soil, which influences its application methods, and is somewhat mobile in plants.

Potassium

Potassium is the third most commonly supplemented macronutrient. It has important functions in plant metabolism, is part of the regulation of water loss, and is necessary for adaptations to stress (such as drought and cold). Plants that are deficient in potassium may exhibit reductions in yield before any visible symptoms are noticed. These symptoms include yellowing of the margins and veins and crinkling or rolling of the leaves. An excess, meanwhile, will result in reduced plant uptake of magnesium, due to chemical interactions.

Distinguishing each macronutrient as mobile or immobile in the plant

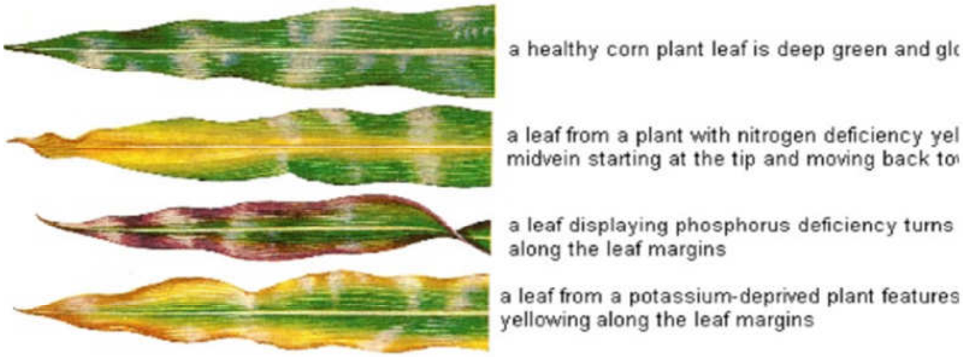
- The mobility of a nutrient in the soil determines how much can be lost due to leaching or runoff.
- The mobility of a nutrient in the plant determines where deficiency symptoms show up.

- Nutrients that are mobile in the plant will move to new growth areas, so the deficiency symptoms will first show up in older leaves.
- Nutrients that are not mobile in the plant will not move to new growth areas, so deficiency symptoms will first show up in the new growth.

Nutrient mobility varies among the essential elements, and represents an important consideration when planning fertilizer applications. For instance, NO_3^- nitrogen is very mobile in the soil, and will leach easily. Excessive or improper application increases the risk of water contamination. Meanwhile, phosphorus is relatively immobile in the soil, and is thus less likely to runoff. At the same time, it is also less available to plants, as it cannot "migrate" easily through the soil profile. Thus, P is often banded close to seeds to make sure it can be reached by starting roots.

Nutrients also have variable degrees of mobility in the plant, which influences where deficiency symptoms appear. For nutrients like nitrogen, phosphorus, and potassium, which are mobile in the plant, deficiency symptoms will appear in older leaves. As new leaves develop, they will take the nutrients from the old leaves and use them to grow. The old leaves are then left without enough nutrients, and display the symptoms. The opposite is true of immobile nutrients like calcium; the new leaves will have symptoms first because they cannot take nutrients from the old leaves, and there is not enough in the soil for their needs

Fig.1.1: Nutrient deficiencies in crops



3.4 Chemical uptake forms for each macronutrient

- Nitrogen: nitrate (NO_3^-) and ammonium (NH_4^+)
- Phosphorus: phosphate (HPO_4^{2-} and $H_2PO_4^-$)
- Potassium: K^+
- Calcium: Ca^{2+}
- Magnesium: Mg^{2+}

- Sulfur: sulfate (SO_4^-)

Table 1.4: Showing the functions and plant-available forms of the nutrients

Nutrient Element	Functions in Plants	Plant available form
Nitrogen (N)	Promotes rapid growth, chlorophyll formation and protein synthesis.	NO_3^-, NH_4^-
Phosphorus (P, P_2O_5[1])	Stimulates early root growth. Hastens maturity. Stimulates blooming and aids seed formation.	HPO_4^{2-}, $H_2PO_4^-$
Potassium (K, K_2O[1])	Increases resistance to drought and disease. Increases stalk and straw strength. Increases quality of grain and seed.	K^+
Sulphur (S)	Amino acids, vitamins. Imparts dark green colour. Stimulates seed production.	Ca^{2+}

Calcium (Ca)	Improves root formation, stiffness of straw and vigour. Increases resistance to seedling diseases	Mg^{2+}
Magnesium (Mg)	Aids chlorophyll formation and phosphorus metabolism. Helps regulate uptake of other nutrients.	SO_4^-
Boron (B)	Aids carbohydrate transport and cell division.	H_3BO_3. BO_3^+
Iron (Fe)	Chlorophyll formation.	Cu^{2+}
Manganese (Mn)	Oxidation-reduction reactions. Hastens germination and maturation.	Fe^{2+}, Fe^{3+}
Copper (Cu)	Enzymes, light reactions.	Mn^{2+}
Zinc (Zn)	Auxins, enzymes.	Zn^{2+}
Molybdenum (Mo)	Aids nitrogen fixation and nitrate assimilation	MoO_4^-
Chlorine (Cl)	Water use.	Cl^-
Cobalt	Essential for nitrogen fixation.	Co^{2+}
Nickel (Ni)	Grain filling, seed viability	Ni^{2+}
Carbon (C)	Component of most plant	CO_2, H_2CO_3
Oxygen (O_2)	Component of most plant	O_2
Hydrogen (H_2)	Component of most plant	H^+, OH^-, H_2O

3.5 How Nutrient Demand Changes at Different Plant Growth Stages

In general, plant nutrient needs start low while the plants are young and small, increases rapidly through vegetative growth, and then decreases again around the time of reproductive development (i.e., silking and tasseling). While absolute nutrient requirements may be low for young plants, they often require or benefit from high levels in the soil around them. The nutrient status of the early seedling will affect the overall plant development and yield. Plants entering the reproductive stages have high nutrient requirements, but many of these are satisfied by redistributing nutrients from the vegetative parts.

SELF-ASSESSMENT EXERCISE

1. Explain the structural, primary and secondary nutrients
2. Discuss the major functions of N, P, K in the plants and outline different forms in which nutrient elements are used by plants in the soil

4.0 CONCLUSION

Soil is a major source of nutrients needed by plants for growth. The three main nutrients are nitrogen (N), phosphorus (P) and potassium (K). Together they make up the trio known as NPK. Other important nutrients are calcium, magnesium and sulfur. Plants also need small quantities of iron, manganese, zinc, copper, boron and molybdenum, known as trace elements because only traces are needed by the plant. The role these nutrients play in plant growth is complex.

5.0 SUMMARY

1. Plants require 18 essential nutrients to grow and survive, classified by their importance into macronutrients (C, H, O, N, P, K, Ca, Mg, S) and micronutrients (B, Cu, Fe, Mn, Zn, Mo, Cl, Co, Ni). Study Tip!
2. Nutrients may be mobile or immobile in the plant and in the soil, which influences redistribution of nutrients and display of deficiency symptoms, and the fertilization of crops.
3. Nutrient demands change throughout the life of the plant, in general increasing during vegetative growth but decreasing during reproductive development.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain what you understand by essential elements.
2. Highlight structural, primary and secondary nutrients.

3. What are the functions of N, P, K in the plants?
4. Outline different forms in which nutrient elements are used by plants in the soil.
5. How does nutrient demand changes at different plant growth stages?

7.0 REFERENCES/FURTHER READING

Roy, R.N., Finck, A., Blair, G.J. & Tandon, H.L.S. (2006). *Plant Nutrition for food security: A guide for integrated nutrient management.* Food and Agriculture Organisation of the United Nations, Rome. 386 pp.

https://nrcca.cals.cornell.edu/soilFertilityCA/CA1/CA1_print.html
https://www.dpi.nsw.gov.au/agriculture/soils/improvement/plant-nutrients

UNIT 2 NUTRIENT ABSORPTION BY CROPS

CONTENTS

1.0 INTRODUCTION

Nutrient uptake by crops can vary from less than 50 kg/ha to more than 1 000 kg/ha depending on the crop, variety, the nutrient, its availability, growth conditions and the biomass produced. Major nutrients constitute the bulk of the nutrients taken up. For example, the total amount of nutrients absorbed by wheat and rice (paddy) per tonne of grain production is about 82 kg and 74 kg, respectively. Out of this, N and K2O alone account for about 75 percent. On an element basis, S uptake is generally similar to P uptake. The six micronutrients taken together add up to about 1 kg/ha.

2.0 OBJECTIVES

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

- discuss nutrient absorption methods by plants
- explain the fate of nutrients applied to the soil
- describe the mechanisms of nutrients uptake by plant cells.

3.0 MAIN CONTENT

3.1 How Nutrients Get to the Root Surface into Plant Cell

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

3.1.1 Mass–flow

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

3.1.2 Diffusion

Diffusion is a continual process in the soil whereby plant nutrients move from area of higher concentration towards the areas of lower concentration around the root surface. The amount of an element moved to the root surface by diffusion depends on the path followed by the movement of water, on soil acidity, the amount of organic matter and the nature of the element itself. Other factors that have been found to affect rate of diffusion of an ion to the root surface are the nature of the plant root system (tap or fibrous) which dictates the absorbing area of root surface, the soil type (clay, loam, sand, etc.) and the difference between the concentration of the nutrient at root surface and in the bulk soil solution.

3.1.3 Root Interception

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

3.2 Mechanisms of Nutrient Uptake into Plant Cell

The mechanisms of absorption of nutrient ions into the root cells continue to be a subject of research by plant nutritionists. Nutrients move into the cortex free space of the root by the **diffusion process.** But this cannot account for the high concentration of ions in plant cells compare to the very low quantity of the same ions in soil solution. For example the normal concentration of potassium in soil solution is about 5-10mg kg-1, plant content of this element is between 1-5%. Plant roots have both positively and negatively charged surfaces. The ions attached to the root surface charges often could be exchanged for those in the soil solution depending on the requirement of the plant. This phenomenon is referred to as **ion Exchange.** For example, H+ ion on the root surface may be exchanged for the K+ ion in soil solution.

However, the **carrier Hypothesis (active transport)** is the most acceptable mechanism by which nutrient ions are taken up by plants. Within the plants, there are **carriers,** organic compounds, which react with ions to form carrier-nutrient complexes which can pass through the membrane into the cell. By means of the organic carriers, plants can have selective absorption of certain elements to the exclusion of others. The most probable theory is that all the three mechanisms – diffusion, ion exchange and carrier hypothesis – are employed in nutrient uptake but carrier hypothesis is used to explain absorption against nutrient concentration gradient.

3.2.1 Movement of Ions into the Root System

The movement of nutrient ions from root surface into the root can be described by two processes: **Passive movement/transport Active**

movement/transport. Passive movement or transport of ions Passive transport of ions occurs in the outer or free spaces in the wall of epidermal and cortical cells of roots and is controlled by ion concentration (diffusion) and electrical (ion exchange) gradient. The concentration of ions in the apparent free space is normally less than the bulk solution concentration and therefore, diffusion occurs with concentration gradient, from high to low concentration.

Passive transport is non-selective process and does not require energy from the metabolic activities of the plant. Active movement or transport of ions Active transport of ions is the movement of an ion against its concentration gradient using energy i.e. when the cell uses energy to pump a solute across the membrane against a concentration gradient. The process of nutrient entry known as ion-carrier mechanism or carrier theory involves a metabolically produced substance (carriers) that combines with free ions. The ion-carrier complex can then cross membranes and other barriers not permeable to free ions and later dissociate to release ions into the inner space of the cell. Active ion transport is selective process such that specific ions are transported across the plasmalemma by specific carrier mechanism.

3.3 Volumes of Nutrient uptake

Higher production through higher cropping intensity also results in substantially higher nutrient uptake, which can range from 400 to 1 000 kg N + P_2O_5 + K_2O/ha/year. The share of N, P_2O_5 and K2O in nutrient uptake is generally 35 percent N, 17 percent P_2O_5 and 48 percent K_2O, in the ratio 1.0:0.5:1.4. Thus, every tonne of N removed is accompanied by the removal of 0.5 tonnes P_2O_5 and 1.4 tonnes K_2O on average. In addition to major nutrients, a grain production level of 10 tonnes/ha through a rice–wheat rotation (6 tonnes paddy + 4 tonnes wheat) can absorb about 3–4 kg of Fe or Mn, 0.5 kg Zn, 200–300 g of Cu or B but only 20 g Mo. Thus, at the same production level, the uptake among nutrients by a crop can vary by more than 10 000 times (260 kg K vs 20 g Mo). Within the group of micronutrients itself, the uptake of Fe and Mn can be 200 times that of Mo. For successful crop production, the crop must be able to access and absorb the indicated nutrients whether these are 150–200 kg of N or K_2O or 15–20 g of Mo. Nutrient uptake by a crop depends on a large number of factors, both controllable and otherwise. This is why large variations are encountered for a given nutrient or for a given crop even under similar conditions.

Nutrient uptake can differ owing to the differences among crops, genetic character of a variety, environment where they grow, fertility level of the field, yield level, luxury consumption, nutrient imbalances and post-absorption events such as lodging and leaf fall. Thus, in order to produce 1 tonne of grain, the uptake by a given crop can vary 1.7-fold in the case of N, 2.3-fold in the case of P and 3.6-fold in the case of K among locations

3.4. Fate of Nutrients Applied to the Soil

The amounts of nutrients added through fertilizers and other sources are only partly utilised by the crop (Figure 2.1). There are four possibilities for what may happen to the added nutrients:

- They enter the pool of available forms and are absorbed by the fertilized plants (recovered portion).
- They are not absorbed but remain available and are partly utilised by the next crop (residual).
- They are "fixed" and thus removed from nutrient cycling for longer periods.
- They are lost from the soil (through ammonia volatilisation, leaching, and denitrification in the case of N).

3.4.1 Fate of Nutrients Absorbed by Crops

The nutrients taken up by a crop are distributed in different parts of the plant during its life span. In the case of grain crops, 70–75 percent of N and P, 25– 30 percent of K and 40–60 percent of S absorbed ends up in the grain, the rest stays in straw/stover. In rice, more than 70 percent of the N absorbed is transferred to the grain while a greater proportion of K, Ca, Mg, Fe, Mn and B remains in the straw. The absorbed S, Zn and Cu are distributed about equally in grain and straw. In groundnut, out of the nutrients absorbed, the kernels contain 41 percent of N, 52 percent of P, 28 percent of K, 11 percent of Mg and 1 percent of Ca. The leaves and stalks contain 45–50 percent of total NPK absorbed and also the bulk of Ca and Mg. In potato, harvested tubers account for 80, 83–88 and 70–78 percent of total N, P and K absorbed, respectively. In cassava, the proportion of absorbed nutrients present in tubers is 23 percent of N, 32 percent of P, 38 percent of K, 12 percent of S, 11 percent of Ca and 29 percent of Mg. In jute, the proportion of absorbed nutrients that is returned to the soil before harvest through leaf fall is particularly high.

3.4.2 Crop recovery of added nutrients and their implications

The recovery or utilisation rate of an applied nutrient is the portion of the added nutrient that is taken up by the plants. It is expressed as a percentage of the nutrient amount supplied. A recovery of 50 percent means that half of the fertilizer nutrients applied has been utilized by the fertilized The recovery rate for applied nutrient is often high for K (up to 70 percent), medium for N (35–70 percent), comparatively low for P and S (15–30 percent), and very low (less than 10 percent) for micronutrients.

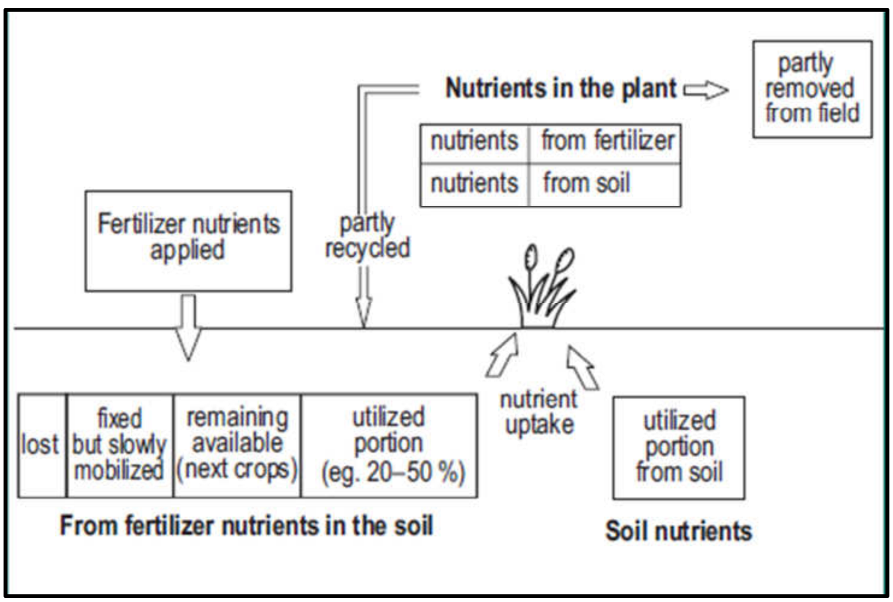


Fig. 2.1: An illustration of partial recovery of applied nutrients by crops ***Source: Finck, 2006***.

SELF-ASSESSMENT EXERCISE

1. Explain "Mass-flow, Diffusion, and Root interception" as regards nutrient absorption

2. Discuss the mechanism of nutrient uptake in plant cell and state the fate of nutrient applied to the soil?

4.0 CONCLUSION

The mechanisms of absorption of nutrient ions into the root cells continue to be a subject of research by plant nutritionists. Nutrients move into the cortex free space of the root by the **diffusion process.** But this cannot account for the high concentration of ions in plant cells compare to the very low quantity of the same ions in soil solution.

5.0 SUMMARY

Within the plants, there are **carriers,** organic compounds, which react with ions to form carrier-nutrient complexes which can pass through the membrane into the cell. By means of the organic carriers, plants can have selective absorption of certain elements to the exclusion of others. The most probable theory is that all the three mechanisms – diffusion, ion exchange and carrier hypothesis – are employed in nutrient uptake but carrier hypothesis is used to explain absorption against nutrient concentration gradient.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss “Mass-flow, Diffusion, and Root interception” as regards nutrient absorption
2. Explain the mechanism of nutrient uptake in plant cell
3. What is the fate of nutrient applied to the soil?
4. Discuss the concept of nutrient recovery or utilization rate

7.0 REFERENCES/FURTHER READING

Finck, A. 2006. Soil nutrient management for plant growth. *In,* B. Warkentin, (Ed.). *Footprintsin the soil*. IUSS Monograph. The Netherlands, Elsevier. (in press)

Kanwar, J.S. 1983. *Groundnut nutrition and fertilizer responses in India*. New Delhi,ICAR. pp.135.

Tandon, H.L.S. 2004. *Fertilizers in Indian agriculture – from 20th to 21st century*. New Delhi, Fertilizer Development and Consultation Organisation. Pp. 239.

Yoshida, S. 1981. *Fundamentals of rice crop science*. Los Banos, Philippines, IRRI. pp.269.

UNIT 3 MAINTENANCE OF SOIL NUTRIENT

CONTENTS

1.0 INTRODUCTION

Organic inputs derived from plant remains provide most of the essential nutrient elements, but usually insufficient quantities. Because of their richness in carbon, organic resources provide an energy source for soil microorganisms which drive the various soil biological processes that enhance nutrient transformation and other quality parameters of soil. As these organic materials undergo the process of decomposition (or breakdown) in soil, they contribute to the formation of soil organic matter (SOM), which is generally considered to be the backbone of soil fertility. Most of the lasting impacts of organic inputs on soils are related to the functions of SOM. During decomposition, the organic materials interact with soil minerals forming complex substances that influence nutrient availability (e.g. binding of otherwise toxic chemical substances such as aluminium or leading to better release of phosphorus bound to soil mineral surfaces).

2.0 OBJECTIVES

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

- explain some activities that maintain nutrients in our soils
- discuss the role of organic matter in soil fertility maintenance.

3.0 MAIN CONTENT

3.1 Organics as Sources of Soil Nutrients

The role of organic materials as nutrient sources is underpinned by the biological processes of decomposition, which involve the biochemical breakdown of dead organic tissue into its inorganic constituent forms, primarily through the action of microorganisms. The process by which essential nutrient elements in unavailable organic forms are converted into their inorganic forms that are available for use by growing plants is known as mineralisation. It is during decomposition of organic materials in soils that SOM is formed and nutrients are released. SOM can therefore said to be made up of organic materials of diverse origin that are at various stages of decomposition through the action of soil microorganisms. Soil microorganisms also grow, multiply and die during the process of decomposition and, in turn, contribute to the dynamic changes in SOM formation and mineralisation (nutrient release).

The amounts of SOM formed as well as quantities of nutrients released depend on the amount and frequency of organic inputs applied to the soil. Under undisturbed natural vegetation such as permanent forests or grasslands, there is usually equilibrium between the organic materials added to the soil in the form of plant litter and the SOM status because nutrients are tightly recycled and not removed in crop products. When the soil is used to cultivate crops, however, the rate of SOM formation and nutrient release is less than the demand for nutrients by crops, particularly when farmers aim for commercial yields. Extra effort is therefore required to add more organic materials to the soil, necessitating the use of mineral fertilizer to increase the amount of organic resources available for use in crop production.

3.1.1 Factors Affecting Organic Matter Supply Of Nutrients

Soil organic matter is a significant source of nitrogen (N), phosphorus (P) and sulfur (S) in crop production. The supply of these nutrients from SOM is dependent upon a number of factors including:

- the *quantity* and frequency with which organic inputs are added to the soil;
- the *quality* of the organic resources; and
- the effect of soil type (e.g. texture and mineralogy) and environmental conditions (e.g. moisture and temperature) that provide an environment in which the processes of decomposition and mineralisation occur.

3.1.2 The Role of Organic Matter in Soil Fertility

By directly supplying available forms of C that stimulate soil biological activity and contribute to SOM formation, organic inputs also influence soil chemical and physical properties. The roles of SOM in improving soil productivity include:

- regulation of the rates and amounts of nutrients released for plant uptake in soils;
- improvement of soil water infiltration rate and soil water-holding capacity;
- increasing cation exchange capacity, or the soil's capacity to store nutrients;
- enhancing soil aggregation (SOM particles act as binding agents), improving soil structure, reducing bulk density and promoting good aeration; and
- binding of toxic elements in soils and minimising their impacts on growing plants.

3.2 Use of Mineral Fertilizers

Fertilizer is a material that contains at least one of the plant nutrients in chemical form that, when applied to the soil, is soluble in the soil solution phase and 'available' for plant roots. Some fertilizers such as urea, potassium chloride (KCl) and diammonium phosphate (DAP) are completely soluble in water, while others such as rock phosphate and dolomite are partly soluble and release nutrients slowly over several months or years.

The objective of fertilizer use is to deliver nutrients to crop plants. As a guide, fertilizer materials should contain at least 5% of one or more of the essential nutrients in an immediately available form. The nutrient content of proper mineral fertilizers is always stated on the bag label. The P, potassium (K) and magnesium (Mg) content is expressed in the oxide form, i.e. P2O5, K2O and MgO. Secondary and micronutrients are often included in compound fertilizers. Note that mineral fertilizers have been discussed extensively previously in this study material.

3.3 Use of Soil Amendment such as Lime

Liming materials are used to increase the pH in acid soils where crops are intolerant of high aluminium (Al) saturation, which often (but not always) accompanies low soil pH. By correcting soil pH and supplying calcium (Ca), lime improves the soil environment for plant growth. In some very acid soils (pH <5.5), Al and manganese (Mn) toxicity is prevented and P and molybdenum (Mo) availability is increased following an application of lime. Other microbiological processes such as nitrification and N2-fixation are also improved and liming may contribute to improved physical soil properties because of increased microbial activity. Acidity is often associated with highly leached soils which are deficient in Ca and Mg so that lime plays an important role in supplying these nutrients. Lime and liming materials have been discussed earlier in this study material.

Table 3.1: The range of agricultural practices, and their likely impacts on soil fertility

Practices	Comment on occurrence	Direct (D) or indirect (I) impact on aspects of soil fertility		
		Biological	Chemical	Physical
Multi-annual rotations Rotation of a variety of crops, including cover crops and green manures	Diversity in space and time encouraged as good practice. Cover crops prevent erosion, structural damage and nutrient loss over winter.	D	D	D

Crop Residue	Incorporation of crop residues encouraged where tillage is practicable.	I	D	I
Tillage	Common within ley-arable, predominately arable and horticultural systems. Less common in intensive grassland.	I	I	D
Grass/clover mixture	Most common on ley-arable systems and intensive grassland. May be found on in bye land on upland/extensive systems. Arable and horticultural systems may use pure clover and/or other legumes in preference.	D	D	I
Livestock management Grazing intensity/ stocking rates	Land related activity, in so far as the number of animals relate to the land area available without causing problems of over-grazing, erosion and to allow for the spreading of	D	D	D

	livestock manures without adverse effects on the environment. Livestock units equivalent must not exceed 170 kg N/ha.			
Applied organic and inorganic materials Lime	May be applied if crop nutrition and soil condition cannot be maintained through rotation and recycling composts, FYM, etc.	I	D	I
Fertilizer1 (or supplementary nutrients)	May be applied if crop nutrition and soil condition cannot be maintained through rotation and recycling composts, FYM, etc. Generally products of low solubility approved by Certification Body.	I	D	I
FYM	On farm derived materials must not exceed 170 kg N/ha/yr of agricultural area used. Off-farm materials – need recognized by inspection body,	D	D	I

	GM free and not exceeding 170 kg N/ha/yr.			
Slurry	On farm derived materials must not exceed 170 kg N/ha/yr of agricultural area used. Off-farm materials – need recognised by inspection body, GMfree and not exceeding 170 kg N/ha/yr.	D	D	I
Compost	Product derived from source that has been submitted to either composting or anaerobic fermentation.	D	D	I
Other Practices				
Pesticide application	Use restricted to a narrow range of products predominantly used in intensive horticultural systems.	D	D	I
Herbicides		D	D	I
Sewage sludge		D	D	I

Drainage/irrigation	Need recognized by inspection body.	I	I	D

Davis and Abbot, (2006)

3.4 Other Soil Fertility Management Practices

Other measures are often needed besides the use of suitable fertilizers and organic inputs, particularly if there are other soil fertility constraints that prevent good crop growth. Some examples are given below, recognizing that this list is not necessarily complete:

3.4.1 Soil Acidity Correction

Some soils are strongly acid, either because of inherent soil properties or due to long term acidity-inducing management practices (e.g. <4) the long-term use of ammonium-based fertilizer). Acidity in itself is often not the major problem, unless the pH is very low (e.g. but acid soils often have high exchangeable Al contents which severely restrict the growth of some crops (e.g. maize). Lime application rates should be calculated to reduce exchangeable Al (to about 15%) rather than increasing soil pH.

3.4.2 Supply of Deficient Micronutrient

Deficiencies to particular micronutrients may be observed (e.g. Zn, B). Such deficiencies are often expressed during plant growth. Some fertilizer blends such as Mavuno fertilizer in Kenya contain micronutrients.

3.4.3 Breaking Hardpans

Continuous management on soils that are prone to compaction can result in a sub-surface soil barrier to crop root growth. Breaking such hardpans by deep ploughing or chisel ploughing to a depth of up to 30 cm allows roots to penetrate the hardpan and access more nutrients and water, resulting in better crop growth.

3.4.4 Water Harvesting

Nutrients will only be recovered efficiently if the crop has sufficient water. The amount of rainfall captured and made available to crops can be increased in areas that are prone to drought. Most approaches aim to harvest extra water by installing structures that decrease runoff (e.g. the Zaï system used in the Sahel or the use of planting basins in southern Africa), or by maintaining organic mulch on the soil surface to promote infiltration and reduce evaporation from the soil surface. All such practices require extra resources in terms of labour or organic materials and an assessment of the risk of drought stress in a particular area will determine whether the deployment of these extra resources is worthwhile.

3.4.5 Erosion control

Soil erosion can be a serious problem, especially on fields with steep slopes, but also on slightly sloping fields with coarse-textured top soil that is prone to erosion. Soil organic matter and nutrients are lost in eroded soil, which may substantially reduce the agronomic efficiency of applied inputs. Several measures can assist in controlling erosion, including planting of live barriers (e.g. grass strips), construction of terraces, or surface mulch application.

SELF-ASSESSMENT EXERCISE

1. What are the factors affecting organic matter supply of nutrients
2. Explain some soil fertility management practices you have studied

4.0 CONCLUSION

Organic inputs used in soil fertility management commonly consist of livestock manures (farmyard manure), crop residues, woodland litter, household organic refuse, composted plant materials (compost), and any plant biomass harvested from within or outside the farm environment for purposes of improving soil productivity. In urban and peri-urban areas, organic inputs can also be made up of industrial organic waste and sewage sludge. Organic resources have multiple functions in soil, ranging from their influence on nutrient availability to modification of the soil environment in which plants grow. There are however other sources which contribute in soil fertility maintenance and sustainability. They include use of inorganic fertilizers, soil amendments and water harvesting.

5.0 SUMMARY

Organic resources have multiple functions in soil, ranging from their influence on nutrient availability to modification of the soil environment in which plants grow. Other measures are often needed besides the use of suitable fertilizers and organic inputs, particularly if there are other soil fertility constraints that prevent good crop growth. They may include acidity correction, supply of micronutrients, water harvesting and erosion control.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss the role of organic matter in soil fertility.
2. What are the factors affecting organic matter supply of nutrients?
3. In tabular form, show some agricultural practices and their likely impact of soil fertility.
4. Discuss some soil fertility management practices you have studied.

7.0 REFERENCES/FURTHER READING

Davis J, Abbot L. Soil fertility in organic farming systems. In, Kristiansen P, Taji A, ReganoldJ, (eds.). Organic Agriculture: A Global Perspective. CABI Publishing, Wallingford, UK; 2006. pp. 25–52.

Fairhurst, T. (ed.) (2012) *Handbook for Integrated Soil Fertility Management*. Africa Soil Health Consortium, Nairobi.

UNIT 4 LOSS OF SOIL NUTRIENT IN INTENSIVE AGRICULTURE

CONTENTS

1.0 INTRODUCTION

Soil properties and landscape characteristics vary considerably on land used to grow crops across the globe, as do climatic conditions. As a result, the crop mix and specific crop production practices (tillage, nutrient applications, pesticide applications, irrigation practices) differ substantially from one part of the country to another. If appropriate management activities and conservation practices are not used, the interaction between wind and water, soil and landscape characteristics, and crop production practices results in the loss of soil, nutrients, and pesticides from farm fields, contributing to water quality degradation in some watersheds. Moreover, onsite soil erosion and soil quality degradation, if not addressed, can jeopardize prospects for sustaining future crop production.

2.0 OBJECTIVES

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

- state some of the activities that lead to the loss of nutrients from the soil
- explain how fertility losses can be minimised
- discuss the concept of soil quality.

3.0 MAIN CONTENT

3.1 Water and Wind Erosion

Water and wind erosion are major factors contributing to the loss of nutrients. Recent studies indicate that annual erosion losses in low-input production systems are about 10 kg N/ha, 2 kg P/ha and 6 kg K/ha. Losses may be greater in high-input systems, or where rainfall is very high. Water barriers, such as grass strips and stone rows, are effective options to reduce erosion and to keep applied fertilizer and manure in place. Erosion and runoff can also be reduced by covering the soil with a mulch layer of living or dead biomass. Soil mulch reduces water speed, avoids crust formation and improves soil porosity and infiltration rates. Even a relatively thin layer of mulch provides a significant increase in water infiltration. Indeed, studies have shown that the application of 2 t/ha of straw led to a 60% reduction in runoff and a 90% reduction in erosion. With 6 t/ha of straw mulch, runoff was reduced by 90% and erosion levels were reduced to zero. Leaving straw in the field leads also to significant reduction in soil losses due to wind erosion. In Niger, 1.4 t/ha millet straw cover reduced wind erosion losses by 63%. The problem faced by most farmers is that their priority is to use organic materials for livestock feed.

Soil preparation methods may also be efficient in increasing infiltration and reducing runoff. The so-called ‘Zaï’ technique is an effective technique to deal with surface crusting: small pits are dug in the soil and small amounts of mineral and/or organic fertilizers are added. Improving SOM content will generally reduce the susceptibility of the soil to form surface crusts and improves soil structure and water holding capacity.

3.2 Leaching

Leaching of nutrients occurs if water carrying nutrients percolates beyond the reach of crop roots in the soil profile and the nutrients are, therefore, lost to the crop. Leaching is a particular problem in areas with high rainfall intensity (>30 mm/day) and coarse-textured sandy soils (>35% sand). Leaching concerns mainly mineral N (principally nitrate, NO_3^-) and exchangeable bases (K and Mg) which are often leached together with NO_3^-. Phosphorus is generally not susceptible to leaching except in very coarse-textured sandy soils.

Some studies suggest that 50–60% of K fertilizer applied in banana plantations in Côte d'Ivoire are lost through leaching. Reducing losses due to deep drainage is difficult, but two approaches can be considered:

- Promoting root development by applying nutrients and improving soil structure. This will allow the crop to better profit from water that has infiltrated into the soil below the present depth of root penetration, and therefore reduce the loss of nutrients.
- Association of annual crops and trees – trees can 'pump' water and nutrients from depths below the rooting depth of annual crops, leading to better overall water and nutrient use.

3.3 Gaseous losses through denitrification and volatilization

Under anaerobic conditions (e.g. poorly drained field or paddy rice field), nitrate is reduced to N2O and N2 (denitrification). Denitrification also occurs in aerobic soils because of the presence of anaerobic microsites that are created following the application of decomposable organic resources. The best way to reduce denitrification in upland fields is to improve soil drainage and maintain a good soil structure to avoid anaerobic growing conditions. Nitrogen can also be lost by volatilisation as NH3-N losses through volatilization are important in alkaline soils (high soil pH). As much as 60% of N applied as urea on paddy (i.e. flooded rice fields) may be lost due to volatilization.
Losses can be reduced by deep placement of N fertilizers, by manual incorporation.

Nitrogen is lost by NH3 volatilisation during the storage and handling of manure. Losses can be reduced by using anaerobic storage pits with or without the addition of crop residues.

3.4 Loss of Phosphorus

Generally, the factors that cause phosphorus movement are similar as those that cause nitrogen movement. Transport mechanisms are erosion, surface water runoff from rainfall and irrigation, and leaching. Factors that influence the source and amount of phosphorus available to be transported are soil properties, and the rate, form, timing, and method of phosphorus applied. The phosphate ion attaches strongly to soil particles and makes up a part of soil organic particles. Any erosion of these particles will transport phosphorus from the site. Phosphorus can also be transported as soluble material in runoff and leaching water. When water moves over the soil surface, as it does in runoff events, or passes through the soil profile during leaching, soluble phosphorus will be transported with the water.

Applying phosphorus fertilizer or manures on the soil surface will subject them to both runoff and erosion, particularly if the application takes place just before a rainfall, irrigation, or wind event that can carry the phosphorus material off site. If, however, the fertilizer or manure material is incorporated into the soil profile, it becomes protected from the transport mechanisms of wind and water. Leaching of phosphorus is at a higher risk through coarse textured soils or organic soils that have low clay content.

Phosphorus is primarily lost from farm fields through three processes:

- attached to the sediment that erodes from the field,
- dissolved in the surface water runoff,
- or dissolved in leachate and carried through the soil profile.

On cultivated fields, most is lost through erosion, whereas on non-tilled fields most phosphorus losses are dissolved in surface water runoff or in leachate. Cultivated acres with phosphorus-rich soils, however, can also lose significant amounts of phosphorus dissolved in the runoff or the leachate.

3.5 Minimising losses of added nutrients

An important objective in fertilizer management is to implement management practices that minimise the loss of nutrients added to the farming system. With good management practices, a significant proportion of nutrients added to the farming system in the form of mineral fertilizers or crop residues and manure can be recycled many times through crops and livestock. Some nutrients taken up by the crop are exported in crop products (grain, tubers) that are exported from the farm but a large part of nutrients taken up by crop plants can be recycled back to the soil in the form of crop residues.

Alternatively, crop residues may be used as fodder for livestock and the manure they produce can be recycled to the field. With proper management, nutrients applied to the field build up the nutrient stocks or capital in the farm and add value to the land. Nutrients added as mineral fertilizer, recycled in crop residues and manure as well as soil nutrient stocks may be lost from the farming system or the farm plot through water or wind erosion, leaching or gaseous losses.

Nitrogen is the most susceptible to losses because it is very mobile and can be lost due to leaching as well as volatilisation. There are three main forms of N ‘capital’ in the soil:

- mineral N (ammonium NH4+ and nitrate NO3–);
- N in soil organic matter; and
- N in a more stable form of soil organic matter.

NH4-N can be held as an exchangeable cation or trapped in the layers within some 2:1 clay minerals, such as montmorillonite, vermiculite and illite. Under aerobic conditions (i.e. well-drained soils) nitrifying bacteria quickly transform NH4-N into NO3-N (nitrification). Nitrate is highly mobile and easily lost by leaching or by denitrification (NO3– is transformed into the gases NO, N2O and N2). Substantial losses of NH4-N can also occur through volatilization (gaseous losses as NH3), especially in alkaline soils and where urea is applied to the soil surface.

3.6 The Concept of soil quality

Soil quality in its simplest terms is how well a soil is doing what we want it to do. The definition of soil quality adopted by the Soil Science Society of America is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. The definition of soil quality includes two aspects: the inherent properties of soil and the effect of human use and management on the ability of the soil to function. The inherent properties of the soil establish the basis from which to set expectations for a specific soil to function. Evaluation of changes in soil quality is based on whether management has enhanced, sustained, or degraded the ability to provide the chosen service, without adverse effects on its surroundings.

Soil provides the following basic functions or services:

- **Controlling water flow.** Soil helps control where rain, snowmelt, and irrigation water goes. Water and dissolved solutes flow either over the soil surface or into and through the soil profile.

- **Sustaining plant and animal productivity.** The diversity and productivity of living things depends on soil. This includes not only crops, but also soil biota such as earthworms and microbes that are beneficial for sustained crop production.

- **Filtering potential pollutants.** The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits.

- **Cycling nutrients**. Carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled through the soil.

- **Supporting structures.** Soils provide a stable medium for plant root growth with sufficient porosity to allow solute flow and aeration. For land uses other than crop production, buildings need stable soil for support, and archeological treasures associated with human habitation are protected in soils.

3.6.1 Soil organic carbon as an indicator of soil quality

The key to managing for improved soil quality for purposes of crop production is to manage for soil organic matter. Soil organic matter is the organic faction of the soil including plant and animal residues, soil organisms, and many combinations of chemical elements. Much of the soil organic matter consists of the element carbon. Carbon is key, because we have the ability to manipulate it, and it has a major role in physical, chemical, and biological properties of soil.

3.6.2 Managing Soil Organic Carbon to enhance Soil Quality

Managing for carbon includes adding organic material such as manure and managing crop residues through reduced tillage, crop rotations, and cover crops. Through microbial breakdown of residues and other natural processes, soil carbon accumulates in the soil. The soil's structure improves through greater aggregation produced by water insoluble proteins and other organic products from the breakdown of residues that bind smaller particles together. This improved aggregation further resists the impacts of rainfall and enhances infiltration, providing more water for plant growth and less for runoff. The reduction in runoff improves water quality by reducing sediment and nutrient loads and increasing the use of the soil as a natural filter. Organic matter removes contaminants from the environment through strong chemical bonds with the soil, rendering the contaminants harmless, or degrading the contaminants to less toxic forms. A soil's ability to retain water is enhanced by the chemical nature of organic matter, which can hold from 10 to 1,000 times more water than inorganic soil matter.

Change in soil organic carbon is an indicator of soil quality. Cropland soils that are increasing in soil organic carbon over time will have an increased capacity to sustain plant and animal activity retain and hold water, filter potential pollutants, and cycle nutrients— that is, enhanced soil function. However, not all cropland soils that are losing soil organic carbon are in a degraded state with respect to soil function. Loss of soil organic carbon is much less serious for cropland acres with inherently high levels of soil organic carbon than for acres with inherently low levels of soil organic carbon. Some soils with relatively high percent losses can continue to lose soil organic carbon for many years before soil function is impaired. Other soils, on the other hand, may only be able to tolerate very small percent losses before soil function is impaired.

SELF-ASSESSMENT EXERCISE

Explain nutrient losses through erosion, leaching and volatilisation and how can these losses be controlled?

4.0 CONCLUSION

Water and wind erosion are major factors contributing to the loss of nutrients. Losses may be greater in high-input systems, or where rainfall is very high. Water barriers, such as grass strips and stone rows, are effective options to reduce erosion and to keep applied fertilizer and manure in place. Erosion and runoff can also be reduced by covering the soil with a mulch layer of living or dead biomass. Soil mulch reduces water speed, avoids crust formation and improves soil porosity and infiltration rates.

5.0 SUMMARY

Nutrients added as mineral fertilizer, recycled in crop residues and manure as well as soil nutrient stocks may be lost from the farming system or the farm plot through water or wind erosion, leaching or gaseous losses. Nitrogen is the most susceptible to losses because it is very mobile and can be lost due to leaching as well as volatilisation. Therefore, management practices that will check erosion, leaching and volatilisation should always be adopted in our croplands. With good management practices, a significant proportion of nutrients added to the farming system in the form of mineral fertilizers or crop residues and manure can be recycled many times through crops and livestock. Some nutrients taken up by the crop are exported in crop products (grain, tubers) that are exported from the farm but a large part of nutrients taken up by crop plants can be recycled back to the soil in the form of crop residues.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss nutrient losses through erosion, leaching and volatilization
2. How can the losses mentioned above be ameliorated
3. Explain the concept of "Soil Quality"
4. Highlight the basic functions the soil provides that bothers on its quality
5. Discuss soil carbon as indicator of soil quality.

7.0 REFERENCES/FURTHER READING

Fairhurst, T. (Ed.) (2012). *Handbook for Integrated Soil Fertility Management*. Africa Soil Health Consortium, Nairobi.

Steven R. P., Susan A., Jay D. A., Robert L. K., Jerry L., Lee N., & Dean, O. (2006). Model Simulation of Soil Loss, Nutrient Loss, and Change in Soil Organic Carbon Associated with Crop Production. United States Department of Agriculture (USDA) Publication. pp 237.

UNIT 5 ROLE LEGUMES IN SOIL

CONTENTS

1.0 INTRODUCTION

Legume crops could play an important role in food security and lowering the risk of climate change by delivering multiple services in line with sustainability principles. In addition to serving as fundamental, worldwide source of high-quality food and feed, legumes contribute to reduce the emission of greenhouse gases, as they release 5–7 times less GHG per unit area compared with other crops; allow the sequestration of carbon in soils with values estimated from 7.21 g kg−1 DM, 23.6 versus 21.8 g C kg−1 year; and induce a saving of fossil energy inputs in the system thanks to N fertilizer reduction, corresponding to 277 kg ha−1 of CO_2 per year. Legumes could also be competitive crops and, due to their environmental and socioeconomic benefits, could be introduced in modern cropping systems to increase crop diversity and reduce use of external inputs.

They also perform well in conservation systems, intercropping systems, which are very important in developing countries as well as in low-input and low-yield farming systems. Legumes fix the atmospheric nitrogen, release in the soil high-quality organic matter and facilitate soil nutrients' circulation and water retention. Based on these multiple functions, legume crops have high potential for conservation agriculture, being functional either as growing crop or as crop residue.

Some **legumes** have the ability to solubilize otherwise unavailable phosphate by excreting organic acids from their roots, in addition to improving soil fertility. **Legumes** also help to restore soil organic matter and reduce pest and disease problems when used in rotation with non-**leguminous crops**.

2.0 OBJECTIVES

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

- state how useful legumes are to agriculture
- explain the importance of legumes in nodulation
- describe the impact of legume on soil quality.

3.0 MAIN CONTENT

3.1 Nodulation in the Legume Family (the *Leguminosae*)

The *Leguminosae* contains roughly 19,000 species that are classified into three sub-families: the*Caesalpiniodeae*, the *Mimosoideae* and the *Papilionoideae*. The *Caesalpiniodeae* is considered to be the oldest and ancestral subfamily from which the other sub-families diverged. The vast majority of legumes in the *Mimosoideae* and the *Papilionoideae* are able to form root nodules and fix N_2 gas, but only a quarter of the caesalpiniod legume species can nodulate and fi x N_2. One well-known example of a N_2-fixing caesalpiniod legume is the forage legume, Wynn cassia (*Chamaecrista rotundifolia*). Some non-nodulating legumes are widely planted as ornamentals (e.g. *Bauhinia* spp., *Delonix regia*) or are used as agroforestry trees (e.g. *Senna siamea*, *Senna spectabilis*) as they grow fast and provide shade and fuelwood. Under some circumstances *Senna* spp. have been observed to be suitable for rehabilitation of degraded soils. In Benin, the deep rooting of *S. siamea* allowed it to recover nutrients from

3.2 Challenges of the Legume Crop

Legumes are often women's crops, grown for home consumption. They are often grown in poorer soils with little application of fertilizers or manure, and with less attention in terms of labour for crop management. This means that environment and management often override the potential of the legume–rhizobium symbiosis for N_2-fixation. In such circumstances, opportunities need to be sought for including legumes in rotation with other crops such as cereals that receive fertilizer so that the legume can benefit from the residual nutrients in the soil. Where there are market opportunities for grain legumes, direct use of basal fertilizer on legumes may be appropriate and necessary to achieve good yields. The nutrient most commonly required by legumes is P, but increasingly deficiencies of K and other nutrients are observed in the field.

3.2 The need for inoculation with rhizobia

Legumes vary widely in their ability to form root nodules with 'indigenous' rhizobia – i.e. compatible rhizobia commonly found in the soils where the legumes are grown:

- Soybean (*G. max*) and chickpea (*Cicer arietinum*) nodulate with a restricted number of rhizobial strains or species and are thus considered as 'specifi c' in their rhizobia requirement.
- Cowpea (*V. unguiculata*) is considered the most promiscuous (non-specific or naturally nodulating) of the grain legumes, and nodulates with a wide range of rhizobia found in many soils.

In nature there is a huge range of promiscuity and specificity, but the most common state is for legumes to be promiscuous in nodulation with indigenous strains in the soil. Thus grain legumes such as cowpea and groundnut, and the vast majority of fodder, green manure and tree legumes do not need to be inoculated with rhizobia. Legumes that have a specific requirement for rhizobia, particularly soybean and chickpea, need inoculation. Rhizobial inoculants are applied on the seed at planting (see http://www.n2africa.org/N2media for a series of educational videos on inoculant manufacture and use).

Most rhizobial inoculants are used with soybean, and on poor soils they can make the difference between crop success and failure. Most varieties of soybean are specific in their requirement for rhizobia and need to be inoculated to get good yields. Newer (and some old) soybean varieties are promiscuous in their nodulation, but although they can form nodules and fix N2 with indigenous rhizobia, inoculation still often increases their yield by up to 20%. Although little research has been done on inoculation with chickpea in Africa, the available evidence suggests that this crop responds strongly to rhizobial inoculants. The situation with common bean (*P. vulgaris*) is less clear – most experimental results indicate small and highly sporadic responses to inoculants, though some scientists recommend inoculation with rhizobia.

Three situations occur where legumes generally do need inoculation:

- where compatible rhizobia are absent from the soil;
- where the population of compatible rhizobia is small; and
- where the indigenous rhizobia are less effective in fixing N2 with the legume compared with selected inoculant strains.

Although inoculation may give increased yields in the first season with newly introduced legumes where they have never been previously grown, some compatible rhizobia are often present. These rhizobia will multiply in the rhizosphere of a compatible host so that the population builds up and inoculation is not essential in subsequent seasons. If inoculants are available they are not costly compared with other production inputs like fertilizer, so that using inoculants is preferable to risking a loss in yield. New research with high-quality inoculants indicates that yield gains through inoculation could be possible even with the most promiscuous legumes in the longer term.

3.4 Legume contributions

Biological N2-fixation can contribute as much as 300 kg N/ha in a season in grain legumes or legume green manures and exceptionally as much as 600 kg N/ha in a year in tree legumes. But where constraints such as drought or deficiencies in P or K limit legume productivity, inputs from N2-fixation are also reduced. The contribution of legumes to soil fertility depends on the amount of N2-fixed in relation to the amount of N taken from the field at harvest time. Legumes grown for soil fertility improvement, such as green manures or agroforestry trees, add the largest amount of N as little is removed from the There are large differences between grain legumes in the amounts of N returned to the soil. In general the greater the biomass produced, the larger the inputs from N2-fixation – so the multi-purpose soybean varieties, or the creeping varieties of groundnut and cowpea leave behind the most N.

3.5 Benefits of Legumes

3.5.1 Grain legumes impacts on atmosphere and soil quality

Among the many important benefits that legumes deliver to society, their role in contributing to climate change mitigation has been rarely addressed. Legumes can (1) lower the emission of greenhouse gases (GHG) such as carbon dioxide (CO2) and nitrous oxide (N2O) compared with agricultural systems based on mineral N fertilization, (2) have an important role in the sequestration of carbon in soils, and (3) reduce the overall fossil energy inputs in the system.

Greenhouse gas emissions: The introduction of legumes into agricultural rotations help in reducing the use of fertilizers and energy in arable systems and consequently lowering the GHG emissions

3.5.2 Improves Soil properties

Cultivation and cropping may cause significant soil organic carbon losses through decomposition of humus. Shifting from pasture to cropping systems may result in loss of soil C stocks between 25 and 43%. Legume-based systems improve several aspects of soil fertility, such as SOC and humus content, N and P availability. With respect to SOC, grain legumes can increase it in several ways, by supplying biomass, organic C, and N, as well as releasing hydrogen gas as by-product of BNF, which promotes bacterial legume nodules' development in the rhizosphere. In sandy soils, the beneficial effect of grain legumes after three years of study was registered in terms of higher content of SOC compared with soils with oats (7.21 g kg^{-1} DM, on average).

Specifically, cultivation of pea exerted the most positive action to organic carbon content (7.58 g kg^{-1} , after harvest, on average), whereas narrow-leaved lupin had the least effect (7.23 g kg^{-1} , on average) [30]. In southern America (Argentina), the intercropping of soybean with maize at different rates favoured a SOC accumulation of 23.6 g C kg^{-1} versus 21.8 g C kg^{-1} of the sole maize; the greatest potential for enhancing SOC stocks occurred in the 2:3 (maize:soybean) intercrop configuration. Furthermore, just only amending the soil with soybean residues allows to obtain an increase of 38.5% in SOC.

3.5.3 Role of grain legumes in cropping systems

Legumes could be competitive crops, in terms of environmental and socioeconomic benefits, with potential to be introduced in modern cropping systems, which are characterized by a decreasing crop diversity and an excessive use of external inputs (i.e. fertilizers and agrochemicals).

Grain legumes into crop-sequences: In the recent years, many studies have focused on the sustainable re-introduction of grain legumes into crop rotations, based on their positive effects on yield and quality characteristics on subsequent crops. However, assessment of the rotational advantages/ disadvantages should be based on a pairwise comparison between legume and non-legume pre-crops. Some experimental designs involving multi-year and multispecies rotations do not provide information on yield benefits to the subsequent species in the rotation sequence. Therefore, it is difficult to formulate adequate conclusions. The agronomic pre-crop benefits of grain legumes can be divided into a 'nitrogen effect' component and 'break crop effect' component. The 'nitrogen effect' component is a result of the N provision from BN, which is highest in situations of low N fertilization to subsequent crop cycles. The second one (break crop effect) includes non-legume-specific benefits, such as improvements of soil organic matter and structure, phosphorus mobilization, soil water retention and availability, and reduced pressure from diseases and weeds. In this case, benefits are highest in cereal-dominated rotations.

3.5.4 Grain legumes in intercropping

Intercropping systems consist in simultaneous growth of two or more crop species on the same area and at the same time. Intercropping is widely used in developing countries or in low-input and low-yield farming systems. Despite several recognised beneficial aspects of intercropping such as better pest control, competitive yields with reduced inputs, pollution mitigation, more stable aggregate food or forage yields per unit area, there are a number of constrains that make intercropping not common in modern agriculture, such as example the request of a single and standardized product and the suitability for mechanisation or use of other inputs as a prerogative in intensive farming system. It is therefore necessary to optimize intercropping systems to enhance resource-use efficiency and crop yield simultaneously, while also promoting multiple ecosystem services. Most recent research has focalised on the potential of intercropping in sustainable productions and in particular on grain legumes that can fix N2 through biological mechanisms (BNF). Indeed, legumes are pivotal in many intercropping systems, and of the top 10 most frequently used intercrop species, seven are legumes.

3.5.5 Grain legumes and conservation agriculture

Legumes have some characteristics particularly suitable for sustainable cropping systems and conservation agriculture, and making them functional either as growing crop or as crop residue. Conservation agriculture is based on minimal soil disturbance and permanent soil cover combined with rotations. As previously described, major advantages of legumes include the amount of nitrogen fixed into the soil and the high quality of the organic matter released to the soil in term of C/N ratio. Some legume species have also deep root systems, which facilitate nutrients solubilisation by root exudates and their uptake/recycling as well as water infiltration in deeper soil layers. Many countries already rely on conservation agriculture.

Brazil has implemented conservation agriculture systems using soybean as legume crop. Grain legumes like lentil, chickpea, pea and faba bean play a major role in conservation agriculture in North America, Australia, and Turkey. In Australia, some advantages of minimum tillage for grain legumes have been quantified for water limited environments. Some studies indicate that the majority of grain-legumes producers use direct seeding after a legume pre-crop. This change from conventional tillage (CT) to reduced or no tillage (NT) systems (with at least 30% of the soil surface covered) would lead to significant positive impacts on SOC. In contrast, other results indicate that such positive effects are limited to the first 20 cm depth, while little or no difference between CT and NT in total SOC can be seen lower down the soil profile.

SELF-ASSESSMENT EXERCISE

1. What are the challenges of the legume crops and explain the role of legumes in conservation agriculture.
2. Describe the beneficial impact of legumes to soil properties, crop rotation and inter-cropping.

4.0 CONCLUSION

The roles and importance of grain legumes in a context of sustainability in agriculture could be enhanced by the emerging research opportunities for the major topics discussed above. A major task in the future will be the selection of legume species and cultivars which could be effectively introduced across different cropping systems. An important point concerns balancing yield, which gives economic return, with the environmental and agronomic benefits. Some priority areas seem emerge. Nitrogen fixation activity of grain legumes should be evaluated in relation with soil, climatic, plant characteristics and management conditions to find the suitable approach to achieve the best improvements. With this respect, the ability of the host plant to store fixed nitrogen appears to be a major component of increasing nitrogen fixation input. A particular focus should be paid also to the study of abiotic stress limitations and in particular water deficit, salinity and thermal shocks require extensive investigation. Legumes that can recover unavailable forms of soil phosphorus could be major assets in future cropping systems. Consequently, those legumes which are able to accumulate phosphorus from forms normally unavailable need to be further studied, since phosphorus represents an expensive and limiting resource in several cropping systems.

5.0 SUMMARY

Grain legumes have beneficial impacts on atmosphere and soil quality. Among the many important benefits that legumes deliver to society, they also play significant role in climate change mitigation. Legumes can (1) lower the emission of greenhouse gases (GHG) such as carbon dioxide (CO2) and nitrous oxide (N2O) compared with agricultural systems based on mineral N fertilization, (2) have an important role in the sequestration of carbon in soils, and (3) reduce the overall fossil energy inputs in the system. The introduction of legumes into agricultural rotations helps in reducing the use of fertilizers and energy in arable systems and consequently lowering the GHG emissions.

Some **legumes** have the ability to solubilize otherwise unavailable phosphate by excreting organic acids from their roots, in addition to improving soil fertility. **Legumes** also help to restore soil organic matter and reduce pest and disease problems when used in rotation with non-**leguminous crops**.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss legume nodulation in agriculture.
2. What are the challenges of the legume crops?
3. Describe the beneficial impact of legumes to soil properties, crop rotation and inter-cropping.
4. What is the role of legume in conservation agriculture?

7.0 REFERENCES/FURTHER READING

Bichel A, Oelbermann M, Voroney P, Echarte L. (2016). Sequestration of native soil organic carbon and residue carbon in complex agroecosystems. Carbon Manag. 7:1 10.

Christopher SF, Lal R. (2007). Nitrogen management affects carbon sequestration in North American cropland soils. Crit Rev Plant Sci.;26, pp.45–64.

Fabio Stagnari, Albino Maggio, Angelica Galieni & Michele Pisante. (2017). Multiple benefits of legumes for agriculture sustainability: An overview Stagnari *et al*. Chem. Biol. Technol. Agric. 4:2 DOI 10.1186/s40538-016-0085-1

Fairhurst, T. (Ed.). (2012). *Handbook for Integrated Soil Fertility Management*. Africa Soil Health Consortium, Nairobi.

Garrigues E, Corson MS, Walter C, Angers DA, van der Werf H. (2012.). Soilquality indicators in LCA: method presentation with a case study. In, Corson MS, van der Werf HMG. (Eds). Proceedings of the 8th international conference on life cycle assessment in the agri-food sector, 1–4 October 2012, INRA, Saint Malo; pp 163–68.

Jensen, E.S., Peoples, M.B., Boddey, R.M., Gresshoff, P.M., Hauggaard- Nielsen H, Alves, B.J., Morrison, M.J. (2012). Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. *A review*. *Agron Sustain Dev*.;32, pp.329–64.

Legume Futures Report 1.6. Reckling M, Preissel S, Zander P, Topp CFE, Watson CA, Murphy-Bokern D, Stoddard, F.L. (2014). Effects of legume cropping on farming and food systems. Available from www.legumefutures.de