COURSE GUIDE

CRP 302
CROP PHYSIOLOGY AND TAXONOMY

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INTRODUCTION

Crop Physiology (CRP 302) is a two (2)-credit unit course on introduction to crop Physiology. The course is broken into 27 units in all in six (6) modules. These units will teach and explain Physiology study as a tool and systematic process for ensuring that physiology considerations are taken into account in all proposed activities. This course guide defines what the course is all about as well as the course material that you will need to consult to ensure that the course is simple and within your reach. It suggests some general guidelines for the amount of time you are likely to spend studying each unit in order to complete it successfully. It also gives you some guidance on your tutor-marked assignments. The course will deal with the basic principles and selected applications of physiology for agricultural crops, emphasizing the need for a different type of agriculture, in order to support the increasing needs for food (quantity and quality) facing climatic changes as well as increased abiotic and biotic stress conditions. The basic aspects of the major biotechnological tools and solutions will be evaluated.

WHAT YOU WILL LEARN IN THIS COURSE

On successful completion of this module, you will be able to:

1. To describe the major basic biotechnologies related to agricultural production.
2. To explain the major practical biotechnologies aimed at solving agriculture and food production problems.
3. To evaluate the achieved progress, the possible risks and future needs of agricultural biotechnologies.
4. To examine the ecological, sociological and ethical issues associated with genetically-modified (GM) plants and their products.

COURSE AIMS

The Course aims and objectives are follows:

1. To expose the students to the basic scientific evidence and technical aspects of the different disciplines of agricultural biotechnologies (mainly for plants and crops).
2. To clarify the major scientific, ecological and sociological aspects of physiology in agriculture and food production.
3. To discuss the general issues and interrelationships of science, agriculture and human well-being.

COURSE OBJECTIVES

For the aims to be achieved, there are set objectives. Each unit of this course also has its specific objectives that are found at the beginning of each unit. You will need to understand these objectives before you start working on each unit. You are encouraged to refer to them periodically to check on your progress in learning and assimilating the content. On completion of a unit, you may re-examine the objectives to ensure that you fully learn what is required. By so doing you can be sure that you have achieved what the unit expects you to acquire.

By meeting these objectives, the aims of the course as a whole would have been achieved. These objectives include:

- Define and explain the meaning of physiology
- Understand the Background to general physiology:
- Explain Agricultural biotechnologies and breeding - global perspectives and trends.
- Describe the Applications of plant Physiology in crop improvement.
- Understand the concept of Micro techniques
- Explain Plant Genetic Engineering and Production of Transgenic Plants.
- State the importance of Applications of Genetic Engineering
- Describe the Application of Cell Culture Systems in Metabolic Engineering.
- State the aims and scope of Molecular Farming and Applications.

WORKING THROUGH THIS COURSE

To complete this course, you are required to read the study units carefully and read other recommended materials. You will be required to answer some questions based on what you have read in the content to reaffirm the key points. At the end of each unit there are some Tutor-Marked Assignments (TMA) which you are expected to submit for Marking. The TMA forms part of your continuous assignments. At the end of the course is a final examination. The course should take you 12 to 13 weeks to complete. The component of the course is given to you to know what to do and how you should allocate your time to each unit in order to complete the course successfully on time.

COURSE MATERIALS

The major components of this course are:

1. Course Guide
2. Study Units
3. References and Further Reading
4. Assignment File
5. Presentation Schedule

STUDY UNITS

MODULE 1 INTRODUCTION TO CROP PHYSIOLOGY AND ITS IMPORTANCE IN AGRICULTURE

Unit 1 Definition of Terms
Unit 2 A Brief History of Crop Physiology
Unit 3 Meaning of Crop Physiology and its Importance in Agriculture

Module 2 Plant Cell: An Overview

Unit 1 Brief Overview Plant Cell
Unit 2 Brief Description of Various Organelles and their Functions

Module 3 Diffusion and Osmosis; Absorption of Water, Transpiration and Stomatal Physiology

Unit 1 Meaning and Definition of Diffusion and Osmosis
Unit 2 Explanation on Different Type of Solutions
Unit 3 Meaning of Water Potential and its Components and Importance
Unit 4 Concept of Water Uptake and Movement (Transpiration Stream)
Unit 5 Methods of Measuring Water Status in Plants
Unit 6 Concept of Stomatal Physiology and Transpiration
Unit 7 Concept of Evapotranspiration
Unit 8 Concept of Soil Water Availability

Module 4 Mineral Nutrition of Plants: Functions and Deficiency Symptoms of Nutrients, Nutrient Uptake Mechanisms

Unit 1 Meaning of Mineral Nutrition

Module 5 **Photosynthesis: Light and Dark Reactions, C3, C4 and CAM Plants**

Unit 1 Meaning and Concept of Photosynthesis

Module 6 **Crop Geometry and Cultural Manipulations**.

Unit 1 Meaning of Crop Geometry

TEXTBOOKS AND REFERENCES

Clements, F. E., Weaver, J. E. & Hanson H. (1949). Carnegie Inst., Washington, D.C. Publ. no. 398.

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ASSESSMENT

You will be assessed in two ways in this course – the Tutor-Marked Assignments (TMA) and a written examination. You are expected to do the assignments and submit them to your tutorial facilitator for formal assessment in accordance with the stated deadlines in the presentation schedule and the assignment file. Your tutor-marked assignment will account for 30 per cent of the total course mark.

TUTOR-MARKED ASSIGNMENT (TMA)

There are Tutor Marked Assignment and self-assignment in each unit. You would have to do the TMA as a revision of each unit. And there are four Tutor Marked Assignment you are required to do and submit as your assignment for the course. This would help you to have broad view and better understanding of subject. Your tutorial facilitator would inform you about the particular TMA you are to submit to him for marking and recording. Make sure your assignment reaches your tutor before the deadline given in the presentation schedule and assignment file. If, for any reason, you cannot complete your work on schedule, contact your tutor before the assignment is due to discuss the possibility of an extension. Extensions will not be granted after the due date unless there are exceptional circumstances. You will be able to complete your assignment questions from the Contents contained in this course material and References/Further reading; however, it is desirable to search other References/Further reading, which will give you a broader view point and a deeper understanding of the subject.

FINAL EXAMINATION AND GRADING

The modalities for the final examination for CRP 302 will be determined by NOUN. The pattern of the questions will not be too different from those you have responded to in the tutor-marked assignment. However, as the university has commenced online examinations, you may have to adjust to whatever format is made available to you at any point in time. Nonetheless, be assured of the content validity of the examinations. You will only be examined strictly on the content of the course, no matter the form the examination takes. It is thus advisable that you revise the different kinds of sections of the course properly before the examination date.

HOW TO GET THE BEST FROM THIS COURSE

The study units in this course have been written in such a way that you can easily go through them without the lecturer being physically around and this is what happens in distance learning. Each study unit is for one week. The study units will introduce you to the topic for that week; give you the objective(s) for the unit and what you are expected to be able to do at the end of the unit. Follow these religiously and do the exercises that follow. In addition to the above, unlike other courses where you just read and jot notes, CRP 302 has a lot of basic principles and theories to learn. You therefore need a lot of concentration while going through the course.

TUTORS AND TUTORIALS

This course has tutorial hours. The dates, times and location of these tutorials will be communicated to you as well as the name and phone number of your tutorial facilitator. You will also be notified of your tutorial group. As you relate with your tutorial facilitator, he/she will mark and correct your assignments and also keep a close watch on your performance in the tutor-marked assignment and attendance at tutorials. Feel free to contact your tutorial facilitator by phone or e-mail if you have any problem with the contents of any of the study units.

SUMMARY

This course intends to introduce you to the physiology and taxonomy of crops. Upon completion of this course, you will be equipped with basic knowledge and understanding of the components of crop Physiology and Taxonomy.

After successfully gone through this course, you would be able to do the following:

- Define some of the Vital terms in Crop Physiology
- Explain the meaning of Crop Physiology
- Explain the meaning of Plant Cell
- Outline the different types of plant cell
- Differentiate between the plant cell and animal cell
- Describe various organelles associated with plant
- Outline functions of the mentioned organelles
- Explain the meaning of Diffusion and Osmosis
- Discuss Diffusion as means of Transport in plants
- List types of Diffusion in plants
- Outline the importance of Diffusion in plants
- Explain how Osmosis affect plant cells
- Define solvent and solute
- Differentiate between solvent and solute
- Explain the meaning of solution
- Identify and explain the various types of solution
- Explain the meaning of water potentials
- Outline and discuss the components of water potential
- State the importance of water potentials in Agriculture
- Explain the uptake of water in plants
- Explain the various methods of measuring water status
- Explain the meaning and define stomata
- Discuss the different theories of stomatal movement of photosynthesis
- Explain the meaning of stomata evapotranspiration
- Outline different factors affecting evapotranspiration with each specific factors
- Explain the meaning of water availability
- Discuss a typical soil profile
- Explain the concept of soil-water availability
- Explain the meaning of mineral nutrition
- Outline the classification of essential elements in two groups
- List the specific roles of essential mineral elements
- Explain the physiology of Nutrient uptake

- Explain the meaning and definition of photosynthesis
- Explain photochemical Reaction
- Outline the concept of cyclic photophorylation

You should be able to use the knowledge acquired to provide practical solutions in Agriculture and Horticulture through better management practice for profitable crop yield in your locality. I wish you success and hope that you find it interesting and useful.

MAIN COURSE

CONTENT **PAGE**

MODULE 1 INTRODUCTION TO CROP PHYSIOLOGY AND ITS IMPORTANCE IN AGRICULTURE

UNIT 1 DEFINITION OF TERMS

CONTENTS

1.0 INTRODUCTION

Genetic potential of a plant and its interaction with environmental factors decides its growth and development by influencing or modifying certain internal processes. Plant physiology studies about these internal processes and their functional aspects.

Plant physiology is a study of **Vital phenomena** in plant. It is the science concerned with Processes and functions, the responses of plants to environment and the growth and development that results from the responses. It helps to understand various biological processes of the plants like Photosynthesis, respiration, transpiration, translocation, nutrient uptake, plant growth regulation through hormones and such other processes which have profound impact on crop yield.

2.0 OBJECTIVE

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

- define vitals terms in crop physiology

3.0 MAIN CONTENT

3.1 Definition of Vital Terms in Crop Physiology

3.1.1 Plant Processes

Processes mean natural event/ sequence of events. Examples of processes that occur in living plants are

- Photosynthesis
- Ion absorption
- Transpiration
- Assimilation
- Seed formation and
- Respiration
- Translocation
- Stomatal opening and closing
- Flowering
- Seed germination

To described and explain the plant processes is the main task or the first task of plant physiology.

3.1.2 Plant Function

Function means natural activity of a cell or tissue, or organ or a chemical substance. So, the second task of plant physiology is to describe and explain the function of an organ, tissue, cell and cell organelle in plants and the function of each chemical constituent, whether it may be an ion, molecule or a macro molecule.

Both processes and functions are dependent on the external factors and are modified by the external factors such as light and temperature. Since these two factors are modified by the external factors, the third task of plant physiology is to describe and explain how processes and functions respond to change in the environment.

Essentially the overall goal of plant physiology is to evolve a detailed and comprehensive knowledge of all the natural phenomena that occur in living plants and thus to understand the nature of plant growth, development and productivity.

Many aspects of practical agriculture can benefit from more intensive research in plant physiology.

3.1.3 Crop

It is a group of plants grown as a community in a specific locality and, for a specific purpose.

3.1.4 Plant nutrients

Soil is a major source of **nutrients** needed by **plants** for growth. The three main **nutrients** are nitrogen (N), phosphorus (P) and potassium (K). The role these **nutrients** play in **plant** growth is complex, and this document provides only a brief outline.

3.1.5 Plant growth

Growth in **plants** occurs as the stems and roots lengthen. Some **plants**, especially those that are woody, also increase in thickness during their life span. The increase in length of the shoot and the root is referred to as primary **growth**, and is the result of cell division in the shoot apical meristem.

3.1.6 Gels

Are thick semisolid elastic colloidal systems which are formed by hydrophilic sols. A gel is a reverse of sol. Gelation- Conversion of hydrosols to gels Solation- Conversion of gels to sols. Emulsion is a mixture of two immiscible liquids. It is essentially unstable and breaks up with time in two distinct layers e.g. oil in water.

3.1.7 Solution

The dispersion of a substance in molecular or ionic form throughout the medium of another is known as solution. True Solution or Crystalloid- A homogeneous and stable mixture of two or more chemical substances which have different molecular species & size of particles is 1nm or below, e.g. common salt in water.

3.1.8 Colloidal solution

A stable and heterogeneous solution in which size of particles is in between 1-200 nm. Suspension- An unstable heterogeneous solution in which the particle size is usually more than 0.1 µm.

3.1.9 Imbibition

It is the phenomenon of adsorption of water or any other liquid by the solid particles of a substance without forming a solution. Here, in this process liquid molecules move from the region of high partial pressure to low partial pressure. Solid particles which imbibe water or any other liquid are called **imbibants** & liquid absorbed is called **imbibate.**

3.1.10 Turgor Pressure (TP)

It is the hydrostatic pressure generated by the protoplasm within the cell against cell wall as a result of osmotic entry of water into it. Turgor Pressure is always less than Osmotic Pressure unless the cell is in water. Cell wall being rigid and elastic exerts an equal and opposite pressure on expanding protoplasm, called wall pressure (WP). At a given time TP=WP

SELF-ASSESMENT EXERCISE

Outline the different definitions of Crop Physiology available in the literature.

4.0 CONCLUSION

This unit has defined several vital terms frequently used in the field of crop physiology.

5.0 SUMMARY

Genetic potential of a plant and its interaction with environmental factors decides its growth and development by influencing or modifying certain internal processes. Plant physiology studies about these internal processes and their functional aspects.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define plant processes and give 10 examples of it.
2. Explain plant functions in crop physiology.
3. Define any five of the following terms.

- Crop
- Plant nutrients
- Gel or gelation
- Turgor pressure
- Plant growth
- Solution

- Colloidal solution
- Imbibition

7.0 REFERENCES/FURTHER READING

Dennis, D. T. & Turpin, D. H. (1990). *Plant Physiology, Biochemistry and Molecular Biology*. Harlow, Essex, UK: Longman Group.

Salisbury, F. B. & Ross, C. W. (1985). *Plant Physiology*, (3rd ed.). Belmont, CA: Wadsworth Publishing,.

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UNIT 2 A BRIEF HISTORY OF CROP PHYSIOLOGY

CONTENTS

1.0 INTRODUCTION

Plant physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture.

The central question of plant physiology is how do plants grow, develop, and reproduce? When primitive humans collected seeds and began raising food plants, they must have noted that plants need sunlight, warmth and moist (but not wet) soil of good tilth, and that seeds from vigorous plants produced vigorous plants. They observed the beneficial effects of manuring (mentioned in the Bible; Luke 13:8). Centuries of agricultural practice produced improved varieties and cultural practices, and early studies of physiology drew on this basic knowledge of plant growth and gross anatomy.

2.0 OBJECTIVE

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

- give a brief history of evolution of crop physiology through various stages.

3.0 MAIN CONTENT

3.1 Brief History of Crop Physiology

3.1.1 Early Experiments on Growth

An early physiological question was where a plant gets the material with which it grows. In the early 1600s, Jan van Helmont, a Belgian physician, decided the source must be water alone. Van Helmont grew a willow seedling in 200 pounds of soil, and only added rainwater. A 164-pound tree was produced with only 57.1 grams (2 ounces) of soil lost. He knew of carbon dioxide but never dreamed that a diffuse gas could produce willow wood.

In the next century Antoine Lavoisier found **organic** matter to be largely formed of carbon and oxygen. Joseph Priestley, Jan Ingenhousz, and Jean Senebier demonstrated that plant leaves in light take up carbon dioxide and emit equivalent amounts of oxygen. Later, Nicholas de Saussure noted that water was involved in the process. The reverse occurred in the dark—plants **respired** like animals, taking up oxygen and emitting carbon dioxide. J. R. Mayer observed that the process converted light energy into the chemical energy of organic carbon. Thus, growth of seedlings in the dark or of roots in the soil was at the expense of this energy. Therefore, by the nineteenth century, photosynthesis, although not understood biochemically, was established as the primary and essential synthetic process in plant growth.

3.1.2 Experiments on Plant Nutrition and Transportation

In his experiment, van Helmont assigned no importance to the two ounces of soil lost. However, starting in the late 1700s and extending into the mid-1800s, Julius Sachs and others used chemical assays to establish that quantitatively minor soil constituents of nitrogen, potassium, phosphate, sulphur, and other elements had major importance in plant growth. The long-recognised importance of manure lay with its content of these **inorganic** nutrients, especially nitrogen. It was discovered these could be added to the soil as inorganic salts, such as potassium nitrate. The organic material of manure, or the residue of its decay, contributed to improved tilth, or soil structure, but did not provide nutrients. From these discoveries came the modern agricultural use of chemical fertilizers.

What about the extensive loss of water from the soil? Van Helmont had to continuously water his willow tree with many more pounds of water than were ultimately incorporated by the tree. In 1727 an English clergyman and amateur physiologist, Stephen Hales, published *Vegetable Staticks,* an account of his pioneering studies on the transpiration, growth, and gas exchanges of plants. Hales demonstrated that water from the soil moves up the stems to the leaves where it is lost as water vapour, a process called transpiration. Subsequent research of the 19th and early 20th centuries showed that the water diffuses out through **stomata** (singular stoma), pores in the leaf epidermis (outer layer of leaf cells).

With light and adequate water, the two cells bounding the stoma inflate, opening the pore to gas diffusion; under dry conditions the cells grow flaccid and the pore closes, conserving water. Capillary forces originating in the microscopic pores of the leaf mesophyll (internal green photosynthetic cells), with some contribution from **osmosis,** pull columns of water up the open vessels and tracheid of the **xylem** (wood) carrying nutrient salts from the roots. The coherence between water molecules and their adherence to cell walls prevents the taut water columns from breaking even in trees of great height. This scheme was first proposed in 1895 by Henry Dixen and John Joly. Numerous researchers in the 20th century confirmed and refined this "cohesion-tension" theory of transportation.

Hales also measured the root pressure (forced bleeding) of decapitated plants. Subsequent work showed that under conditions of good soil moisture and aeration, roots actively secrete high concentrations of salt into the root xylem creating a high osmotic pressure that forces water up the stem and out pores at the tips of leaves (guttation). In 1926, E. Munch proposed a similar mechanism for **translocation**, the movement of sugars from leaves to roots and other plant parts. This mechanism is known as the pressure flow model. In 1915 Crop physiology, with the aim of understanding the dynamics of yield development in crops, really began with the work of W.L. Balls. Along with Holton he analysed the effects of plant spacing and sowing date on the development and yield of Egyptian cotton plants within crop stands, not in isolated plants. It was from his work the term ‘crop physiology’ came into existence. From then onwards, various scientists have started applying the advances in physiological knowledge for better crop management. In 1924, in England- a rapid development of the methods of growth and yield analysis by different investigators (V.H. Blackman, F.G. Gregory, G.E. Briggs etc.) was started. With the development of various methods of growth analysis, they started explaining ‘the physiology of crop yield’ in 1947, the concept of LAI (Leaf area index) was developed by D.J. Watson. This index has provided a more meaningful way of analysing growth in crops, and stimulated renewed interest in crop physiology. In 1950’s, studies on photosynthetic rate of the leaf and the loss of photosynthates by respiration was studied by the development of ‘Infra-Red Gas

Analysis (IRGA)'method. This method has facilitated the estimation of short-term rates of Photosynthesis and respiration by crops in the field. In 1953, Monsi and Saeki explained about the manner of light interception by the crop canopy with their concept of light interception coefficient.

In 1963, Hesketh and Moss showed that photosynthesis by leaves of Maize, Sugarcane and related tropical grasses could reach much higher rates, with less marked light saturation, than leaves of other plants. (This was the starting point for research to find other photosynthetic CO_2 fixation path ways like C4, and CAM Mechanisms). The differences in pathway are associated with differences in photosynthetic rate, in response to light intensity, temperature and oxygen level, in photorespiration, in leaf anatomy and chloroplast morphology, in rate of translocation, and in the efficiency of water use, which can have profound effects on the physiology of yield determination.

3.1.3 Current Research on Cellular and Molecular Plant Physiology

By the 20th century, plant physiologists increasingly turned to chemistry and physics for assistance with fundamental questions. They also established their own societies with journals to publish their findings, which had a catalytic effect in increasing the level and amount of research. A great deal of the fundamental biochemistry of cell growth and function, known from the more extensive medical, animal, and microbiological research, was found to apply to plant cells. Anatomical studies gave structural details to support physiological findings, and sub microscopic cell structure was revealed by the electron microscope.
All the mineral nutrients required for plant growth were established. The key to their selective uptake from the soil and transport into the root xylem proved to lie with an energy-requiring proton (hydrogen **ion)** pumping mechanism in the cell membranes.

Environmental, hormonal, and genetic controls on growth and development have been extensively explored, but there is still more to learn. Ethylene, a simple two-carbon gas generated by plants initiates fruit ripening and regulates aspects of seed germination. Phototropism's (bending in response to unilateral light, investigated by Charles Darwin), and geotropisms (root growth down, stem growth up) were found to be due to displacement of a cell growth **hormone,** or auxin. In some circumstances, auxins could also elicit cell division (root formation in stem cuttings). Other hormones, the gibberellins, regulate cell division at the stem apex and activate **enzyme** formation in seed germination.

Attempts to culture plant tissues led to discovery of more cell division hormones, the cytokinin. Another type of hormone, abscisic acid, initiates the senescence and **abscission** of leaves in the fall, and causes the stomata to close under water stress. Additional growth regulating compounds are being found and investigated but a coordinated picture of hormone interaction is lacking.

Photoperiodism, the regulation of flowering by day length was discovered. Sleep movements, such as the drooping of bean leaves in the evening, were found to be controlled by a biological "clock," a **circadian** rhythm, not by the onset of darkness. In 1952, phytochrome was discovered and found to be the pigment at the center of photoperiodism.

In recent years there has been a major shift to molecular genetics in attempts to locate the genes responsible for physiological processes. In photosynthesis chlorophyll structure was determined and localised in the internal membranes of the chloroplasts of the mesophyll cells. Red and blue portions of the light spectrum were found effective, leading to the discovery that two light reactions are required. In the 1930s, C. B. Van Neil used radioactive water to show that water, not carbon dioxide, was the source of oxygen released during photosynthesis. Sugar was found to be synthesised in the stroma (fluid part) of the chloroplast, and the molecular details of its creation were worked out by Melvin Calvin and Andrew Benson. All plant cells were found to respire, an energy-yielding process essentially the same as that in animals, involving another membranous organelle , the mitochondrion, and yielding metabolic energy available for transport reactions and synthesis of cell substance.

The formation of fats and oils from carbohydrates was found to be similar to that in animals, but plants had the added ability to transform oils in germinating seeds into carbohydrates such as the **glucose** used in **cellulose** wall formation. The symbiotic relationships of plants and microorganisms were explored, notably in the cases of reduced nitrogen formation from atmospheric nitrogen by nodule bacteria.

At the end of 20th century, the small mustard plant *Arabidopsis thaliana* took center stage in the attempt of scientists to understand plant genomes**.** The full sequence of this genome was elucidated in 200 by an international consortium of plant geneticists. Later on, several research works were carried out to understand the processes like translocation of food materials, their partitioning towards economic yield, storage mechanisms, physiology of flowering, effect of stressful environmental factors on crop growth and development, role of plant growth regulators in increasing the crop productivity etc. All these areas have enriched the knowledge of physiological processes and their role in deciding the crop yield.

SELF-ASSESMENT EXERCISE

Attempt to differentiate the history of crop physiology based on different stages of researches with dates.

4.0 CONCLUSION

Plant physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture.

The central question of plant physiology is how do plants grow, develop, and reproduce? When primitive humans collected seeds and began raising food plants, they must have noted that plants need sunlight, warmth and moist (but not wet) soil of good tilth, and that seeds from vigorous plants produced vigorous plants. They observed the beneficial effects of manuring (mentioned in the Bible; Luke 13:8). Centuries of agricultural practice produced improved varieties and cultural practices, and early studies of physiology drew on this basic knowledge of plant growth and gross anatomy.

5.0 SUMMARY

A brief history of Crop Physiology based on Early Experiments on Plant Growth, Experiments on Plant Nutrition and Transportation and Current Research on Cellular and Molecular Plant Physiology were discussed in this unit. Some of the discoveries by different researchers at different times were as follows;

- An early physiological question was where a plant gets the material with which it grows. In the early 1600s, Jan van Helmont, a Belgian physician, decided the source must be water alone. Van Helmont grew a willow seedling in 200 pounds of soil, and only added rainwater. A 164-pound tree was produced with only 57.1 grams (2 ounces) of soil lost. He knew of carbon dioxide but never dreamed that a diffuse gas could produce willow wood.
- Van Helmont assigned no importance to the two ounces of soil lost. However, starting in the late 1700s and extending into the mid-1800s, Julius Sachs and others used chemical assays to establish that quantitatively minor soil constituents of nitrogen,

potassium, phosphate, sulphur, and other elements had major importance in plant growth.

- Crop physiology, with the aim of understanding the dynamics of yield development in crops, really began with the work of Balls (1915). Along with Holton he analysed the effects of plant spacing and sowing date on the development and yield of Egyptian cotton plants within crop stands, not in isolated plants. It was from his work the term ‘crop physiology’ came into existence. From then onwards, various scientists have started applying the advances in physiological knowledge for better crop management.
- In 1924, in England- a rapid development of the methods of growth and yield analysis by different investigators (V.H. Blackman, F.G. Gregory, G.E. Briggs etc.) was started. With the development of various methods of growth analysis, they started explaining ‘the physiology of crop yield’
- In 1947, the concept of LAI (Leaf area index) was developed by D.J. Watson. This index has provided a more meaningful way of analysing growth in crops, and stimulated renewed interest in crop physiology.
- In 1950’s, studies on photosynthetic rate of the leaf and the loss of photosynthates by respiration was studied by the development of ‘Infra-Red Gas Analysis (IRGA)’method. This method has facilitated the estimation of short-term rates of Photosynthesis and respiration by crops in the field. Monsi and Saeki explained about the manner of light interception by the crop canopy with their concept of light interception coefficient.
- In 1963, Hesketh and Moss showed that photosynthesis by leaves of Maize, Sugarcane and related tropical grasses could reach much higher rates, with less marked light saturation, than leaves of other plants. (This was the starting point for research to find other photosynthetic CO_2 fixation path ways like C4, and CAM Mechanisms). The differences in pathway are associated with differences in photosynthetic rate, in response to light intensity, temperature and oxygen level, in photorespiration, in leaf anatomy and chloroplast morphology, in rate of translocation, and in the efficiency of water use, which can have profound effects on the physiology of yield determination.
- By the 20th century, plant physiologists increasingly turned to chemistry and physics for assistance with fundamental questions. They also established their own societies with journals to publish their findings, which had a catalytic effect in increasing the level and amount of research.

6.0 TUTOR-MARKED ASSIGNMENT

Briefly discuss the history of Crop Physiology base on the following headings;

a. Early Experiments on Plant Growth
b. Experiments on Plant Nutrition and Transportation
c. Current Research on Cellular and Molecular Plant Physiology

7.0 REFERENCES/FURTHER READING

Dennis, D. T. & Turpin D. H. (1990). *Plant Physiology, Biochemistry and Molecular Biology*. Harlow, Essex, UK: Longman Group.

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UNIT 3 MEANING OF CROP PHYSIOLOGY AND ITS IMPORTANCE IN AGRICULTURE

CONTENTS

1.0 INTRODUCTION

Plant physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture.

The central question of plant physiology is how do plants grow, develop, and reproduce? When primitive humans collected seeds and began raising food plants, they must have noted that plants need sunlight, warmth and moist (but not wet) soil of good tilth, and that seeds from vigorous plants produced vigorous plants. They observed the beneficial effects of manuring (mentioned in the Bible; Luke 13:8). Centuries of agricultural practice produced improved varieties and cultural practices, and early studies of physiology drew on this basic knowledge of plant growth and gross anatomy.

Many aspects of Agriculture and Horticulture can be benefitted from more intensive research in plant physiology to provide practical solutions in agriculture and horticulture. Understanding the physiological aspects of seed germination, seedling growth, crop establishment, vegetative development, flowering, fruit and seed setting and crop maturity, plant hormone interaction, nutrient physiology, stress (biotic/abiotic) physiology etc., provides a reasonable scientific base for effective monitoring and beneficial manipulation of these phenomena. Since in agriculture we are interested in economic yield which is the output of these phenomenons and well-being of plants, Plant Physiology provides a platform for getting better yield of crops. Studying these phenomena with a view to develop better crop management practices forms the subject matter of crop physiology.

Crop physiology is important in agriculture as well as horticultural crops because:

It studies the entire plant and its communities.

They deal with a plant in terms of knowledge from the different field such as soil science, plant physiology, botany etc.

It aims to "increase the yield" of the plant economically."

2.0 OBJECTIVES

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

- explain the meaning of crop physiology
- outline the importance of crop physiology in agriculture

3.0 MAIN CONTENT

3.1 Meaning of Crop Physiology

Crop physiology is the study of the ways in which plant physiological processes are integrated to cause whole plant responses in communities. The subject matter of crop physiology includes the ways in which the knowledge of plant physiology is applied for better management of crops.

Crop physiology is the study of the plant processes responsible for the growth, development, and production of economic yield by crop plants. Crop physiologists focus on whole plants and plant communities - not individual plant parts, organs, or cells because most of the processes that control yield operate at the whole plant - plant community level. Consequently, most crop physiology research is conducted in growth chambers, greenhouses, or in the field. Crop physiologists investigate processes responsible for the primary productivity of crop communities (e.g., photosynthesis, respiration, light interception, nutrient utilisation), how the products of these processes are converted to economic yield (e.g., sink size, seed growth, partitioning, senescence), and developmental processes that define the length of critical growth stages by controlling flowering and maturation. Crop physiology is an integrative science, bringing information from a variety of disciplines (soil science, ecology, plant physiology, botany, statistics, micro meteorology, modeling) to bear on problems of yield improvement and crop management.

Crop physiology has an important role to play in generating the large increases in yield that will be needed in the next 20 years to feed a burgeoning world population. Increasing total production in a sustainable manner without increasing the land area under cultivation represents a huge challenge that can only be met by integrative investigations at the whole plant-plant community level. Crop physiologists will make significant contributions to meeting this challenge.

3.2 Importance of Crop Physiology in Agriculture

Many aspects of Agriculture and Horticulture can be benefitted from more intensive research in plant physiology to provide practical solutions in agriculture and horticulture. Understanding the physiological aspects of seed germination, seedling growth, crop establishment, vegetative development, flowering, fruit and seed setting and crop maturity, plant hormone interaction, nutrient physiology, stress (biotic/abiotic) physiology etc., provides a reasonable scientific base for effective monitoring and beneficial manipulation of these phenomena. Since in agriculture we are interested in economic yield which is the output of these phenomenon and well-being of plants, Plant Physiology provides a platform for getting better yield of crops. Studying these phenomena with a view to develop better crop management practices forms the subject matter of crop physiology.

The importance of physiology in agriculture and horticulture can be seen from the following examples;

- **Seed Physiology**

Seed is the most important input in agriculture. Germination of seed and proper establishment of seedling depends upon various internal and external factors. Knowledge of Seed physiology helps in understanding of different physiological and morphological changes that occur during germination. Any deviation in these processes causes Seed dormancy. The dormant condition of the seed bars immediate use of harvested seed for next crop which is important in intensive agriculture. By understanding the causes and effects of this problem, Crop physiologists have come up with different methods of breaking the seed dormancy. Example: Whenever Paddy is used as a seed material in the very next season it is recommended to treat the seed either with HNO_3 or with GA.

- **Optimum seedling growth and plant population**

By knowing the process of radicle and plumule emergence and their function we can achieve best plant health, which is the outcome of best plant physiology. By knowing the different inputs requirement of plants (water, nutrients, sunlight) we can easily manage the plant populations to get highest yield. Input interaction of plants within their body is the matter of plant physiology.

- **Growth measurement of crops**

The first prerequisite for higher yields in crops is high total dry matter production per unit area. High dry matter production is a function of optimum leaf area (Optimum leaf area Index) and Net Assimilation rate. (CGR = LAI X NAR).

Example: Pruning operation in horticultural crops like mango is done based on this principle of proper canopy management for better photosynthesis.

- **Harvest index**

The difference between total amount of dry matter produced and the photosynthates used in respiration is the net product of photosynthesis. Economic yield depends on how the dry matter is distributed among different organs of the plant. Partition of total dry matter amongst the major plant organs is of interest to the farmers as they are more interested in its partition towards economic yield. Example: excessive vegetative growth period in Ground nut produces a smaller number of Pods as the reproductive period gets constricted. Thus, groundnut varieties with relatively extended period of reproductive growth are desirable.

- **Mode of action of different weedicides**

The use of herbicides to kill unwanted plants is widespread in modern agriculture. Majority of Herbicides -about half of the commercially important compounds—act by interrupting photosynthetic electron flow (Ex. Paraquat, diuron) or electron flow of respiration. In Photosynthesis when the electron transport is blocked, it virtually stops light reaction of photosynthesis. When light reaction is stopped the dark reaction does not happen and thus CO_2 is not fixed as carbohydrate. Therefore, the weed is killed by starvation.

- **Nutriophysiology**

Nutriophysiology is yet another important area to understand crop physiology. For the healthy growth of a crop around 17 essential elements are required. Knowledge of nutriophysiology has helped in identification of essential nutrients, ion uptake mechanisms, their deficiency symptoms and corrective measures. It also helps to check the toxicity symptoms of various nutrients. The use of fertilizers and their intake by plants can be totally understood by studying plant physiology.

- **Photoperiodism**

Response of plant to the relative length of day and night is called as photoperiodism. This concept was used to choose photo insensitive varieties. The semi dwarf Rice varieties that have revolutionised Indian agriculture, are lodging resistant, fertilizer responsive, high yielding and photo insensitive. Photo insensitivity has allowed rice cultivation in nontraditional areas like Punjab. Even in traditional areas rice-wheat rotation has become possible only due to these varieties.

- **Plant growth regulators**

Plants can regulate their growth through internal growth mechanisms involving the action of extremely low concentrations of chemical substances called Plant growth substances, phytohormones or Plant growth regulators. The regulation of flowering, seed formation and fruit setting has been controlled through the application of different hormones at the appropriate time of plant height and age.

Indian agriculture being predominantly rain fed in nature, so development of drought resistant varieties is very important. Root zone depth, density of roots, plant water potential, relative water content, water use efficiency, xerophytic characters of leaves etc. are some of the characters helped to breed drought tolerant varieties and to develop efficient irrigation management practices (sprinkler and drip irrigation).

Among Several physiological approaches, transpiration efficiency or water use efficiency is the most dependable trait, which is "the amount of dry matter produced per unit amount of water transpired". The importance of water use efficiency (WUE) in influencing grain yield under water limited conditions can be explained by the following model given by passioura.

Grain Yield = T x TE x HI
Where T = Total transpiration by the crop canopy TE = Transpiration Efficiency or WUE
HI = Harvest Index (Economic Fraction of Dry matter)
This relationship provides an analytical tool to select the genotype with high levels of T and TE.

- **Post-harvest physiology**

Post-harvest losses of agriculture and horticulture are causing a great distress to farming community. Moisture and temperature are the two important factors causing physiological changes that reduce the post-harvest quality of grains. Control of moisture content and maintenance of low temperatures have proved effective in storage of grains. Being perishable in nature the magnitude of post-harvest loss is comparatively higher in horticultural crops. Example: In recent years a method called 'modified atmospheric storage' was developed for prolonged post-harvest life of fruits and vegetables. Shelf life of cut flowers can be increased by application of kinetin (cytokinin). This will reduce the burst of ethylene and thus reduces the rate of senescence.

Thus, physiological understanding of crop plants provides the fundamental scientific base about various aspects of metabolism, growth and development. This is immensely important for crop improvement or technology improvement in agriculture or horticulture.

SELF-ASSESTMENT EXERCISE

What is the meaning of crop physiology?
Outline the importance of crop physiology in Agriculture as it's relates to Nigerian Context.

4.0 CONCLUSION

The study of plant physiology is important in agriculture. It is the science and art of how plants are cultivated. Agriculture is the base of the development of human civilisation. The works related to farming of domesticated species generate food surpluses which make people able to live in cities. The modern agriculture deals with plant breeding, agronomy and agrochemicals such as the use of the fertilizers and the pesticides. The technological developments have changed the conventional agricultural processes significantly. The technological developments have increased the number of crops. Along with it, the technological tools caused environmental and economic changes.

The modern agricultural practices are also shaped by depletion of aquifers, global warming, deforestation, use of growth hormones and antibiotics. Increase demand for genetically modified organisms is another key trend in agriculture. The products in the agricultural industry are broadly categorised as fibres, foods, raw materials and fuels. The food products obtained from the agricultural industry are classified as vegetables, cereals, oil and fruit.

The applied researches, on the contrary, give importance to solving practical problems. However, the crop physiology studies the plants and plant communities as a whole. This is because the processes which control the production. The area also gives importance to studying how the plants interact with the environment.

5.0 SUMMARY

In this unit, it has been established that crop physiology is concerned with the life processes of plants, and from the beginning has been focused largely on the higher green terrestrial plants, the autotrophic (self-feeding) plants that feed us animals. In part, plant physiology has roots in agriculture. The knowledge of the physiological factors associated with the plants is essential for conducting the agricultural works effectively. Crop physiology is an important part of the subject. It deals with investigating different processes in the plants. The key areas of focus in the domain of Crop physiology are — the activities which drive growth in the plants, the development processes and the production of crop plants in an economic manner.

This area of the subject includes both the basic and applied research to determine the functionalities of the crop plants. The basic researches in the crop physiology give importance to developing knowledge in the area.

6.0 TUTOR-MARKED ASSIGNMENT

Briefly discuss Crop Physiology base on the following headings;

a. meanings
b. importance and
c. current research d molecular plant physiology

7.0 REFERENCES/FURTHER READING

Dennis, D. T. & Turpin, D. H. (1990). *Plant Physiology, Biochemistry and Molecular Biology*. Harlow, Essex, UK: Longman Group.

Salisbury, F. B. & Ross, C. W. (1985). *Plant Physiology*, 3rd ed. Belmont, CA: Wadsworth Publishing.

Taiz, Lincoln & Eduardo, Zeiger (n.d.). *Plant Physiology*, (2nd ed.). Sunderland, MA: Sinauer Associates, http://www.biologyreference.com/Gr-Hi/History-of-Plant-Physiology.html#ixzz6fwOQSNmG

MODULE 2 PLANT CELL: AN OVERVIEW

UNIT 1 BRIEF OVERVIEW OF PLANT CELL

CONTENTS

1.0 INTRODUCTION

The cell (from Latin cellar, meaning "small room") is the basic structural, functional, and biological unit of all known living organisms. A cell is the smallest unit of life. Cells are often called the "building blocks of life". The study of cells is called cell biology. The cell was discovered by Robert Hooke in 1665, who named the biological units for their resemblance to cells inhabited by Christian monks in a monastery. Cell theory, first developed in 1839 by Matthias Jakob Schleiden and Theodor Schwann, states that

1) All organisms are made up of one or more cells and the products of those cells.
2) All cells carry out life activities (require energy, grow, have a limited size).
3) New cells arise only from other living cells by the process of cell division.

Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Animals, fungi, and protists also have eukaryotic cells, while bacteria and archaea have simpler prokaryotic cells. Plant cells are differentiated from the cells of other organisms by their cell walls, Pastids (chloroplasts and chromoplasts), cell to cell communication by plasmodesmata and central vacuole.

2.0 OBJECTIVES

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

- explain the meaning of plant cell
- give different definitions of plant cell
- outline different types of plant cell
- differentiate between plant cell and animal cell

3.0 MAIN CONTENT

3.1 Meaning and Definitions of Plant Cell

Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Plant cells have special organelles called chloroplasts, which create sugars via photosynthesis. They also have a cell wall that provides structural support.

3.1.1 Plant Cells vs. Animal Cells

Plant and animal cells are both eukaryotic cells, meaning they possess a defined nucleus and membrane-bound organelles. They share many common features, such as a cell membrane, nucleus, mitochondria, Golgi apparatus, endoplasmic reticulum, ribosomes, and more.

However, they have some apparent differences. Firstly, plant cells have a cell wall that surrounds the cell membrane, whereas animal cells do not. Plant cells also possess two organelles that animal cells lack: chloroplasts and a large central vacuole.

These additional organelles allow plants to form an upright structure without the need for a skeleton (cell wall and central vacuole), and also allow them to produce their own food through photosynthesis (chloroplasts).

Parts of a Plant Cell

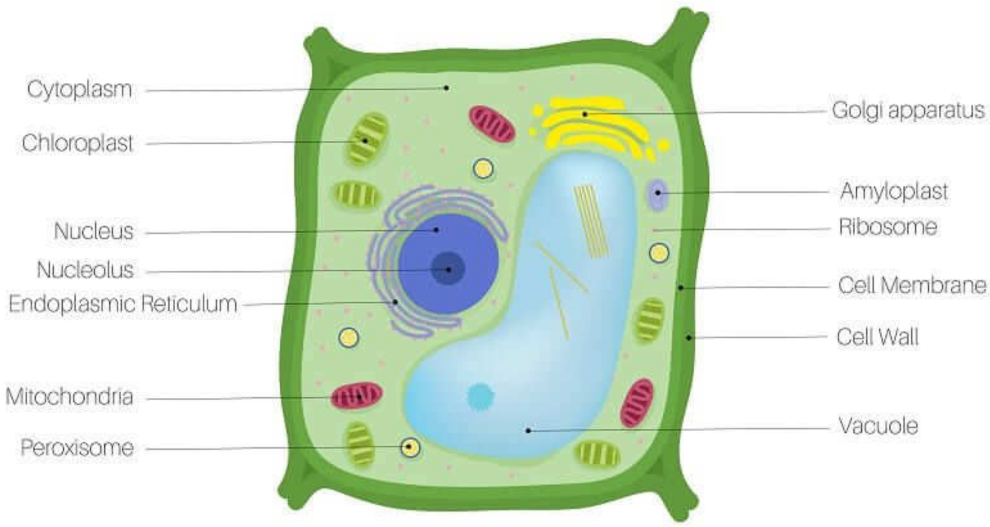

Fig 1: Diagram of a Plant Cell with the Organelles Labeled

The plant cell has many different features that allow it to carry out its functions. **Each of these structures, called organelles, carry out a specialised role.**

Animal and plant cells share many common organelles, which you can find out more about by visiting the "Animal Cell" article. However, there are some specialised structures in plant cells, including chloroplasts, a large vacuole, and the cell wall.

3.1.2 Specialised Structure in Plant Cells

- **Chloroplasts**

Chloroplasts are specialised organelles found only in plants and some types of algae. **These organelles carry out the process of photosynthesis, which turns water, carbon dioxide, and light energy into nutrients from which the plant can obtain energy.**

There can be over one hundred chloroplasts in certain plant cells.

Chloroplasts are disk-shaped organelles that are surrounded by a double membrane. The outer membrane forms the external surface of the chloroplast and is relatively permeable to small molecules, allowing substances entry into the organelle. The inner membrane lies just beneath the outer membrane and is less permeable to external substances. Between the outer and inner membrane is a thin

intermembrane space that is about 10-20 nanometres wide. The center of the chloroplast that is enclosed by the double membrane is a fluid matrix called the stroma (you can think of this like the cytoplasm of the chloroplast).
Within the stroma, there are many structures called thylakoids, which look like flattened disks. Thylakoids are stacked on top of one another in vascular plants in stacks called grand. Thylakoids have a high concentration of chlorophyll and carotenoids, which are pigments that capture light energy from the sun. The molecule chlorophyll is also what gives plants their green colour.

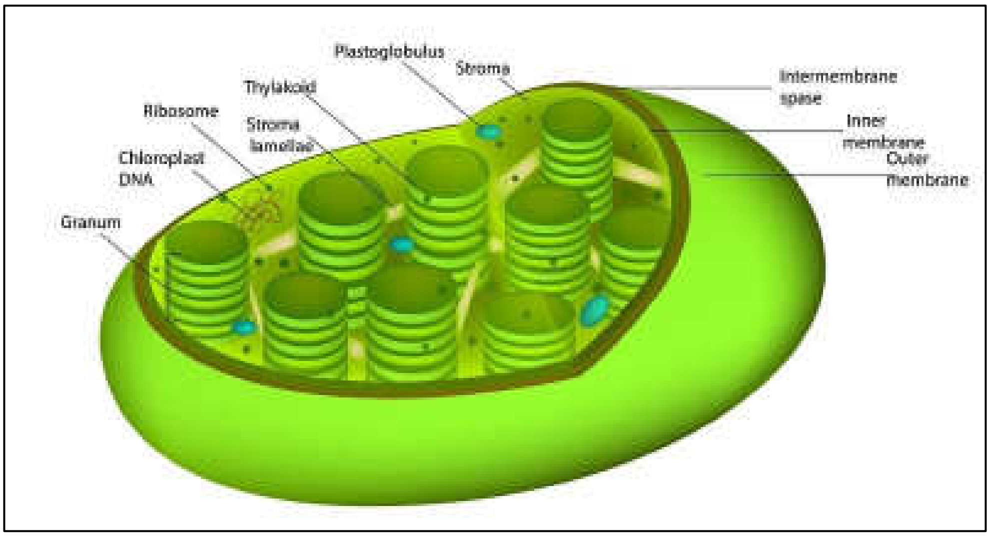

Fig..2: Labeled Diagram of a Chloroplast

- **Vacuoles**

Plant cells are unique in that they have a large central vacuole. **A vacuole is a small sphere of plasma membrane within the cell that can contain fluid, ions, and other molecules.** Vacuoles are essentially just large vesicles. They can be found in the cells of many different organisms. However, plant cells characteristically have a large vacuole that can take up anywhere from 30% to as much as 90 per cent of the total cell volume.

The central vacuole of a plant cell helps maintain its turgor pressure, which is the pressure of the contents of the cell pushing against the cell wall. A plant thrives best when its cells have high turgidity, and this occurs when the central vacuole is full of water. **If turgor pressure in the plants decreases, the plants begin to wilt.** Plant cells fare best in hypotonic solutions, where there is more water in the environment than in the cell. Under these conditions, water rushes into the cell by osmosis, and turgidity is high.

Animal cells, in comparison, can lyse if too much water rushes in; they fare better in isotonic solutions, where the concentration of solutes in the cell and in the environment is equal and the net movement of water in and out of the cell is the same.

Many animal cells also have vacuoles, but these are much smaller and tend to play a less crucial function.

- **Cell Wall**

The cell wall is a tough layer found on the outside of the plant cell that gives it strength and also maintains high turgidity. **In plants, the cell wall contains mainly cellulose, along with other molecules like hemicellulose, pectin, and lignin.** The composition of the plant cell wall differentiates it from the cell walls of other organisms.

For example, fungi cell walls contain chitin, and bacterial cell walls contain peptidoglycan. These substances are not found in plants. **Importantly, the main difference between plant and animal cells is that plant cells have a cell wall, while animal cells do not.**

Plant cells have a primary cell wall, which is a flexible layer formed on the outside of a growing plant cell. Plants can also have a secondary cell wall, a tough, thick layer formed inside the primary plant cell wall when the cell is mature.

3.1.3 Plant Cell Types

There are five types of **tissue** formed by plant cells, each with different **functions.** Parenchyma, collenchyma, and sclerenchyma are all simple plant tissues, meaning they contain a single cell type. In contrast, xylem and phloem contain a mixture of cell types and are referred to as complex tissues.

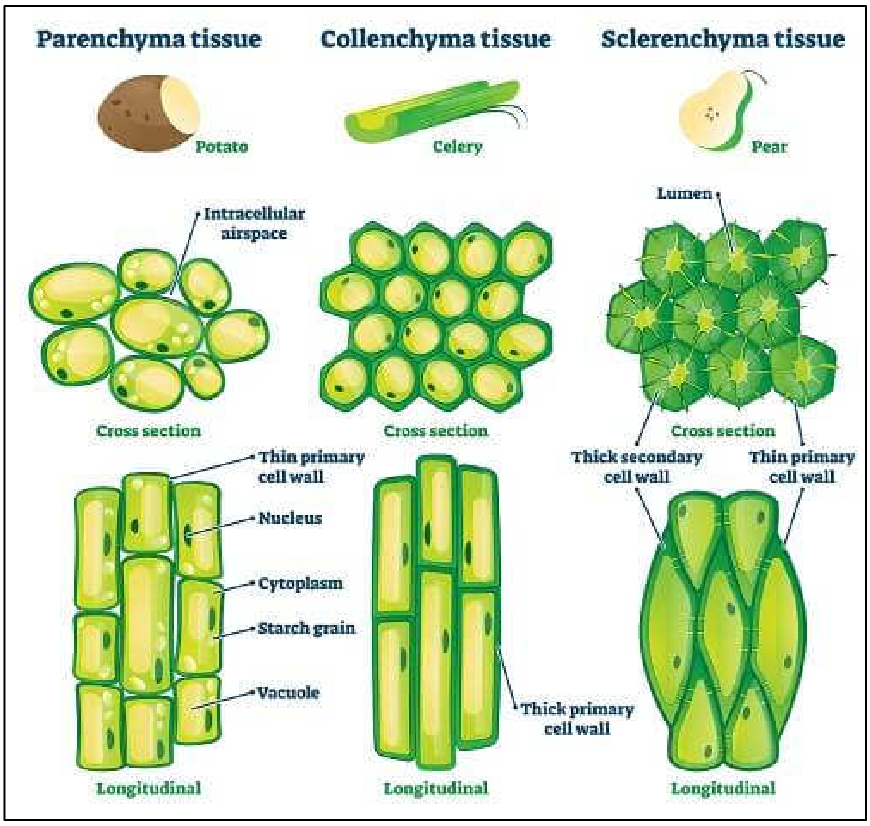

Fig.13: Plant Tissue Types Form by Parenchyma, Collenchyma and Sclerenchyma Cells

- **Parenchyma tissue** represents the majority of cells in a plant. They are found in leaves and carry out photosynthesis and cellular respiration, along with other metabolic processes. They also store substances like starches and proteins and have a role in plant wound repair.
- **Collenchyma tissue** provides support to growing parts of a plant. They are elongated, have thick cell walls, and can grow and change shape as a plant grows.
- **Sclerenchyma tissue** contains hard cells that are the main supporting cells in the areas of a plant that have ceased growing. Sclerenchyma cells are dead and have very thick cell walls.
- **Xylem cells** transport mostly water and a few nutrients throughout a plant, from the roots to the stem and leaves.
- **Phloem cells** transport nutrients made during photosynthesis to all parts of a plant. They transport sap, which is a watery solution high in sugars.

SELF-ASSESTMENT EXERCISE

Explain the meaning of plant cell

Give different definitions of plant cell
Outline and explain different types of plant cell
Differentiate between plant cell and animal cell

4.0 CONCLUSION

The cell (from Latin cellar, meaning "small room") is the basic structural, functional, and biological unit of all known living organisms. Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Animals, fungi, and protists also have eukaryotic cells, while bacteria and archaea have simpler prokaryotic cells. Plant cells are differentiated from the cells of other organisms by their cell walls, Pastids (chloroplasts and chromoplasts), cell to cell communication by plasmodesmata and central vacuole.

5.0 SUMMARY

Plant cells are the basic unit of life in organisms of the kingdom Plantae. They are eukaryotic cells, which have a true nucleus along with specialised structures called organelles that carry out different functions. Animals, fungi, and protists also have eukaryotic cells, while bacteria and archaea have simpler prokaryotic cells. Plant cells are differentiated from the cells of other organisms by their cell walls, Pastids (chloroplasts and chromoplasts), cell to cell communication by plasmodesmata and central vacuole. Plant and animal cells are both eukaryotic cells, meaning they possess a defined nucleus and membrane-bound organelles plant cells have a cell wall that surrounds the cell membrane, whereas animal cells do not. Plant cells also possess two organelles that animal cells lack: chloroplasts and a large central vacuole. These additional organelles allow plants to form an upright structure without the need for a skeleton (cell wall and central vacuole), and also allow them to produce their own food through photosynthesis (chloroplasts).

However, there are some specialized structures in plant cells, including chloroplasts, a large vacuole, and the cell wall. There are five types of tissue formed by plant cells, each with different functions**.** Parenchyma, collenchyma, and sclerenchyma are all simple plant tissues, meaning they contain a single cell type.

6.0 TUTOR-MARKED ASSIGNMENT

Explain the meaning of plant cell

1. Give different definitions of plant cell
2. Outline and explain different types of plant cell
3. Differentiate between plant cell and animal cell

7.0 REFERENCES/FURTHER READING

Biology dictionary.net Editors. "Plant Cell." *Biology Dictionary*, Biology dictionary.net, 05 Apr. 2017, https://biologydictionary.net/plant-cell/.

UNIT 2 BRIEF DESCRIPTION OF VARIOUS ORGANELLES AND THEIR FUNCTIONS

CONTENTS

1.0 INTRODUCTION

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1839 by Matthias Jakob Schleiden and Theodor Schwann, states that

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2.0 OBJECTIVES

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

- describe various organelles associated with plant
- outline functions of the about mentioned organelles.

3.0 MAIN CONTENT

3.1 Brief Description of Various Organelles and Their Functions

The brief description of the plant cell and various organelles and their functions are as follows:

3.1.1 Description of Plant Cell Wall

Cell wall is a non-living component of the cell and is secreted and maintained by the living portion of the cell, called protoplasm. A typical cell wall is composed of three different regions 1. Middle Lamella 2. Primary cell wall (1-3 µm thick and elastic) 3. Secondary cell wall (5-10 µm thick and rigid)

Functions of Plant Cell Wall

1. It protects the inner contents of the cell. 2. It gives definite shape to the cell. 3. It provides mechanical support to the tissues and act as a skeletal framework of plants. 4. It helps in transport of substances between two cells. 5. The cell wall is hydrophilic in nature and it imbibes water and helps in the movement of water and solutes towards protoplasm. It also acts as a permeable structure during absorption of minerals and solutes.

3.1.2 Description of Protoplasm

It is the living, colloidal and semi fluid substance. It is also called as cytoplasm. Cell devoid of cell wall is called protoplast. Protoplast is enclosed by a membrane called as cell membrane or plasma membrane.

3.1.3 What is a Cell membrane?

All cells are enclosed by a thin, membrane called plasma membrane or plasmalemma. The plasma membrane and sub cellular membrane are collectively called biological membrane. Cell membrane consists of proteins, lipids and other substances.

1. Proteins: - The proteins present in the membranes can be categorised into two types

a. Intrinsic proteins or integral proteins: - Which are embedded or buried in the lipid layer. These proteins associate with hydrophobic interactions to the tails or fatty acid chains of the lipid layer. In addition to the hydrophobic associations, integral proteins also possess hydrophilic amino acid residues which are exposed at the surface of the membrane. These proteins cannot be removed easily.
b. Extrinsic proteins or peripheral proteins: - They are attached to the membrane surface by weak ionic interactions. These proteins are not much involved in the architecture of membrane. Peripheral proteins are bound to hydrophilic proteins of the integral proteins protruding from the lipid layer.

2. Lipids: - The cell membrane consists of phospholipids and glycolipids. The fatty acid chains in phospholipids and glycolipids usually contain 16-20 even numbered carbon atoms. Fatty acids may be saturated or unsaturated. Other
3. 3 substances like polysaccharide, salicylic acid etc. are found attached to the proteins or lipids on the membrane.

Functions of cell membrane:

1. The cell membrane surrounds the protoplasm of the cell, thus separating the intracellular components from the extracellular environment.
2. It anchors the cytoskeleton to provide shape to the cell, and in attachment to the extracellular matrix.
3. The plasma membrane is differentially permeable and able to regulate the transport across the membrane.
4. The cell membranes maintain the cell potential.

3.1.4 Description of Plant Cell Nucleus:

It is oval or spherical in shape and is generally larger in active cells than in resting cells. A nucleus consists of three main parts viz. nuclear envelope, nucleolus and chromatin. The nucleus is separated from the cytoplasm by a double membrane called the nuclear envelope. The space between the outer and inner membrane is known as nuclear pores which provide direct connection between nucleus and cytoplasm. Nucleolus is a spherical, colloidal body found in the nucleus and is the place where almost all DNA replication and RNA synthesis occur. Chromatin is the basic unit of

chromosome and contains genes which play important role in the inheritance of characters to offspring from parents.
Functions of plant cell nucleus:

1. It regulates growth and reproduction of cells.

2. The nuclear envelope allows the nucleus to control its contents, and separate them from the rest of the cytoplasm where necessary.
3. The DNA replication, transcription and post transcriptional modification occur in the nucleus.

3.1.5 Description of Chloroplast

Chloroplasts are organelles found in plant cells and other eukaryotic organisms that perform photosynthesis because of the presence of green pigment, chlorophyll. They are flattened discs usually 2-10 micrometers in diameter and 1 micrometer thick. The chloroplast is surrounded by double layered membrane. The space between these two layers is called intermembrane space. Stroma is the aqueous fluid found inside the chloroplast. The stroma contains the machinery required for carbon fixation, circular DNA, 70 S ribosomes (that why called as semiautonomous organelle) etc. within the stroma the stacks of thylakoids are arranged as stacks called grana. A thylakoid has a flattened disc shape and has a lumen or thylakoid space. The light reactions occur on the thylakoid membrane.

Functions of chloroplast:

1. The important processes of photosynthesis i.e., light and dark reactions occur within the chloroplast.
2. The granum is the site of NADP reduction forming $NADPH+H^+$ and photophosphorylation i.e., formation of ATP in presence of light. Thus, light reaction of photosynthesis takes place in the granum region.
3. The stroma is the main site for the dark reaction of photosynthesis.
4. The chloroplast has its own genetic system and is self-replicating, thus, associated with cytoplasmic inheritance.

3.1.6 Description of Mitochondria:

Mitochondria are rod shaped cytoplasmic organelles, which are main sites of cellular respiration. Hence, they are referred to as power house of the cell. Each mitochondrion is enclosed by two concentric unit membranes comprising of an outer membrane and an inner membrane. The space between the two membranes is called peri mitochondrial space. The inner membrane has a series of infoldings known as cristae. The inner space enclosed by cristae is filled by a relatively dense material known as matrix. The matrix is generally homogeneous but may rarely show finely filamentous or fibrous structures. The matrix contains several copies of round or circular DNA molecules and 70 S ribosomes (that why it is also called as semiautonomous organelle).

Functions of mitochondria:

1. ATP, the readily available form of energy is produced in mitochondria.
2. Krebs cycle takes place in the matrix of mitochondria.
3. The enzymes of electron transport chain are found in the inner membrane or cristae of mitochondria.
4. Heme synthesis occurs in mitochondria.
5. Controls the cytoplasmic Ca^{2+} concentration

3.1.7 Description of Ribosomes:

Chemically, ribosomes are ribonucleoprotein complexes. This is a membrane less Ribosomes are of two types. Ribosomes of prokaryotes have sedimentation coefficient of 70 S and consist of two sub units of unequal sizes 50S and 30 S subunits. Ribosomes of eukaryotes have 80 S sedimentation coefficient (40S & 60 S). The two or more ribosomes become connected by a single m RNA and then may be called polyribosome. The major function of the smaller subunit of ribosome is to provide proper site for binding of mRNA and its translation. The larger subunit of ribosome supports translation and translocation processes coupled with polypeptide synthesis.

Functions of Ribosomes: 1. They provide the platform for protein synthesis 2. They have the machinery for protein synthesis.

3.1.8 Description of Golgi Complex

Golgi bodies is an assemblage of flat lying cisternae one above the other in close parallel array. Each Golgi complex has 3 to 12 interconnected cisternae which are composed of lipoproteins.

Functions of Golgi complex: 1. It helps in Packaging of proteins for exporting them. 2. It plays a role in sorting of proteins for incorporation into organelles. 3. It is involved in the formation of the cell wall of plant cells.

3.1.10 Meaning of Endoplasmic Reticulum:

Endoplasmic reticulum arises from the outer membrane of the nucleus forming an intermediate meshed network. It is of two types, the granular or rough endoplasmic reticulum in which the outer surface of endoplasmic reticulum is studded with ribosome and agranular or smooth endoplasmic reticulum in which the ribosomes are not attached.

Functions of Endoplasmic reticulum: 1. Rough endoplasmic reticulum is associated with the synthesis of proteins. 2. Smooth endoplasmic reticulum is associated with synthesis of lipids and glycogen. 3. It acts as an inter-cellular transport system for various substances. 4. It contains many enzymes which perform various synthetic and metabolic activities.

3.1.10. Meaning of Vacuole:

It is a membrane bound organelle found in plant cell and occupies most of the area in the plant cell. A vacuole is surrounded by a single layer membrane called tonoplast. It is an enclosed compartment filled with water containing inorganic and organic molecules including enzymes in solution. It maintains the cell's turgor, controls movement of molecules between the cytosol and sap, stores useful material and digests waste proteins and organelles.

Functions of vacuole:

1. Isolating materials that might be harmful or a threat to the cell.
2. Stores waste products.
3. Maintains internal hydrostatic pressure or turgor within the cell.
4. Maintains an acidic internal ph.
5. Exports unwanted substances from the cell.
6. Allows plants to support structures such as leaves and flowers due to the pressure of the central vacuole.
7. Most plants store chemicals in the vacuole that react with chemicals in the cytosol.
8. In seeds, stored proteins needed for germination are kept in protein bodies which are modified vacuole.

3.1.11 Description of Micro bodies

Micro bodies are ubiquitous organelles found in the majority of eukaryotic plant cells. They are mostly spherical and have a diameter ranging from 0.2um to 1.5um. Two types of micro bodies, peroxisomes and glyoxysomes, have been characterised. These organelles differ in their distribution and enzyme composition, although both have the capacity to transform non-carbohydrate material into carbohydrate.

3.1.12. Meaning of Peroxisomes:

Peroxisomes are found in leaves of higher plants. It is a small organelle present in the cytoplasm of many cells, which contains the reducing enzyme catalase and usually some oxidases.

Functions of Peroxisomes: Peroxisomes act in parallel with chloroplast in higher plants and are believed to undertake photorespiration.

3.1.13. Meaning of Glyoxysomes:

A glyoxysome is a specialised form of peroxisome (a type of microbody) found in some plant cells, notably the cells of germinating seeds. Glyoxysomes are temporary as they occur during transient periods in the life cycle of a plant such as in certain beans and nuts which store fats in their seeds as energy reserves. Glyoxysomes appear in the first few days after seed germination in endosperm cells and associate closely with lipid bodies. They disappear after the storage fats are broken down and converted into carbohydrate.

Functions of Glyoxysomes:

Glyoxysomes are involved in the formation of sugars by the breakdown of fatty acids in germinating seeds.

3.1.14. Description of Cytoskeleton

The cytoskeleton is scaffolding contained within the cytoplasm and is made up of protein. The cytoskeleton is present in all cells. The cytoskeleton provides the cell with structure and shape

There are three main kinds of cytoskeleton filaments:

1. Microfilament: - They are composed of actin subunits.
2. Intermediary filaments: - They function in the maintenance of cell shape by bearing tension. They also participate in the cell-cell and cell matrix junctions.
3. Microtubules: - They are like hollow cylinders mostly comprising of 13 protofilaments which in turn are alpha and beta tubulin. They are commonly organised by the centrosome.

Functions of cytoskeleton

1. Provides mechanical support
2. Anchors organelles
3. Helps to move substances intracellular.

3.1.15. Description of Plasmodesmata:

Plasmodesmata (singular: plasmodesma) are microscopic channels which traverse the cell walls of plant cells and some algal cells, enabling transport and communication between them. Specialised cell-to-cell communication pathways known as plasmodesmata, pores in the primary cell wall through which the plasmalemma and endoplasmic reticulum of adjacent cells are continuous. Unlike animal cells, almost every plant cell is surrounded by a polysaccharide cell wall. Neighbouring plant cells are therefore separated by a pair of cell walls and the intervening middle lamella, forming an extracellular domain known as the apoplast. Although cell walls are permeable to small soluble proteins and other solutes, plasmodesmata enable direct, regulated, symplastic transport of substances between cells. There are two forms of plasmodesmata: primary plasmodesmata, which are formed during cell division, and secondary plasmodesmata, which can form between mature cells.

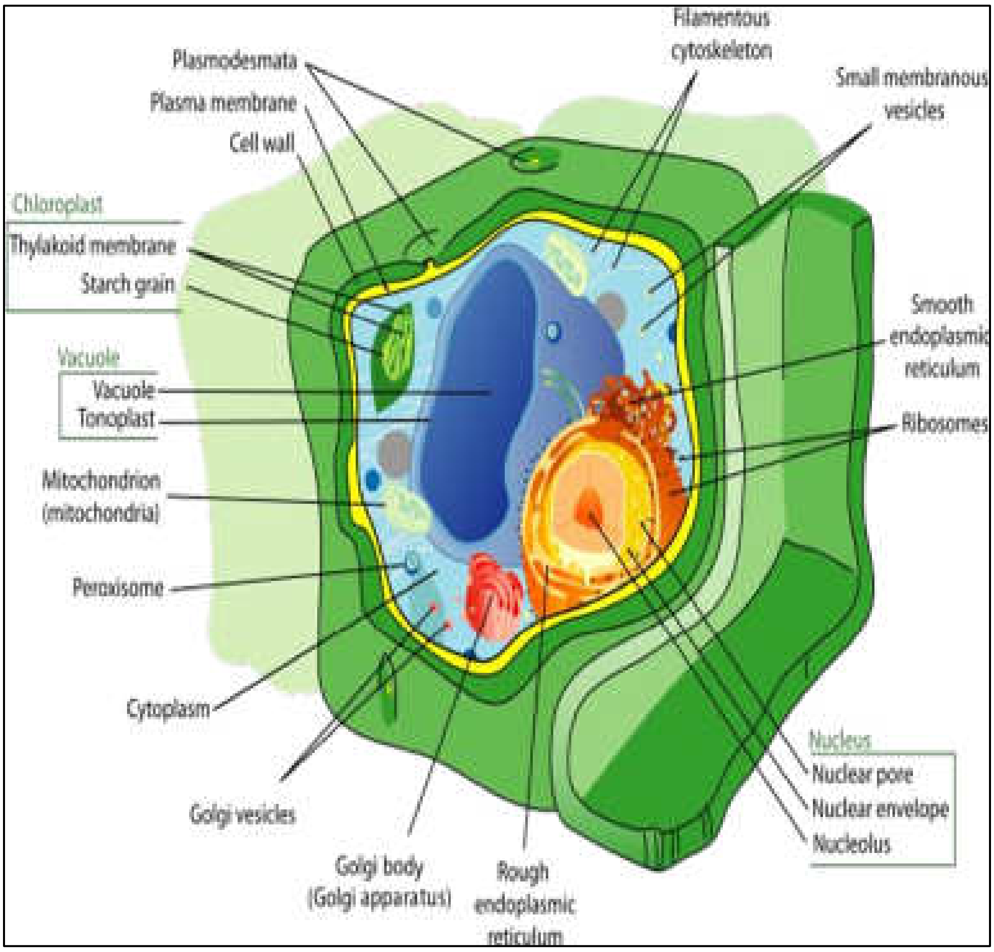

Fig.4: Diagrammatic Representation of Typical Plant Cell

SELF-ASSESSTMENT EXERCIS(SAE)

Describe various organelles associated with plant
Outline functions of the about mentioned organelles.

4.0 CONCLUSION

In this unit, the brief description of various organelles and their functions were brought forth.

5.0 SUMMARY

The descriptions and functions were done various organelles such as Plant Cell Wall, Cell membrane, Cell Nucleus, Chloroplast, Mitochondria, Ribosomes, Golgi complex, Endoplasmic reticulum, Vacuole, Microbodies, Peroxisomes, Glyoxysomes, Cytoskeleton and Plasmodesmata

6.0 TUTOR-MARKED ASSIGNMENT

Give Descriptions and functions of any five of the following;

- Plant Cell Wall,
- Cell membrane,
- Cell Nucleus,
- Chloroplast,
- Mitochondria,
- Ribosomes,
- Golgi complex,
- Endoplasmic reticulum,
- Vacuole,
- Microbodies,
- Peroxisomes,
- Glyoxysomes,
- Cytoskeleton and
- Plasmodesmata

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MODULE 3 DIFFUSION AND OSMOSIS; ABSORPTION OF WATER, TRANSPIRATION AND STOMATAL PHYSIOLOGY

UNIT 1 MEANING AND DEFINITION OF DIFFUSION AND OSMOSIS

CONTENTS

1.0 INTRODUCTION

Plants need water, minerals, and food for their growth and survival. Water and minerals are taken up by roots and leaves prepare the food. These are then transported to the other parts of the plants. When we talk about transport, there should be some means of transportation. Diffusion is the main pathway of transportation in plants.

2.0 OBJECTIVES

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

- explain the meaning of diffusion and osmosis
- discuss diffusion as means of transport in plants
- list types of diffusion in plants
- outline importance of diffusion in plants
- explain how osmosis affects cells
- give examples of osmosis

3.0 MAIN CONTENT

3.1 Meaning and Definition of Diffusion and Osmosis:

3.1.1 Diffusion

Diffusion is the process of movement of molecules from a region of higher concentration to a region of lower concentration.

Diffusion is the process by which molecules spread from areas of high concentration, to areas of low concentration. Diffusion occurs when the spontaneous net movement of particles or molecules spreads them from an area of high concentration to an area of low concentration through a membrane. It is simply the statistical outcome of random motion. As time progresses, the differential gradient of concentrations between high and low will drop (become increasingly shallow) until the concentrations are equalised. Molecules will always move down the concentration gradient, toward areas of lesser concentration. Think of food coloring that spreads out in a glass of water, or air freshener sprayed in a room. Diffusion increases entropy (randomness), decreasing Gibbs free energy, and therefore is a clear example of thermodynamics. Equilibrium - When the molecules are even throughout a space, concentration gradient - a difference between concentrations in a space.

Diffusion is a very important process for photosynthesis where carbon dioxide from the stomata diffuses into the leaves and finally into the cells. Also, during transpiration, the water and oxygen diffuse from the leaves into the environment.

It includes the movement of particles of a medium from the region of its higher concentration to the region of its lower concentration without the expenditure of energy. This process is slow and occurs mostly in gases and liquids. The rate of diffusion is affected by various factors like temperature and pressure, concentration gradient, separating membrane's permeability etc.

Diffusion as Means of Transport in Plants

Transportation in plants is an important and natural phenomenon which takes place in all the higher plants. All plants require some essential organic material and inorganic material for the proper functioning of cells and tissues. This process is carried out by three means of transport.

a. Diffusion
b. Facilitated Diffusion
c. Active Transport

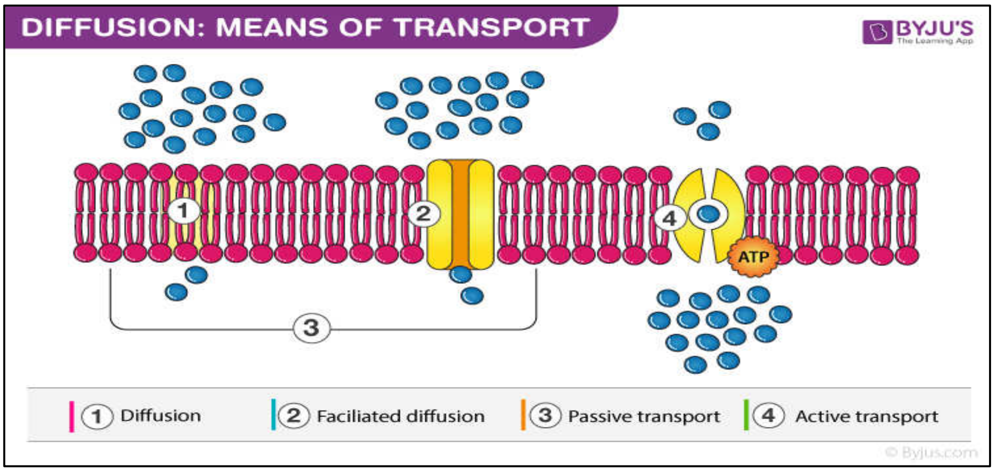


Fig.5: Diffusion as Means of Transport in Plants

Types of Diffusion in Plants

Diffusion in plants is of two major types:

Simple Diffusion: The diffusing molecules do not combine with the constituents of the membrane.

Facilitated Diffusion: The molecules diffuse through the membrane with the help of transporter proteins.

Factors Affecting Diffusion in Plants

Following are the important factors affecting diffusion in plants:

- Diffusion Pressure Gradient

The difference in the diffusion pressure determines the rate of diffusion. The rate of diffusion is directly proportional to the difference in concentration of the molecules in the two regions.

Temperature

The rate of diffusion is directly proportional to the increase in temperature.

- Density

The rate of diffusion is inversely proportional to the square root of density of the gas.

Importance of Diffusion in Plants

The process of diffusion is important for the plants in the following ways:

1. The exchange of gases through stomata takes place by the process of diffusion.
2. Transpiration occurs by the principle of diffusion.
3. The ions are absorbed by simple diffusion.
4. The food material is translocated by this process.
5. This process keeps the walls of the internal tissues of the plant moist.
6. It is responsible for spreading the ions and molecules throughout the protoplast.
7. Aroma of flowers is due to the diffusion of aromatic compounds to attract insects.

3.1.2 Meaning and Definition of Osmosis

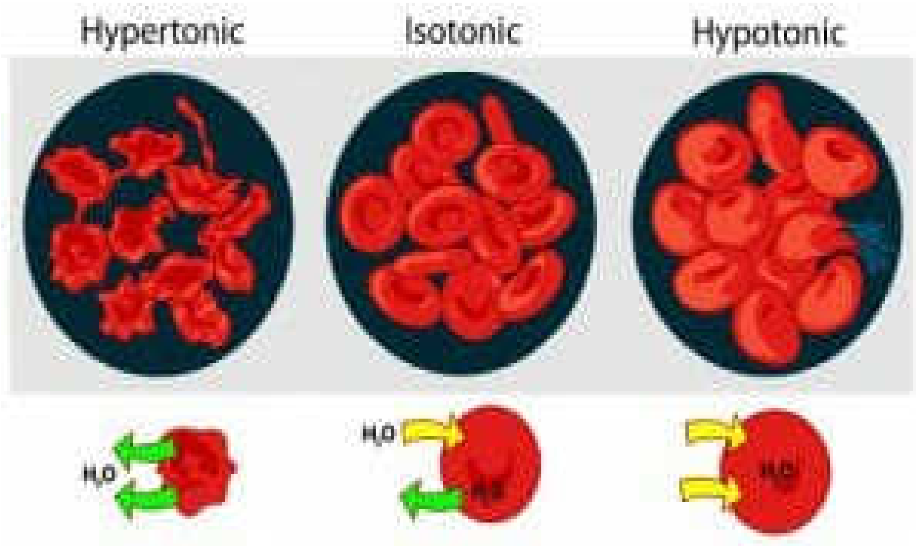
Osmosis is the process of diffusion **of water** across a semipermeable membrane. Water will move in the direction where there is a high concentration of solute (and hence a lower concentration of water). Water molecules are free to pass across the cell membrane in both directions, either in or out, and thus osmosis regulates hydration, the influx of nutrients and the outflow of wastes, among other processes.

Osmosis is a type of diffusion that, in biology, is usually related to cells. Diffusion is when molecules or atoms move from an area of high concentration to an area of low concentration. Osmosis is when a substance crosses a semipermeable membrane in order to balance the concentrations of another substance. In biology, this is usually when a solvent such as water flows into or out of a cell depending on the concentration of a solute such as salt. Osmosis happens spontaneously and without any energy on the part of the cell.

How Osmosis Affects Cells

Osmosis affects plant and animal cells differently because plant and animal cells can tolerate different concentrations of water. In a hypotonic solution, an animal cell will fill with too much water and lyse, or burst open. However, plant cells need more water than animal cells, and will not burst in a hypotonic solution due to their thick cell walls; hypotonic solutions are ideal for plant cells. The optimal

condition for an animal cell is to be in an isotonic solution, with an equal amount of water and solutes both inside and outside. When a plant cell is in an isotonic solution, its cells are no longer turgid and full of water, and the leaves of the plant will droop. In a hypertonic solution, water will rush out of both animal and plant cells, and the cells will shrivel (in plants, this is called plasmolyzation). This is why slugs and snails shrivel and die when salt is sprinkled onto them; water leaves their cells in order to balance the higher concentration of salt outside the cells.
This figure shows the effects of osmosis on red blood cells:



Examples of Osmosis

Osmosis is how plants are able to absorb water from soil. The roots of the plant have a higher solute concentration than the surrounding soil, so water flows into the roots. In plants, guard cells are also affected by osmosis. These are cells on the underside of leaves that open and close to allow gas exchange. When the plant's cells are full of water, the guard cells swell and open the stomata, small holes that allow the plant to take in carbon dioxide and release oxygen.

Osmosis can have adverse effects on animals such as fish. If freshwater or saltwater fish are put into water that has a different salt concentration than they are used to, they will die from having too much water enter or leave their cells. Osmosis can affect humans as well; in a person infected with cholera, bacteria overpopulate the intestines, leaving the intestines unable to absorb water. The bacteria actually reverse the flow of absorption because osmosis causes water to flow out of the intestinal cells instead of in. This causes severe dehydration and sometimes death.

SELF-ASSESSTMENT EXERCISE (SAE)

Differentiate between diffusion and osmosis
State the importance of each mentioned above and relates their relationships with plant cell

4.0 CONCLUSION

Diffusion is the process of movement of molecules from a region of higher concentration to a region of lower concentration. The process by which molecules spread from areas of high concentration, to areas of low concentration is also call diffusion. Osmosis is the process of diffusion **of water** across a semipermeable membrane. Water will move in the direction where there is a high concentration of solute (and hence a lower concentration of water).

5.0 SUMMARY

Meaning and definition of Diffusion and Osmosis were discussed.

Diffusion is the process of movement of molecules from a region of higher concentration to a region of lower concentration."

Diffusion is the process by which molecules spread from areas of high concentration, to areas of low concentration while Osmosis is how plants are able to absorb water from soil. The roots of the plant have a higher solute concentration than the surrounding soil, so water flows into the roots. In plants, guard cells are also affected by osmosis. **Diffusion as Means of Transport in Plants** discussed as a process and carried out by three means of transport, Diffusion, Facilitated and Diffusion. Diffusion in plants is of two major types: **Simple Diffusion and Facilitated Diffusion.** The important factors affecting diffusion in plants: Diffusion Pressure Gradient and Density. The process of diffusion is important for the plants in the following ways:

1. The exchange of gases through stomata takes place by the process of diffusion.
2. Transpiration occurs by the principle of diffusion.
3. The ions are absorbed by simple diffusion.
4. The food material is translocated by this process.
5. This process keeps the walls of the internal tissues of the plant moist.
6. It is responsible for spreading the ions and molecules throughout the protoplast.

7. Aroma of flowers is due to the diffusion of aromatic compounds to attract insects.

Osmosis affects plant and animal cells differently because plant and animal cells can tolerate different concentrations of water.

2.0 TUTOR-MARKED ASSIGNMENT

1. Explain the meaning of diffusion and osmosis
2. Discuss diffusion as means of transport in plants
3. List all types of diffusion in plants
4. Outline the importance of diffusion in plants
5. Explain how osmosis affects cells
6. Give examples of osmosis

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UNIT 2 EXPLANATION ON CONCEPT OF SOLVENT AND SOLUTIONS

CONTENTS

1.0 INTRODUCTION

Solutions have two parts, a solvent and a solute. When solute dissolves in a solvent, the end product is called a solution. Salt water is an example of a solution; salt is the solute, and water is the solvent. *A simple rule to remember is: salt sucks. Salt is a solute, when it is concentrated inside or outside the cell, it will draw the water in its direction. This is also why we get thirsty after eating something salty.

2.0 OBJECTIVES

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

- define solvent and solute
- differentiate between solvent and solute
- explain the meaning of Solution
- identify and describe the various types of solution

3.0 MAIN CONTENT

3.1 Solvents and Solutes

Solutions have two parts, a solvent and a solute. When solute dissolves in a solvent, the end product is called a solution. Salt water is an example of a solution; salt is the solute, and water is the solvent.

A solution is a homogeneous mixture of one or more solutes dissolved in a solvent.

- ***solvent***: the substance in which a solute dissolve to produce a homogeneous mixture
- ***solute***: the substance that dissolves in a solvent to produce a homogeneous mixture

Definition of Solvent

A solvent is a substance that dissolves the solute particles during the formation of a solution.

- Most solvents are in a liquid state, but some solvents might be in a gas or solid-state.
- The solvent breaks down the larger solute particle into smaller particles that can then be dispersed throughout the solution.
- Solvent forms the medium of the solution that makes up most of the volume of the solution.
- The amount of solute that can be dispersed in the solvent depends on the temperature of the medium.
- A solution is a homogenous mixture where the solute particles are uniformly distributed throughout the solvent. Thus, each volume of solvent in the solution has the same concentration of solute.
- The solvent and solute in a solution exist in the single-phase forming solute-solvent complexes, also known as solvates.
- During the formation of a solution, multiple solvent particles surround the solute particle where heat energy is transferred from solvent to the solute, creating a more thermodynamically stable condition.
- The polarity of the solvent particle is crucial to determine the solubility of any solute in the solvent.
- Water is a polar compound that is also considered as a universal solvent that dissolves a large number of solute particles.
- Most solvents are classified into two categories as polar and non-polar solvents. Mercury forms a particular type of solvent called amalgams.
- The boiling point of the solvent is lower than that of solute.
- Examples of the solvent include water, hydrocarbons, alcohols, esters, etc.

Definition of Solute

A solute is a substance that is added to a solvent to form a solution.

- The solute can exist in all three forms of matter as solid, liquid, or gas.

- In a homogenous mixture, the solute completely dissolves in another substance, and the solute is uniformly distributed throughout the solution.
- In a heterogeneous mixture, the solute is not distributed uniformly, and its concentration is different in different parts of the solution.
- The amount of solute in a solution is measured in terms of its concentration. The concentration of solute in a solution is determined by the ratio of the amount of the solute and the total volume of the solution.
- The property of solute particles to dissolve within the solvent is termed as solubility. The solubility of a solute depends on a number of factors.
- In solids and gases, temperature directly affects the solubility of the solute. Pressure, however, only affects the solubility of gases.
- Besides, the ability of solid particles to dissolve in a solvent is dependent on their own chemical structure. Polar solute dissolves in a polar solvent and vice versa.
- The molecular size of the solute is also essential in the solution as the solvent breaks down the solute particles and distributes it throughout the solution.
- In almost all types of solutions, the amount or volume of solute is less than that of the solvent.
- Solute particles tend to have a higher boiling point than solvents.
- Examples of solute include salt in seawater, protons in the cytosol, sugar in tea, etc.

Key Differences (Solute vs Solvent)

Basis for Comparison	Solute	Solvent
Definition	A solute is a substance that is added to a solvent to form a solution.	A solvent is a substance that dissolves the solute particles during the formation of a solution.
Phase	The solute is the dispersed phase of a solution.	The solvent is the medium phase of a solution that disperses solute particles.
Quantity	The quantity of	The quantity of

	solute is less than the solvent in a solution.	solvent is more than solute in a solution.
Physical state	Solute might exist in a solid, liquid, or gaseous state.	Most solvents are in a liquid state, but some solvents might exist in the gaseous state.
State of solution	The solution might or might not in the state of the solute.	The solution is almost definitely in the state of the solvent.
Boiling point	Solute has a higher boiling point than the solvent.	Solvents have a lower boiling point than solute.
Solubility	The solubility of a solute depends on the properties of solute like the surface area and size of molecules.	Solubility depends on the properties of solvent like its polarity.
Heat transfer	In a solution, heat is transferred to the solute.	In a solution, heat is transferred from the solvent.
Examples	Examples of solute include salt in seawater, protons in the cytosol, sugar in tea, etc.	Examples of the solvent include water, hydrocarbons, alcohols, esters, etc.

Examples of Solutes

Salt in seawater

- Salt is the solute, and water is the solvent in seawater.
- The salt, NaCl, is an ionic compound where the negatively charged chloride ion is attracted by the slightly positively charged

hydrogen atom of water. A similar attraction occurs between sodium and oxygen atoms.

- This attraction causes the breakdown of NaCl into smaller particles which are then dispersed throughout the water.
- The range of solubility and time period depends on the surface area of the solute particle.
- Thus, coarse salts dissolve to a lesser extent than finer salts with a larger surface area.
- Once all the salt is dissolved, no salt crystals will be visible in the solution.

Examples of Solvent

- Water is considered a universal solvent as it dissolves a wide variety of solute particles.
- Water forms the basis of many biological solutions that carries important particles and moves them throughout the body.
- Water is a polar solvent where the oxygen atom carries a partial negative charge, and the hydrogen atom carries a partial positive charge.
- The polarity of water molecules makes it very compatible with several solutes' molecules.
- One of the most important examples of water as a solvent is the seawater. Seawater carries large quantities of salt dissolved in water.

Oil

- Oil also acts as a solvent in cooking where it prevents the sticking of polar and non-polar solutes to the pan.
- The hot oil creates a solution where other foods can be cooked.
- The oil carries some solute which can then be added to the food being cooked.
- Oil is an organic compound and an example of a non-polar solvent that allows the dispersal of non-polar solute molecules throughout the solution.
- When compared to other petroleum solvents, vegetable oil is considered a non-volatile organic compound (VOC) that have high dissolving power and flash point, together with low toxicity and less environmental impact.

Note that the ***solvent*** is the substance that is present in the greatest amount.

Many different kinds of solutions exist. For example, a solute can be a gas, a liquid or a solid. Solvents can also be gases, liquids or solids.

Types of Solutions

In crop physiology, there are three different types of solutions that cells can be in: isotonic, hypotonic, and hypertonic. Different types of solutions have different impacts on cells due to osmosis.

Isotonic

An isotonic solution has the same concentration of solutes both inside and outside the cell. For example, a cell with the same concentration of salt inside it as in the surrounding water/fluid would be said to be in an isotonic solution. Under these conditions, there is no net movement of solvent; in this case, the amount of water entering and exiting the cell's membrane is equal.

Hypotonic

In a hypotonic solution, there is a higher concentration of solutes inside the cell than outside the cell. When this occurs, more solvent will enter the cell than leave it to balance out the concentration of solute.

Hypertonic

A hypertonic solution is the opposite of a hypotonic solution; there is more solute outside the cell than inside it. In this type of solution, more solvent will exit the cell than enter it in order to lower the concentration of solute outside the cell. Therefore, it is dangerous to drink sea water - it's a myth that drinking sea water will cause you to go insane, but people marooned at sea will speed up dehydration (and death) by drinking sea water. This is also why "salting fields" was a common tactic during war, it would kill the crops in the field, thus causing food shortages. Both Diffusion and Osmosis are types of **passive transport**, that is, no energy is required for the molecules to move into or out of the cell. Sometimes, large molecules cannot cross the plasma membrane, and are "helped" across by carrier proteins - this process is called **facilitated diffusion**.

SELF-ASSESSTMENT EXERCISE (SAE)

In a tabular form outline the key differences of Solute and Solvent.

4.0 CONCLUSION

Solutions have two parts, a solvent and a solute. When solute dissolves in a solvent, the end product is called a solution. Salt water is an example of a solution; salt is the solute, and water is the solvent.

5.0 SUMMARY

A solution is a homogeneous mixture of one or more solutes dissolved in a solvent.

- ***solvent***: the substance in which a solute dissolve to produce a homogeneous mixture
- ***solute***: the substance that dissolves in a solvent to produce a homogeneous mixture

Note that the ***solvent*** is the substance that is present in the greatest amount. Many different kinds of solutions exist. For example, a solute can be a gas, a liquid or a solid. Solvents can also be gases, liquids or solids. In crop physiology, there are three different types of solutions that cells can be in: isotonic, hypotonic, and hypertonic. Different types of solutions have different impacts on cells due to osmosis.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define solvent and solute
2. Differentiate between solvent and solute
3. Explain the meaning of Solution
4. Identify and describe the various types of solution

7.0 REFERENCES/FURTHER READING

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UNIT 3 MEANING OF WATER POTENTIAL AND ITS COMPONENTS

CONTENTS

1.0 INTRODUCTION

Water potential or chemical potential of water is a quantitative expression of the free energy associated with water. Water potential is symbolised by the Greek letter ψ (psi) and is defined relative to the water potential of pure water, which is zero. Hence the value of psi is always negative. The units of water potential are mega Pascal (MPa). It is a relative quantity and depends on concentration, pressure and gravity at the same temperature. Water potential as the sum of component potentials which may be written as,

$\Psi = \Psi s + \Psi m + \Psi p + \Psi g$
Where, Ψs = Solute osmotic potential (symbol π) Ψm = Matric potential (symbol T)
Ψp = Pressure potential (symbol P)
Ψg = Gravitational potential (symbol G)

2.0 OBJECTIVES

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

- explain the meaning of water potentials
- outline and discuss the components of water potentials
- state the importance of water potentials in crop physiology

3.0 MAIN CONTENT

3.1 Meaning of Water Potentials

Water potential integrates a variety of different potential drivers of water movement, which may operate in the same or different directions. Within complex biological systems, many potential factors may be operating simultaneously. For example, the addition of solutes lowers the potential (negative vector), while an increase in pressure increases the potential (positive vector). If flow is not restricted, water will move from an area of higher water potential to an area that is lower potential. A common example is water with a dissolved salt, such as sea water or the fluid in a living cell. These solutions have negative water potential, relative to the pure water reference. With no restriction on flow, water will move from the locus of greater potential (pure water) to the locus of lesser (the solution); flow proceeds until the difference in potential is equalized or balanced by another water potential factor, such as pressure or elevation.

3.2 Components of Water Potential

Osmotic potential

The osmotic potential, Ψs (or π) is the component produced by the solute dissolved in the cell sap, chiefly vacuolar sap.

Matric Potential:

The matric potential Ψm (or T) refers to water held in micro capillaries or bound on surfaces of the cell walls and other cell components.

Pressure potential

The pressure potential Ψp (or P) is the turgor pressure produced by diffusion of water into protoplasts enclosed in walls which resist expansion. In the xylem of transpiring plants Ψp is usually negative and in guttating plants it is positive as a result of root pressure.

Gravitational Potential:

The effect of gravity, Ψg (or G) is a term of negligible importance within root or a leaf but becomes important in comparing potentials in leaves at different heights on trees and in soils.

Upward movement of water in a tree trunk must overcome a gravitational force of 0.01 Mpa/m and gravity cause drainage of water downward in soil. The volume of matric water is very small as compared to the volume of vacuolar water in parenchyma, therefore potential water constitutes a small fraction of the total water, matric potential can control the cell water potential. Thus, for herbaceous

$$\Psi = \Psi s + \Psi p \text{ or } P\_\pi$$

plants and annual field crops of a short vertical height (less than 10 m) the values of the matric potential and gravitational potential are small and are commonly omitted. Thus, water always moves from less negative water potential to more negative water potential. (Figure 6)

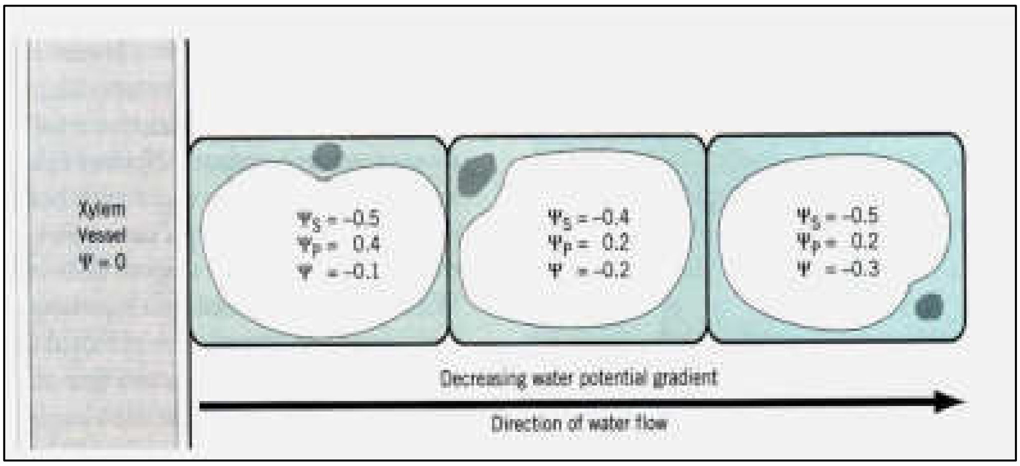

Fig.6: Water Movement from Negative to Positive

3.3 Importance of Water Potential

1. Water potential is a diagnostic tool that enables the plant scientist to assign a precise value to the water status in plant cells and tissues.
2. The lower the water potential in a plant cell or tissue, the greater is its ability to absorb water.
3. Conversely, the higher the water potential, the greater is the ability of the tissue to supply water to other more desiccated cells and tissues.
4. Thus, water potential is used to measure water deficit and water stress in plant cells and tissues.
5. As a general rule, leaves of most plants rooted in well-watered soils are likely to have water potentials between about -2 to -8 bars.
6. With decreasing soil moisture supply, leaf water potential will become more negative than -8 bars and leaf growth rates will decline.
7. Most plant tissues will cease growth completely (i.e., will not enlarge) when water potential drops to about -15 bars.

SELF-ASSESSTMENT EXERCISE (SAE)

Explain the meaning of water potentials
Outline and discuss the components of water potentials
State the importance of water potentials in crop physiology

4.0 CONCLUSION

Water potential or chemical potential of water is a quantitative expression of the free energy associated with water. Water potential is symbolised by the Greek letter ψ (psi) and is defined relative to the water potential of pure water, which is zero. Hence the value of psi is always negative. The units of water potential are mega Pascal (MPa). It is a relative quantity and depends on concentration, pressure and gravity at the same temperature. Water potential as the sum of component potentials which may be written as

$\Psi = \Psi s + \Psi m + \Psi p + \Psi g$, Where, Ψs = Solute osmotic potential (symbol π)

Ψm =Matric potential (symbol T)
Ψp = Pressure potential (symbol P)
Ψg = Gravitational potential (symbol G)

5.0 SUMMARY

Water potential or chemical potential of water is a quantitative expression of the free energy associated with water. The Components of Water Potential are; Osmotic potential: Matric Potential, Pressure potential Gravitational Potential. However, the Importance of water potential are identified as follows;

1. Water potential is a diagnostic tool that enables the plant scientist to assign a precise value to the water status in plant cells and tissues.
2. The lower the water potential in a plant cell or tissue, the greater is its ability to absorb water.
3. Conversely, the higher the water potential, the greater is the ability of the tissue to supply water to other more desiccated cells and tissues.
4. Thus, water potential is used to measure water deficit and water stress in plant cells and tissues.
5. As a general rule, leaves of most plants rooted in well-watered soils are likely to have water potentials between about -2 to -8

bars.

6. With decreasing soil moisture supply, leaf water potential will become more negative than -8 bars and leaf growth rates will decline.
7. Most plant tissues will cease growth completely (i.e., will not enlarge) when water potential drops to about -15 bars.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the meaning of water potentials
2. Outline and discuss the components of water potentials
3. State the importance of water potentials in crop physiology

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UNIT 4 UPTAKE OF WATER AND MOVEMENT (TRANSPIRATION STREAM) IN PLANT

CONTENTS

1.0 INTRODUCTION

The use of water, since population pressures and human activities are constantly increasing, is a matter of crucial interest. If we were bound to summarise the overall problem of water use in just a few sentences, those will probably include: the distribution of water resources for agricultural, industrial and urban use is causing frequent social conflicts in arid and semiarid areas; environmental anxiety is increasing as a consequence of the degradation in the quality of ground and surface water due to non-sustainable practices in the use of water and agrochemicals; planners are demanding more information on the fate of water in natural and cropped systems, and on how the use of this natural resource can be optimised. Over recent decades, some positive developments have occurred: first, the problem has been identified, which is always the first step to solve it. Biologists, growers, environmentalists, planners, and society, in general, are now well aware of the need for optimising the use of water. Second, technological improvements are giving us an invaluable hand in understanding water transport and consumption processes. There are different components to the hydrological cycle, and this article deals with the root zone, the soil region explored by roots. The aim of this article is to give a comprehensive picture of the processes involved in water uptake by plants: how water moves in the soil and into the roots, and how it is transported within the plant up to the aerial parts and to the atmosphere. Many of those processes are not yet well understood. This is due, on the one hand, to the fact that they occur mostly below the ground surface. Being out of sight has curtailed the amount of research on the subject. On the other hand, the processes involved are certainly complex. There is a strong relation between root structure and function, but the existing knowledge is far from capable of giving a clear picture. It is well known that root behavior not only depends on the plant species, but it changes with time and growth conditions. The reader, therefore, may be disappointed when, after reading this article, many of his or her detailed questions still remain unanswered. The good news is that the development of new instruments and novel techniques for determining the fate of water in the soil-plant-atmosphere system is improving. The speed of these developments would have been unthinkable just a few years ago. The use of these techniques is changing our view of the root structure and functioning, and new insight is being added to our understanding of water uptake, and certain aspects of theories that had been accepted for decades are now being clarified. This article shows the main advances in the understanding of water movement in the soil-plant system, and the newest theories describing the nature of water uptake.

2.0 OBJECTIVES

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

- explain the uptake of water in the plants
- discuss the movement of stream in plants

3.0 MAIN CONTENT

3.1 Uptake of Water

The way in which water is entered into the root hair and the precise mechanism of water absorption can be explained by two different approaches:

(a) Active uptake

Water is absorbed because of activities in the root itself and does not concern with any process in shoot.

(b) Passive uptake of water

The governing force of water absorption originates in the cells of transpiring shoots rather than in root itself. Although the absorption of water by roots is believed to be a passive, pressure driven process, it is nonetheless dependent on respiration. Respiratory inhibitors (such as cyanide), anaerobic conditions (waterlogged condition) decrease in the hydraulic conductance of most roots. These are some supporting points for active absorption of water. However, the exact role of respiration and active uptake is not clear.

Except for few exceptions, it is now believed that uptake of water is a Passive process. Tension or negative pressure originating at the actively transpiring leaf surface creates a pulling force for water movement in xylem (Cohesion-tension theory of Dixon and Jolly).

The movement of water inside the plant is driven by a reduction in free energy, and water may move by diffusion, by bulk flow or by a combination of these fundamental transport mechanisms. Water diffuses because molecules are in a constant thermal agitation, which tends to even out concentration differences. Water moves by bulk flow in response to a pressure difference, whenever there is a suitable path way for bulk movement of water. Thus, water potential difference (i.e., solute potential and pressure potential) across the cells starting from root hairs to xylem plays an important role in uptake and transport of water.

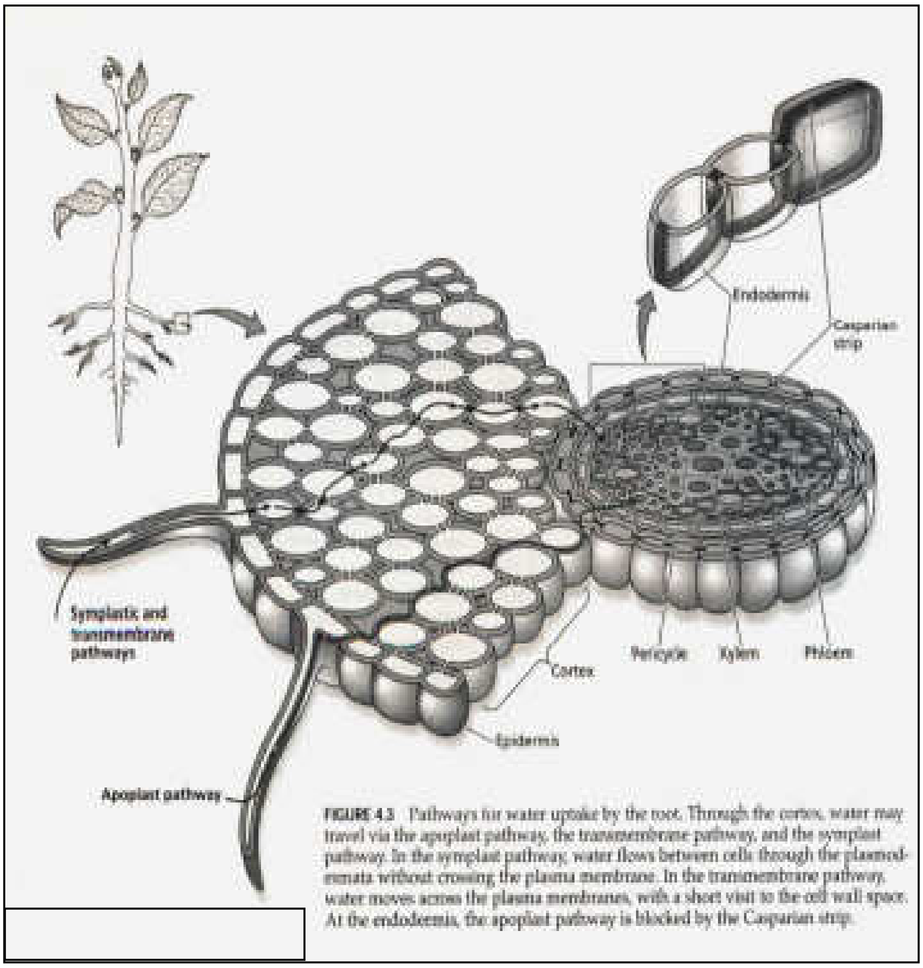

Fig. 7: Pathways of Uptake of Water by Roots

3.2 Movement (Transpiration Stream)

Air (atmosphere) usually has extremely low water potential, compared with plants or soils, so water gradient develops from the soil to the air. Since water moves from a high water to a low water, water will flow from roots to leaves.

Water lost by transpiration must be replenished by absorption of an equivalent amount of water from the soil through the root system. This establishes an integrated flow of water from the soil through the plant, and into the atmosphere, referred to as the soil- plant-atmosphere continuum (SPAC) (transpiration stream).

Soil is a very complex medium, consisting of solid phase comprised of inorganic rock particles and organic material, a soil solution containing dissolvent solutes and a gas phase generally in equilibrium with the atmosphere. Soil structure affects the porosity of a soil and ultimately, its water retention and aeration. When a soil is freshly watered, either by rain or irrigation, the water will percolate down through the pore space until it has displaced most of the air. The soil is then saturated with water. Water will drain freely from the large spore space due to gravity.

The water that remains after free drainage is held in the capillary pores. At this point, the water in the soil is said to be at field capacity. Consequently, soil water at or below field capacity will be under tension and its water potential will be negative, as the water content of the soil decreases, either by the evaporation from the soil surface or because it is taken up by the roots the air water interface will retreat into capillary spaces between the soil particle.

As water is removed from the soil by a root, tensions in the soil will draw more bulk water toward the root. The effectiveness of the roots as absorbing organs is related to the extent of the root system. Plant can only absorb water from the soil when the water potential of the plant sap (cell sap) is lower than water potential of the soil.

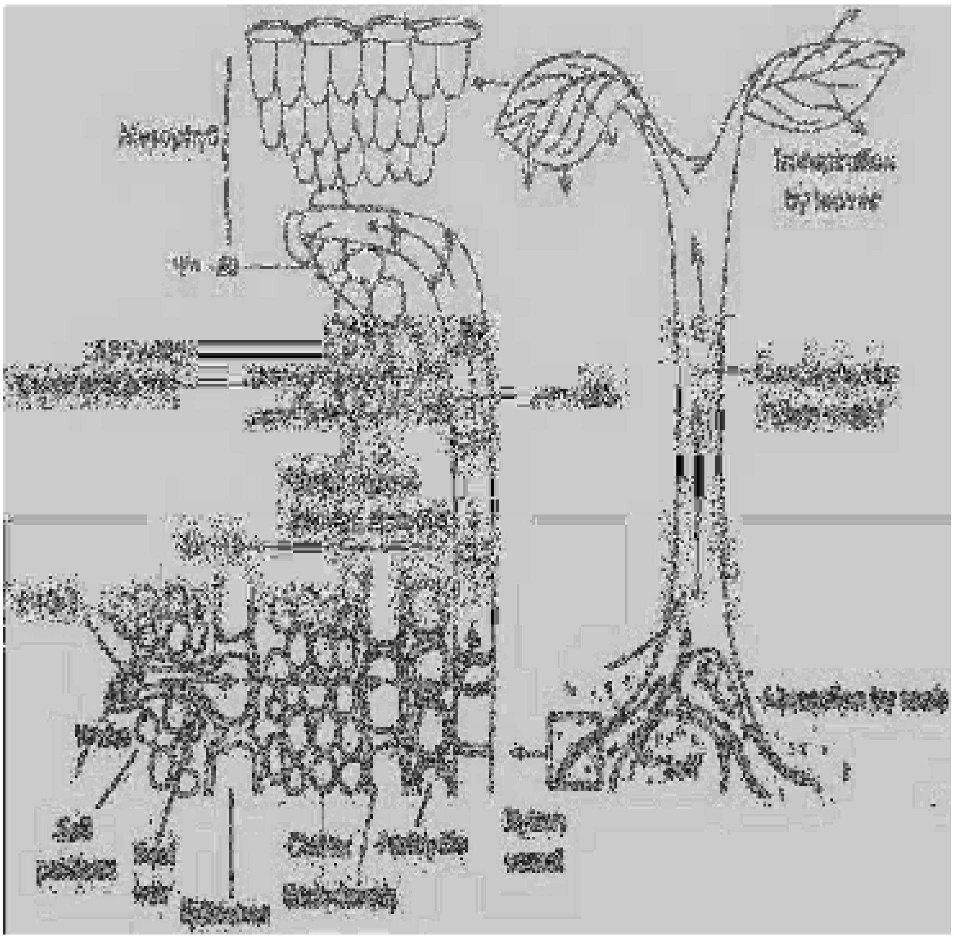

Fig. 8: Movement of Water Stream in Plant

Movement of water towards more negative water potential

SELF-ASSESSTMENT EXERCISE (SAE)

Explain the uptake of water in the plants
Discuss the movement of stream in plants

4.0 CONCLUSION

The way in which water is entered into the root hair and the precise mechanism of water absorption can be explained by two different approaches: Active uptake: Water is absorbed because of activities in the root itself and does not concern with any process in shoot and Passive uptake of water: The governing force of water absorption originates in the cells of transpiring shoots rather than in root itself.

Air (atmosphere) usually has extremely low water potential, compared with plants or soils, so water gradient develops from the soil to the air. Since water moves from a high water to a low water, water will flow from roots to leaves

5.0 SUMMARY

The way in which water enters into the root hair and the precise mechanism of water absorption can be explained by two different approaches: Active and Passive uptake of water. The governing force of water absorption originates in the cells of transpiring shoots rather than in root itself. Although the absorption of water by roots is believed to be a passive, pressure driven process, it is nonetheless dependent on respiration. Respiratory inhibitors (such as cyanide), anaerobic conditions (waterlogged condition) decrease in the hydraulic conductance of most roots. These are some supporting points for active absorption of water. However, the exact role of respiration and active uptake is not clear. Water lost by transpiration must be replenished by absorption of an equivalent amount of water from the soil through the root system. This establishes an integrated flow of water from the soil through the plant, and into the atmosphere, referred to as the soil- plant-atmosphere continuum (SPAC) (transpiration stream).

Soil is a very complex medium, consisting of solid phase comprised of inorganic rock particles and organic material, a soil solution containing dissolvent solutes and a gas phase generally in equilibrium with the atmosphere. Soil structure affects the porosity of a soil and ultimately, its water retention and aeration. When a soil is freshly watered, either by rain or irrigation, the water will percolate down through the pore space until it has displaced most of the air. The soil is then saturated with water. Water will drain freely from the large spore space due to gravity.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the uptake of water in the plants
2. Discuss the movement of stream in plants

7.0 REFERENCES/FURTHER READING

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UNIT 5 METHODS OF MEASURING WATER STATUS IN PLANTS

CONTENTS

1.0 INTRODUCTION

Precise definition of both the environmental conditions and of the plant responses is a prerequisite for the conduct of repeatable and interpretable experiments. This paper reviews the range of approaches available for monitoring plant and soil water status, includes discussion of both direct and indirect methods, and aims to provide some recommendations as to how to select the most appropriate technique for specific purposes. The discussion builds on the general concepts presented previously, with the aim being to compare and contrast the general types of measurement available rather than attempting to evaluate all the specific instruments on the market for measurement of water status. Further details of the necessary instrumentation and its use may be found in appropriate literature.

The choice of measurement technique in any experiment depends critically on the experimental objectives, and also on any pre-existing hypotheses concerning the mechanisms of any response or adaptation to the water deficit. All too often, modern plant physiologists do not incorporate an understanding of the control systems underlying the expected physiological responses into the design of their experiments and their analysis or into their choice of water-status measure. For example, recent improvements in the understanding of mechanisms involved in plant adaptation to drought have only developed through the increasing recognition of the involvement of root–shoot signalling in the control of stomata aperture and growth in some water-stressed plants. Although these advances might have been expected to lead to a shift in the ways in which water status is quantified in drought studies, there has been surprisingly little recognition of these changes in much modern experimental work relating to plant response or adaptation to drought. Where water status is measured (and that is all too rarely) it is too commonly based on measurements of water potential in the leaves, neither of which (water potential or leaves) is usually optimal. In this paper, some of the evidence which indicates a need for a change in the general approach to measurement of water status in modern drought studies, including a need for a shift away from the reliance on leaf water potential, is reassessed. Although these arguments are not new (Jones, 1990) a survey of typical usage (outlined below) highlights the deficiencies in current practice and the need for a more thoughtful approach to the choice of method for monitoring water status in experimental systems.

Why measure water status?

It is generally accepted that the accurate measurement of plant and/or soil water status is critical in any experiment where one is concerned with understanding the effects of differing water supply. Such measurements are essential to define the conditions of the experiment (both in terms of the treatments applied and in terms of the effects on the plants) and as a first step in facilitating repetition of the experiment (which is an essential part of rigorous scientific method). Precise definition of water status in different parts of the soil–plant system is also required for the formulation and testing of any rigorous mechanistic hypotheses, such as those relating to the mechanisms of drought tolerance or adaptive responses in any plant. It is also essential that the measure of water status chosen is relevant to the physiological process of interest. Reliable measures of water status also provide powerful tools for crop management purposes where there is a need for repeatable control as in irrigation scheduling.

In measuring water status, it is useful to distinguish cause and effect (= ‘stress’ and ‘strain’ using the terminology. For example, soil water deficits and the consequently lowered soil water potentials are usually considered as the underlying stresses in the system; the leaf water status is then a result of the soil water deficit. Indeed, the actual leaf water status is modulated by plant responses such as stomatal closure or changing xylem hydraulic conductance, so it neither uniquely nor usefully describes the experimental treatment. For some purposes, however, the leaf water status can usefully be regarded as a stress: these are where one is concerned with the direct effects of leaf water status on metabolic or physiological processes within the leaf. The leaf water status can therefore be regarded both as a strain and a stress, with its role at any time being dependent on the adaptive mechanisms that occur in the plant.

Unfortunately, there is not necessarily any unique or ‘best’ measure of water status that is applicable in all situations. The choice of the most appropriate method(s) for measuring or describing water status in any situation depends on the purpose of the experimenter and may be very different for (i) those concerned primarily with practical management such as irrigation scheduling or quantification of the benefits of management treatments such as mulching or pruning, (ii) those aiming to understand the mechanisms of water movement, (iii) those aiming to understand the mechanisms involved in water stress effects on growth and physiology and the adaptive plant responses involved, and (iv) those aiming to identify differences in drought tolerance, to isolate the controlling genes, or to breed or test drought-tolerant genotypes.

General principles and approaches to measurement of water status

Before what should be measured and reported in studies of plant water relations is considered in detail, it is worth reviewing some of the fundamental principles of water-status measurement. The available measures of soil or plant water status can be broadly divided into those based either on (i) the amount of water or on (ii) its energy status. The principles and practice underlying the quantification and measurement of soil and plant water status have been well described in a number of texts and reviews. And these should be consulted for more detail and background theory.

2.0 OBJECTIVE

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

- explain the various methods of measuring water status.

3.0 MAIN CONTENT

3.1 Methods of Measuring Water Status

The first one is based on the energy associated with water in the plant tissue. Water potential is considered by most plant physiologists to be the most useful and significant way to describe the water status of plant tissues. In terms of water potential, water deficit exists in a tissue whenever its water potential is less i.e., more negative than zero mega Pascal (Mpa). The water potential is measured by (1) liquid immersion method (dye method) (2) vapour equilibration method (Thermocouple Psychrometer) and (3) pressure chamber method. The second way to describe water status is to measure the quantity of water in a tissue, i.e., its water content and to express it in relation to a selected reference. Three of these methods are

1. fresh weight method
2. dry weight method and
3. relative water content (RWC) method.

1. Liquid immersion method or dye method or Chardakov's Falling Drop Method:

Tow graded series of sucrose solutions (ranging from 0.15 to 0.50 molal in increments of 0.5 molality) are placed in test tubes, set up in duplicate. Homogeneous plant tissue is placed into each test tube of one of the series (test series). Only a drop of methylene blue is mixed into each solution of the second series (control series). Plant tissue is not added to the control series and the dye does not appreciably change the osmotic potentials.

After the tissue is incubated for 15 to 30 minutes, it is removed from each tube. The actual time of incubation can be just long enough for osmosis to proceed and change the concentration of each solution in the test series; the attainment of equilibrium is not necessary. After the tissue is removed, a small drop of the respective control series solutions is introduced below the surface of its corresponding test solution. If the drop rises in the test solution, it means that the drop is lighter and that the tissue incubation solution is more concentrated; an indication that water from the solution entered the tissue. Conversely, if the drop falls, it means that the test solution is lighter-an indication that water has left the tissue and diluted the solution. In this latter instance, the water potential of the solution initially is more negative than that of the tissue. Accordingly, if the density of the drop from the methylene blue solution is the same as that of the test solution, the drop will diffuse into the solution uniformly. At this point (called the null point), the water potential of the tissue and solution is equal.

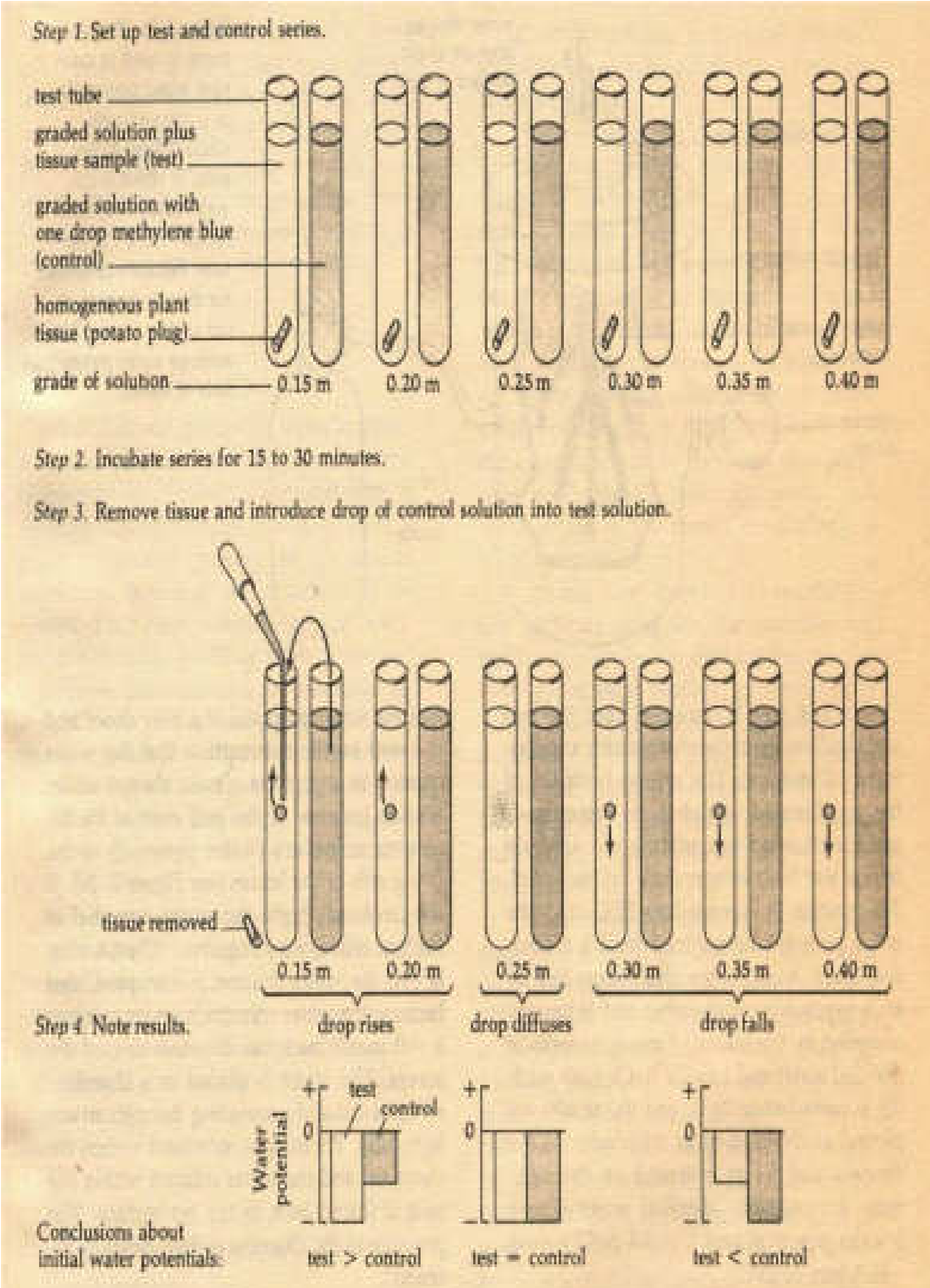

Figure 2-9. Chardakov's, or falling drop, method. Drop rising in test solution indicates test solution became more dense than its counterpart. Water diffused out of test solution into tissue, which initially had a more negative ψ_w. Reverse is true when drop descends in test solution. Diffusion of drop in test solution indicates no change, hence water potentials were equal initially.

Fig.9: Schematic Representation of Liquid Immersion Method or Dye Method or Chardakov's Falling Drop Method

2. Vapour equilibration (Thermocouple Psychrometer) Method

Psychrometry (the prefix "psychro-" comes from the Greek word psychein, "to cool") is based on the fact that the vapor pressure of water is lowered as its water potential is reduced. Psychrometers measure the water vapour pressure of a solution or plant sample, on the basis of the principle that evaporation of water from a surface; cools the surface.

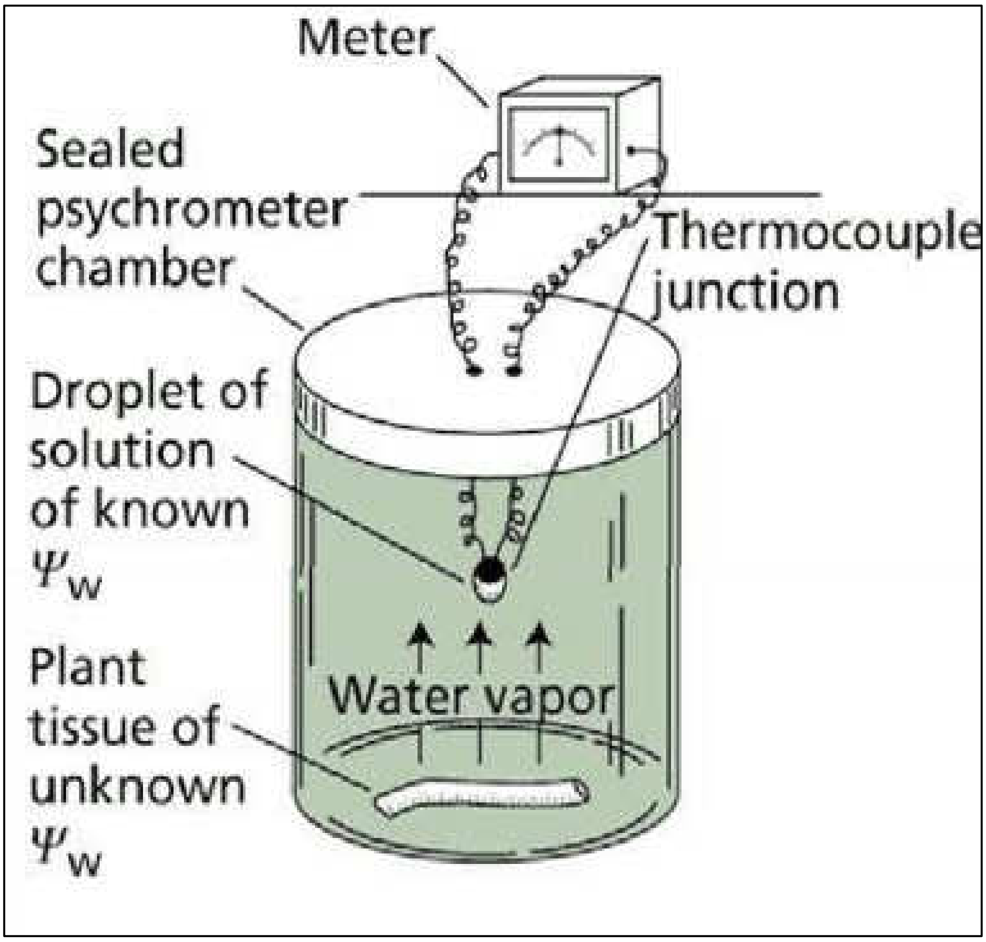

Fig.10: Schematic Representation of Vapour Equilibration (Thermocouple Psychrometer)

Method

Investigators make a measurement by placing a piece of tissue sealed inside a small chamber that contains a temperature sensor (in this case, a thermocouple) in contact with a small droplet of a standard solution of known solute concentration (known Ψ_S and thus known Ψ_W). If the tissue has a lower water potential than that of the droplet, water evaporates from the droplet, diffuses through the air, and is absorbed by the tissue. This slight evaporation of water cools the drop. The larger the difference in water potential between the tissue and the droplet, the higher will be the rate of water transfer and hence the cooler the droplet. If the standard solution has a lower water potential than that of the sample to be measured, water will diffuse from the tissue to the droplet, causing warming of the droplet. Measuring the change in temperature of the droplet for several solutions of known Ψw makes it possible to calculate the water potential of a solution for which the net movement of water between the droplet and the tissue would be zero signifying that the droplet and the tissue have the same water potential.

Psychrometers can be used to measure the water potentials of both excised and intact plant tissue. Moreover, the method can be used to measure the Ψs of solutions. This can be particularly useful with plant tissues.

A major difficulty with this approach is the extreme sensitivity of the measurement to temperature fluctuations. For example, a change in temperature of 0.01°C corresponds to a change in water potential of about 0.1 MPa. Thus, psychrometers must be operated under constant temperature conditions. For this reason, the method is used primarily in laboratory settings.

3. Pressure chamber method

A relatively quick method for estimating the water potential of large pieces of tissues, such as leaves and small shoots, is by use of the pressure chamber. This method was popularised by P. Scholander and coworkers. The pressure bomb is a device that is used to determine the plant moisture stress and the water potential of a leafy shoot and is based on the assumption that the water column in a plant is almost always under tension because of the pull exerted by the osmotic influences (water potential) of the living cells of the leaves. If the tension is high, the water potential of the leaf cells is very negative. When a stem is cut, the water column (in xylem) is disrupted and because the water column is under tension, it will recede back into the stem toward the leaves. The shoot is placed in a chamber, with the cut end protruding through an airtight hole. Pressure is increased within the chamber and the water column within the twig is forced back to the cut surface. The pressure in the chamber is then carefully recorded.

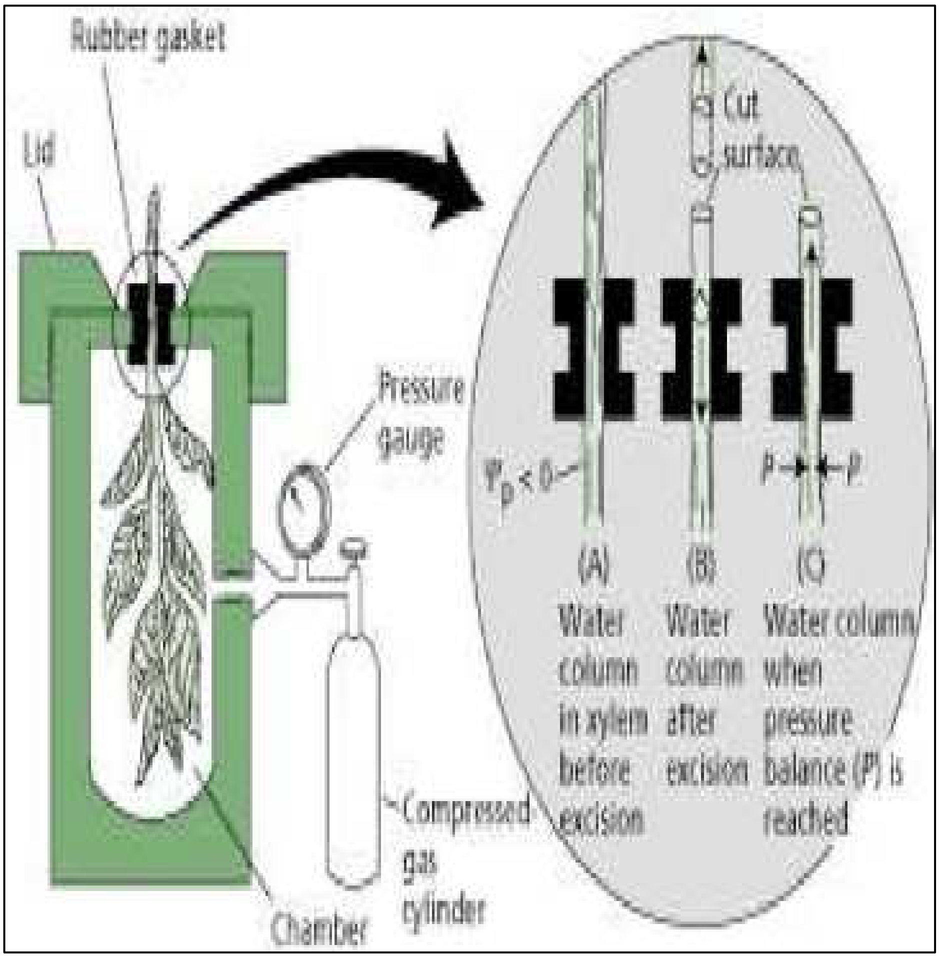

Fig.11: Schematic Representation of Pressure Chamber Method

The pressure required to force the water to appear at the cut surface is equal to the tension (but with the opposite sign) of the water column at the time the shoot was cut. If low pressure is sufficient to force water to the cut surface of the shoot, the shoot is under relatively low moisture stress. But if high pressure is required to force to the cut surface the moisture stress (tension) is relatively high due to very negative water potential of the leaf cells.

SELF-ASSESSTMENT EXERCISE (SAE)

With the aid of a diagram discuss the vapour equilibration (Thermocouple Psychrometer) method

4.0 CONCLUSION

It is generally accepted that the accurate measurement of plant and/or soil water status is critical in any experiment where one is concerned with understanding the effects of differing water supply. Such measurements are essential to define the conditions of the experiment (both in terms of the treatments applied and in terms of the effects on the plants) and as a first step in facilitating repetition of the experiment (which is an essential part of rigorous scientific method).

5.0 SUMMARY

In measuring water status, it is useful to distinguish cause and effect (= 'stress' and 'strain' using the terminology. For example, soil water deficits and the consequently lowered soil water potentials are usually considered as the underlying stresses in the system; the leaf water status is then a result of the soil water deficit. The water potential is measured by (1) liquid immersion method (dye method) (2) vapour equilibration method (Thermocouple Psychrometer) and (3) pressure chamber method. The second way to describe water status is to measure the quantity of water in a tissue, i.e., its water content and to express it in relation to a selected reference. Three of these methods are

1. fresh weight method
2. dry weight method and
3. relative water content (RWC) method.

6.0 TUTOR-MARKED ASSIGNMENT

1. List and explain the various methods of measuring water status.

7.0 REFERENCE/FURTHER READING

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UNIT 6 CONCEPT OF STOMATAL PHYSIOLOGY AND TRANSPIRATION

CONTENTS

1.0 INTRODUCTION

Stomata was discovered by Pfeffer & name 'stomata' was given by Malphigii. Stomata cover one to two per cent of leaf area. It is minute pore present in soft aerial parts of the plant. Algae, fungi and submerged plants do not possess stomata.

Transpiration is the process of evaporation from plants (i.e., it is the loss of water from the plant in the form of water vapor). The greatest loss (more than 90%) of water vapor from plants occurs through leaves and is driven by differences in vapor pressure between the internal leaf spaces (intercellular space) and ambient air. A small amount of water vapour may be lost through small openings (lenticels) in the bark of young twigs and branches. The cuticle serves to restrict evaporation of water directly from the outer surfaces of leaf epidermal cells and protects both the epidermal and underlying mesophyll cells from potentially lethal desiccation. The integrity of the epidermis and the overlying cuticle is occasionally interrupted by small pores called stomata. Each pore is surrounded by a pair of guard cells. The guard cells function as hydraulically operated valves that control the size of the pore. The interior of leaf is mainly comprised of photosynthetic mesophyll cells. Stomata, when open, provide a route for the exchange of gasses (oxygen, carbon dioxide and water vapour) between the internal air space and the bulk atmosphere surrounding the leaf.

2.0 OBJECTIVES

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

- define stomata
- outline the characteristics of stomata
- list the number of stomata (stomatal frequency)
- explain the distribution and types of stomata
- discuss extensively the theories of stomatal movement
- briefly explain mechanism of stomatal opening and closing
- explain the meaning and definition of transpiration
- highlight the significance of transpiration

3.0 MAIN CONTENT

3.1 Stomatal Physiology

3.1.1 Meaning of Stomata

Stomata may refer to the natural openings to the outside environment, such as those on plant leaves or oral cavities of certain animals. Stomata may also refer to the artificial body openings created by surgery. In plants, the stomata are actually the pores created by the swelling of guard cells to allow CO_2 to enter into the leaf, which is a necessary reactant of photosynthesis. The water vapor and O_2 are also allowed to escape via the pore. In order to form a pore or stoma, osmotic pressure draws water to increase the cells volume; this in turn causes the guard cells to bow apart from each other because the inner wall of the pore is more rigid than the wall on the opposite side of the cell.

Stomata are present in all terrestrial plants (in sporophyte phase), except for the liverworts. Dicots usually have more stomata on the lower epidermis than the upper epidermis whereas monocots usually have the same number of stomata on both sides. Plants whose leaves float in water have stomata only on the upper epidermis whereas plants whose leaves are completely submerged may lack stomata entirely.

3.1.2 Characteristics of Stomata

(a) Stomata are minute pores of elliptical shape, consists of two specialised epidermal cell called guard cells.

(b) The guard cells are kidney shape in dicotyledon and dumbbell shape in monocotyledon.

(c) The wall of the guard cell surrounding the pore is thicken and inelastic due to rest of the walls are thin, elastic and semi-permeable.

(d) Each guard cell has a cytoplasmic lining, central vacuole. Its cytoplasm contains single nucleus and number of chloroplasts. The chloroplast of guard cell is capable of very poor photosynthesis, because the absence of RUBISCO enzyme.

(e) Guard cells are surrounded by modified epidermal cells, known as subsidiary cells or accessory cells, which supports in the movement of guard cells.

(f) The size and shape of stoma and guard cell vary from plant to plant. When fully open, the stomatal pore measures 3-12 µ in width and 10-40 µ in length.

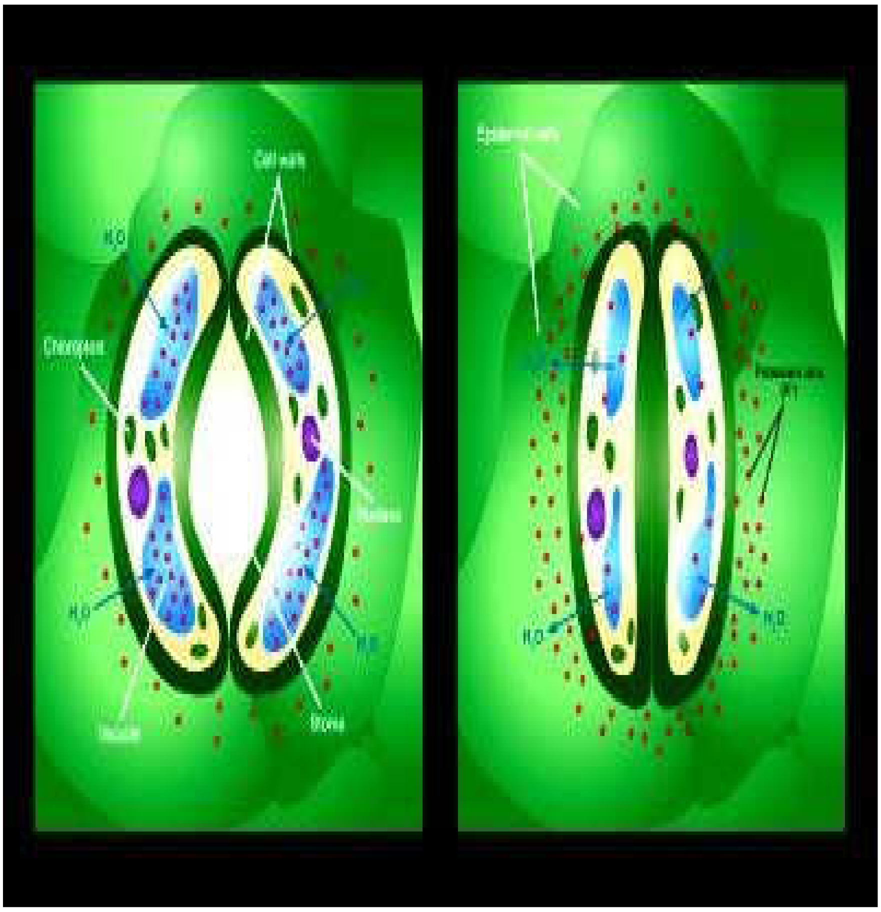

Fig. 12: Opening and Closing of Stomata

(g) In many gymnosperms and xerophytic plants (plants growing in desert), the stomata are present embedded deeply in the leaves, so that they are not exposed to sunlight directly. Such deeply embedded stomata are called sunken stomata. This is an adaptation to check excessive transpiration in these plants.

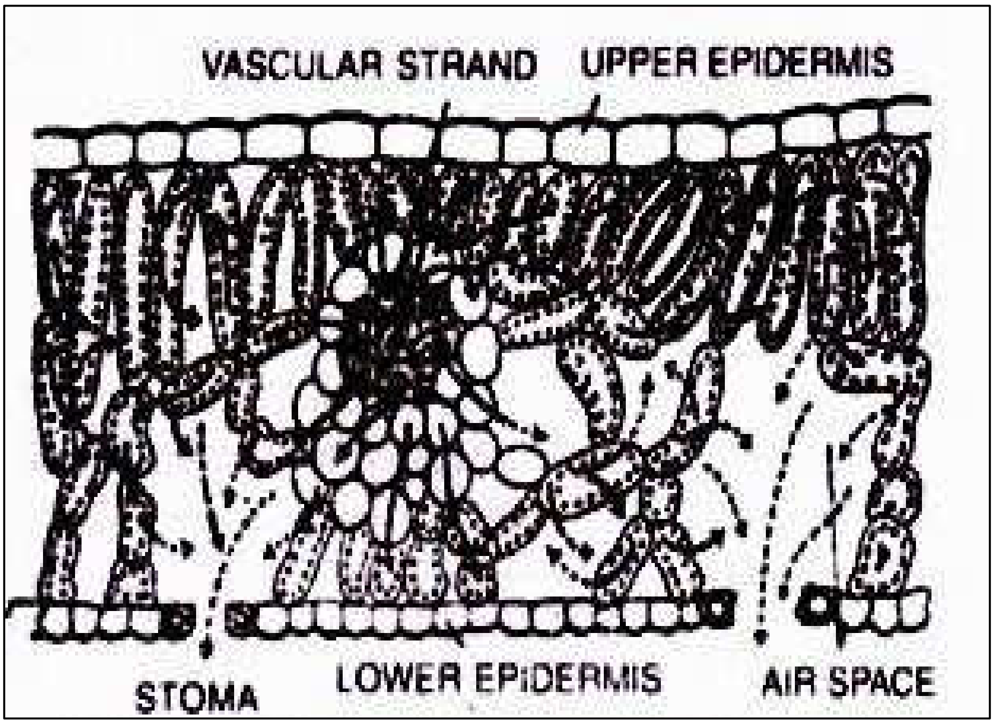

Fig. 13: Vertical Section of Leaf Blade Showing the Passage of Water Vapours During Transpiration

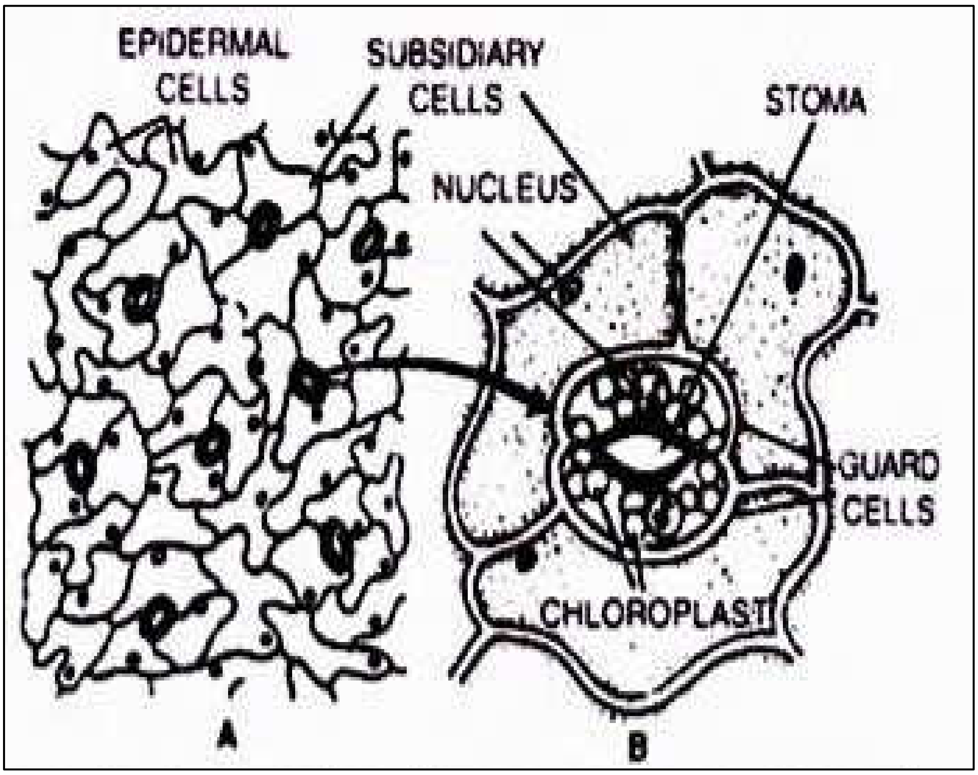

Fig. 14: A) Portion of Lower Epidemis of Leaf Magnified to Show Stomata,
B) A Stoma Magnified

3.1.3 Number of Stomata (Stomatal Frequency)

The number of stomata in a definite area of leaf varies from plant to plant. Xerophytes possess larger number of stomata than Mesophytes. Number of stomata/sq cm. is 1000-60,000 in different plant species. The number of stomata per unit area of leaf is called Stomatal Frequency.

Stomata frequency of trees and shrubs is higher than herbs. Stomata occupy nearly one to two per cent of total leaf area when fully open. In isobilateral leaves (in monocots) approximately the same number of stomata are found on upper surface (adaxial) and lower (abaxial) surface. But in dorsiventral leaves (indicots) the number of stomata on the upper surface is much less in comparison to those found on the lower surface.

3.1.4 Distribution and Types of Stomata:

A. Depending upon the distribution and arrangement of stomata in the leaves five categories of stomatal distribution have been recognised in plants.

1. Apple or mulberry (hypostomatic) type:
   Stomata are found distributed only on the lower surface of leaves, e.g., apple, peach, mulberry, walnut, etc.
2. Potato type:
   Stomata are found distributed more on the lower surface and less on its upper surface, e.g., potato, cabbage, bean, tomato, pea, etc.
3. Oat (amphistomatic) type:
   Stomata are found distributed equally upon the two surfaces, e.g., maize, oats, grasses, etc.
4. Water lily (epistomatic) type:
   Stomata are found distributed only on the upper surface of leaf, e.g., water lily, Nymphaea and many aquatic plants.
5. Potamogeton (astomatic) type:
   Stomata are altogether absent or if present they are vestigeal. e.g., Potamogeton and submerged aquatics.

B. Types of Stomata based on movement

Loftfield (1856) classified three main groups of stomata in accordance with their daily movement:

1. Alfalfa Type: The stomata remain open throughout the day and closed all night, e.g., peas, bean, mustard etc.
2. Potato Type: The stomata will open throughout the day and night except for few hours in the evening, e.g., Allium, cabbage, pumpkin, etc.
3. Barley Type: The stomata open only for a few hours in a day, e.g., Barley and other cereals.

C. Types of stomata based on Behaviour

Considering the behaviour of the stomatal movements, five categories have been recognised:

1. Photo-active movements: Light directly or indirectly controls stomatal movements. Such stomata remain open during day time and closed in nights (dark).
2. Skoto-active movements: Stomata remain closed during day time and open during night. Such cases are found in succulent plants and other CAM Plants.
3. Hydro-active movements: In some cases, stomata open due to excessive loss of water from the epidermal cells and close due to turgid conditions of epidermal cells. This is usually found during mid-day.
4. Autonomous movements: In certain cases, stomata open and close at a rate of 10-15 minutes showing diurnal or rhythmic pulsation.
5. Passive and Active movements: Opening of stomata is considered as active process and closing is the passive process and this is caused by the turgor changes in the guard cells.

3.1.5 Theories of Stomata Movement

Factors affecting stomata opening and closing:

i) There is an endogenous rhythm (a biological clock). Stomata open during the day and close during the night. (Though certain succulents, which are native to hot, dry conditions have a reversed rhythm to enable them to economise on water loss.) However, stomata continue to open and close on an approximately 24-hour clock (circadian = about a day) even when switched to continuous light. The phase of this opening and closure can be shifted (made to occur at other times of the day) by control of the end of the dark period.

ii) The water balance of a plant affects stomata aperture. Wilting plants close their stomata. The plant growth regulator abscisic acid (ABA) seems to act as a mediator under these conditions. Water stress in the roots can transmit its influence to stomata in leaves by the signal of ABA.

iii) Low concentrations of CO_2 cause stomata to open. If CO_2 free air is blown across stomata in darkness, their stomata open. High CO_2 causes stomata to close.

iv) Light causes stomata to open. The minimum light level for opening of stomata in most plants is 1/1000 to 1/30 of full sunlight, just enough to cause some net photosynthesis. Blue light (430-460nm) is nearly 10 times as effective as red light (630-680nm). The wavelengths that are effective in the red part of the spectrum are the same as those that are effective in photosynthesis that is absorbed by chlorophyll. However, the blue light effect is quite independent of photosynthesis. Photosynthesis will change intercellular CO_2 concentrations and may have its effect through the mechanism written in point iii) above.

3.1.6. Mechanism of Stomata Opening a and Closing

The pigment zeaxanthin (a carotenoid) detects blue-light wavelengths of daylight, and activate proton pumps in the guard cell membranes, which proceed to extrude protons from the cytoplasm of the cell; this creates a "proton motive force" (an electrochemical gradient across the membrane) which opens voltage operated channels in the membrane, allowing K^+ ions to flow passively into the cell, from the surrounding tissues. Chloride ions also enter the cell, with their movement coupled to the re-entry of some of the extruded protons (Cl/H symport) to act as a counter-ion to the potassium. Water passively follows these ions into the guard cells, and as their turgidity increases, the stomata pore opens, in the morning. As the day progresses the osmotic role of that of sucrose, which can be generated by several means, including starch hydrolysis and photosynthesis, supplements potassium. At the end of the day (by which time the potassium accumulation has dissipated) it seems it is the fall in the concentration of sucrose that initiates the loss of water and reduced turgor pressure, which causes closure of the stomata pore.

ABA also seems to trigger a loss of K^+ ions from guard cells. Some scientists suggest that in some species, ABA alters turgor pressure without changing solute potential or water potential. There is evidence of a role for increased cytoplasmic calcium (Ca^{2+}) in closure, possibly by effects on opening/closing of ion channels at the plasma membrane.

Break down of starch to phosphoenol pyruvate (PEP) is stimulated by blue light. This PEP then combines with CO_2 to form oxaloacetic acid, which is converted to malic acid. It is H^+ ions from the malic acid, which leave the cell in the mechanism outlined above. Thus, the intake of K ions is matched by formation of anions from malic acid in the guard cells. This causes an increase in osmotically active substances in exchange for the breakdown of starch in guard cells.

3.2 Concept of Transpiration

3.2.1 Meaning and Definition of Transpiration

Transpiration is the process of evaporation from plants (i.e., it is the loss of water from the plant in the form of water vapour). The greatest loss (more than 90%) of water vapour from plants occurs through leaves and is driven by differences in vapour pressure between the internal leaf spaces (intercellular space) and ambient air. A small amount of water vapour may be lost through small openings (lenticels) in the bark of young twigs and branches. The cuticle serves to restrict evaporation of water directly from the outer surfaces of leaf epidermal cells and protects both the epidermal and underlying mesophyll cells from potentially lethal desiccation. The integrity of the epidermis and the overlying cuticle is occasionally interrupted by small pores called stomata. Each pore is surrounded by a pair of guard cells. The guard cells function as hydraulically operated valves that control the size of the pore. The interior of leaf is mainly comprised of photosynthetic mesophyll cells. Stomata, when open, provide a route for the exchange of gasses (oxygen, carbon dioxide and water vapour) between the internal air space and the bulk atmosphere surrounding the leaf.

Diffusion of water through the stomata pores known as stomata transpiration cover 90 to 95 per cent of water loss from leaves. The remaining 5 to 10 per cent is counted for by cuticular transpiration (although the cuticle is composed of waxes and other hydrophobic substances and generally impermeable to water, small quantities of water vapor can pass through).

3.2.2 Significance of Transpiration

Transpiration is advantageous because:

1. It creates suction force and helps in the ascent of sap.
2. It helps in the absorption of water and minerals by roots.
3. It helps in evaporating excess amount of water from moist soil.
4. It plays a role in translocation of food from one part of the plant to the other.
5. It brings opening and closure of stomata which indirectly influences the gaseous exchange for the processes of photosynthesis and respiration.
6. It helps in dissipating the excess energy absorbed from the sun, which will otherwise raise the leaf temperature.
7. It maintains suitable temperature of leaves by imparting a cooling effect.

According to Curtis (1926) transpiration is regarded as an unavoidable (necessary) evil. It is unavoidable because leaf structure (stomata) which is favorable for uptake of CO_2 and O_2 necessary for photosynthesis and respiration is also favourable for the loss of water through transpiration. One of the advantages of transpiration is that it reduces the temperature of the leaf and if it does reduce the temperature then it must be advantageous to plants because we understand the importance of temperature in a cell and how it affects enzymes. Some claim that transpiration helps in translocation of mineral salts to the upper parts of the body. But studies show that only one to two per cent of transpiration is sufficient to translocate the mineral salts.

Transpiration is an ‘evil’ because often it causes injury by dehydration due to heavy transpiration loss when the atmospheric conditions are aggressive such as high light intensity, hot winds, depleted soil moisture and poor water retentive capacity of soil.

SELF-ASSESSTMENT EXERCISE (SAE)

1. Explain the meaning and definition of stomata
2. Outline the characteristics of stomata
3. List the number of stomata (stomatal frequency)
4. List and explain the distribution and types of stomata

4.0 CONCLUSION

Stomata were discovered by Pfeffer & name 'stomata' was given by Malphigii. Stomata cover one to two per cent of leaf area. It is minute pore present in soft aerial parts of the plant. Algae, fungi and submerged plants do not possess stomata.

Transpiration is the process of evaporation from plants (i.e., it is the loss of water from the plant in the form of water vapour). The greatest loss (more than 90%) of water vapor from plants occurs through leaves and is driven by differences in vapour pressure between the internal leaf spaces (intercellular space) and ambient air. A small amount of water vapour may be lost through small openings (lenticels) in the bark of young twigs and branches. The cuticle serves to restrict evaporation of water directly from the outer surfaces of leaf epidermal cells and protects both the epidermal and underlying mesophyll cells from potentially lethal desiccation. The integrity of the epidermis and the overlying cuticle is occasionally interrupted by small pores called stomata. Each pore is surrounded by a pair of guard cells. The guard cells function as hydraulically operated valves that control the size of the pore. The interior of leaf is mainly comprised of photosynthetic mesophyll cells. Stomata, when open, provide a route for the exchange of gasses (oxygen, carbon dioxide and water vapour) between the internal air space and the bulk atmosphere surrounding the leaf.

5.0 SUMMARY

Stomata may refer to the natural openings to the outside environment, such as those on plant leaves or oral cavities of certain animals. Stomata may also refer to the artificial body openings created by surgery. In plants, the stomata are actually the pores created by the swelling of guard cells to allow CO_2 to enter into the leaf, which is a necessary reactant of photosynthesis. The water vapour and O_2 are also allowed to escape via the pore. In order to form a pore or stoma, osmotic pressure draws water to increase the cells volume; this in turn causes the guard cells to bow apart from each other because the inner wall of the pore is more rigid than the wall on the opposite side of the cell.

Stomata are present in all terrestrial plants (in sporophyte phase), except for the liverworts. Dicots usually have more stomata on the lower epidermis than the upper epidermis whereas monocots usually have the same number of stomata on both sides. Plants whose leaves float in water have stomata only on the upper epidermis whereas plants whose leaves are completely submerged may lack stomata entirely.

Transpiration is the process of evaporation from plants (i.e., it is the loss of water from the plant in the form of water vapor). The greatest loss (more than 90%) of water vapor from plants occurs through leaves and is driven by differences in vapour pressure between the internal leaf spaces (intercellular space) and ambient air. A small amount of water vapour may be lost through small openings (lenticels) in the bark of young twigs and branches. The cuticle serves to restrict evaporation of water directly from the outer surfaces of leaf epidermal cells and protects both the epidermal and underlying mesophyll cells from potentially lethal desiccation. The integrity of the epidermis and the overlying cuticle is occasionally interrupted by small pores called stomata. Each pore is surrounded by a pair of guard cells. The guard cells function as hydraulically operated valves that control the size of the pore. The interior of leaf is mainly comprised of photosynthetic mesophyll cells. Stomata, when open, provide a route for the exchange of gasses (oxygen, carbon dioxide and water vapour) between the internal air space and the bulk atmosphere surrounding the leaf.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the Meaning and definition of Stomata
2. Outline the Characteristics of stomata
3. List the Number of Stomata (Stomata Frequency)
4. List and explain the Distribution and Types of Stomata
5. Discuss extensively the Theories of Stomata Movement
6. Briefly explain Mechanism of Stomata Opening and Closing
7. Explain the Meaning and Definition of Transpiration
8. Highlight the Significance of Transpiration

7.0 REFERENCE/FURTHER READING

Hamlyn, G. Jones, *Journal of Experimental Botany*, Volume 58, Issue 2, January 2007, Pages 119–130, https://doi.org/10.1093/jxb/erl118

UNIT 7 CONCEPT OF EVAPOTRANSPIRATION

CONTENTS

1.0 INTRODUCTION

Evapotranspiration (ET) is the sum of water evaporation and transpiration from a surface area to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent exit of water as vapour through stomata in its leaves in vascular plants and phyllids in non-vascular plants. A plant that contributes to evapotranspiration is called an evapotranspiration.[1] Evapotranspiration is an important part of the water cycle.

Potential evapotranspiration (PET) is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop (grass), completely shading the ground, of uniform height and with adequate water status in the soil profile. It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere. Often a value for the potential evapotranspiration is calculated at a nearby climatic station on a reference surface, conventionally short grass. This value is called the reference evapotranspiration (ET0). Actual evapotranspiration is said to equal potential evapotranspiration when there is ample water. Some US states utilise a full cover alfalfa reference crop that is 0.5 m in height, rather than the short green grass reference, due to the higher value of ET from the alfalfa reference.

2.0 OBJECTIVES

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

- explain the meaning of evapotranspiration
- outline the different factors affecting evapotranspiration with each specific factors.

3.0 MAIN CONTENT

3.1 Meaning of Evapotranspiration

Evapotranspiration (ET) is the sum of water evaporation and transpiration from a surface area to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent exit of water as vapour through stomata in its leaves in vascular plants and phyllids in non-vascular plants. A plant that contributes to evapotranspiration is called an evapotranspiration.[1] Evapotranspiration is an important part of the water cycle.

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3.2 General Factors Affecting Evapotranspiration

The total amount of water lost from the field by both evaporation and plant transpiration

A. Environmental factors affecting ET:

1. Solar radiation,
2. Temperature,
3. Relative humidity,
4. Wind

B. Plant factors affecting ET:
1. Stomata closure
2. Stomata number and size
3. Leaf amount
4. Leaf rolling or folding
5. Root depth and proliferation

Knowing how environment and the plant influence evapotranspiration helps to explain the daily pattern of evapotranspiration in the field.

SELF-ASSESSTMENT EXERCISE (SAE)

Explain the meaning of evapotranspiration
Outline the different factors affecting evapotranspiration with each specific factor.

4.0 CONCLUSION

Evapotranspiration (ET) is the sum of water evaporation and transpiration from a surface area to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent exit of water as vapor through stomata in its leaves in vascular plants and phyllids in non-vascular plants. A plant that contributes to evapotranspiration is called an evapotranspiration.[1] Evapotranspiration is an important part of the water cycle.

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5.0 SUMMARY

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6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the meaning of evapotranspiration
2. Outline the different factors affecting evapotranspiration with each specific factor.

7.0 REFERENCE/FURTHER READING

Hamlyn, G. Jones, *Journal of Experimental Botany*, Volume 58, Issue 2, January 2007, Pages 119–130, https://doi.org/10.1093/jxb/erl118

UNIT 8 CONCEPT OF SOIL WATER AVAILABILITY

CONTENTS

1.0 INTRODUCTION

Available water capacity is the amount of water that a soil can store that is available for use by plants. It is the water held between field capacity and the wilting point adjusted downward for rock fragments and for salts in solution.

Of the water entering a soil profile, some will be stored within the rooting zone for plant use, some will evaporate and some will drain away from the plant root zone. Plant available water is the difference between field capacity (the maximum amount of water the soil can hold) and the wilting point (where the plant can no longer extract water from the soil) measured over 100 cm or maximum rooting depth (Hunt and Gilkes, 1992). Beyond the wilting point there is still water in the soil profile, however it is contained in pores that are too small for plant roots to access. Soil texture, soil structure and plant rooting depth are the crucial factors in determining the amount of water available for plants to access.

Definitions;

1. **Available water:** water that can be extracted from the soil by plant roots. It is the difference between the amount of water in the soil at field capacity and the amount of water in the soil at permanent wilting percentage.
2. **Field capacity:** water held in the soil against the gravitational force.

Permanent wilting percentage: the percentage of soil moisture at which a plant will wilt and not recover in an atmosphere of 100% relative humidity.

3. Water use efficiency:

The water use efficiency (WUE) of field crops is defined as 'Amount of dry matter produced per unit amount of water transpired'
Dry matter production (DM) WUE = ... Evapotranspiration

This is expressed as g DM kg^{-1} water. WUE measurements can be made on plants in containers, on individual plants, and on crop communities. They can be used for economic yield as well as total dry matter calculations.

A related term, water requirement is the reciprocal of WUE. Water requirements is usually expressed in weights of equal magnitude, such as g water $(g\ DM)^{-1}$.

3. Water use efficiency in C3, C4 and CAM plants:

Field data for WUE, when regrouped into C3 and C4 species, illustrate a twofold increase for C4 species when calculated for either grasses or dicots. Water use Efficiency (g DM kg^{-1} water) for C4 and C3 species.

Species	Grasses	Dicots
C3	1.49	1.59
C4	3.14	3.44

Large differences in WUE occur when species are categorized by CO_2 fixation pathway. It is now accepted that the WUE of C4 species is generally higher than C3 species. The higher WUE of C4 species is a result of higher photosynthetic rate under high light intensity and temperature and lower transpiration rates under low light.

The WUE values for both C3 and C4 species are low compared with CAM plants. One CAM species, pineapple (*Ananas comosis*), has shown a WUE of 20g DM kg^{-1} water. Use of crop species with CAM is limited because the CO_2 fixation and overall productivity of CAM plants is low (CAM is only a survival mechanism but not a productive mechanism).

2.0 OBJECTIVES

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

- explain the meaning of soil water availability
- discuss a typical soil profile
- explain the concept of soil-water availability

3.0 MAIN CONTENT

3.1 Concept of Soil Water Availability

Soil water availability is the capacity of a soil to hold water that is available for plant use. A soil is simply a porous medium consisting of minerals, organic matter, water, and gases. The traditional definition of soil is: Soil is a dynamic natural body having properties derived from the combined effects of climate and biotic activities, as modified by topography, acting on parent materials over time.

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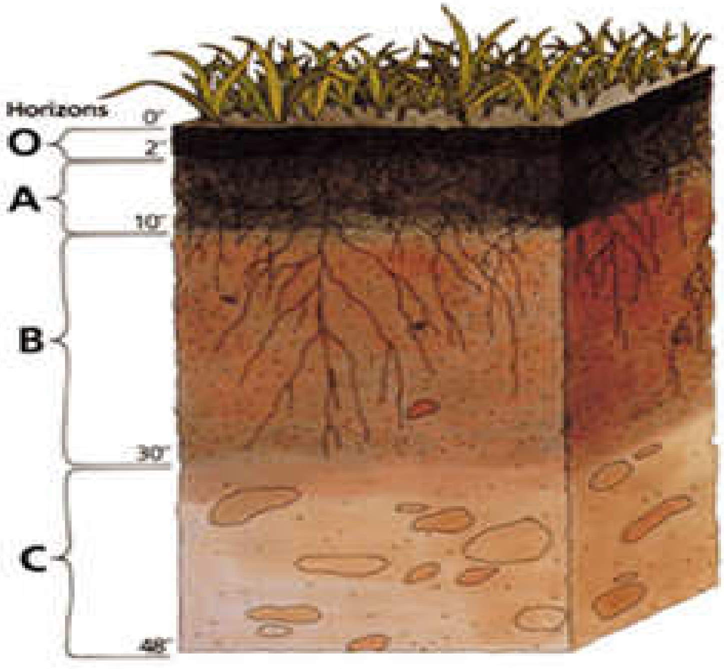


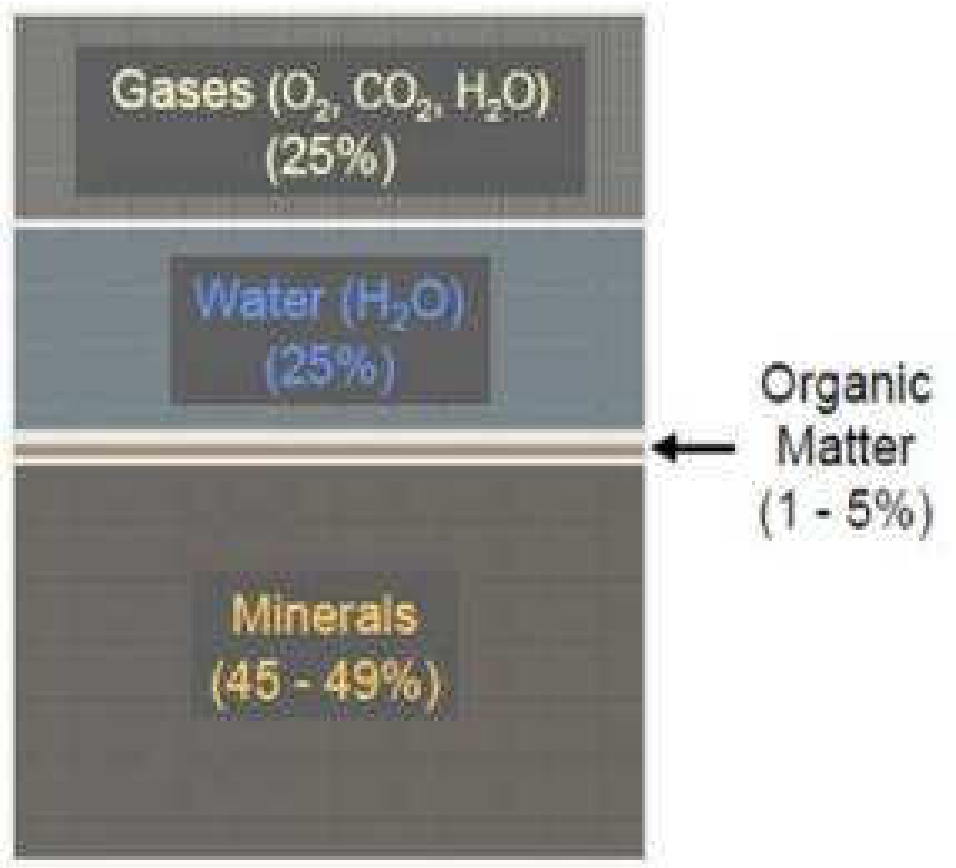


Fig.14: Diagram of a Typical Soil Profile

The capacity of a soil to hold water is largely dependent on soil texture. Soil comes in a variety of textures but results from two principal mineral types. Primary minerals, such as those found in sand and silt, are those soil materials that are similar to the parent material from which they formed. They are often round or irregular in shape. Secondary minerals, on the other hand, result from the weathering of the primary minerals, leading to the formation of plate like particles called clay. Clays have a large surface area, which is important for soil chemistry and water holding capacity. The texture of a soil is based on the percentage of sand, silt, and clay found in that soil. The identification of sand, silt, and clay are made based on size. The following is used in the United States:

Sand 0.02 – 2.00 mm in diameter
Silt 0.002 – 0.02 mm in diameter
Clay < 0.002 mm in diameter

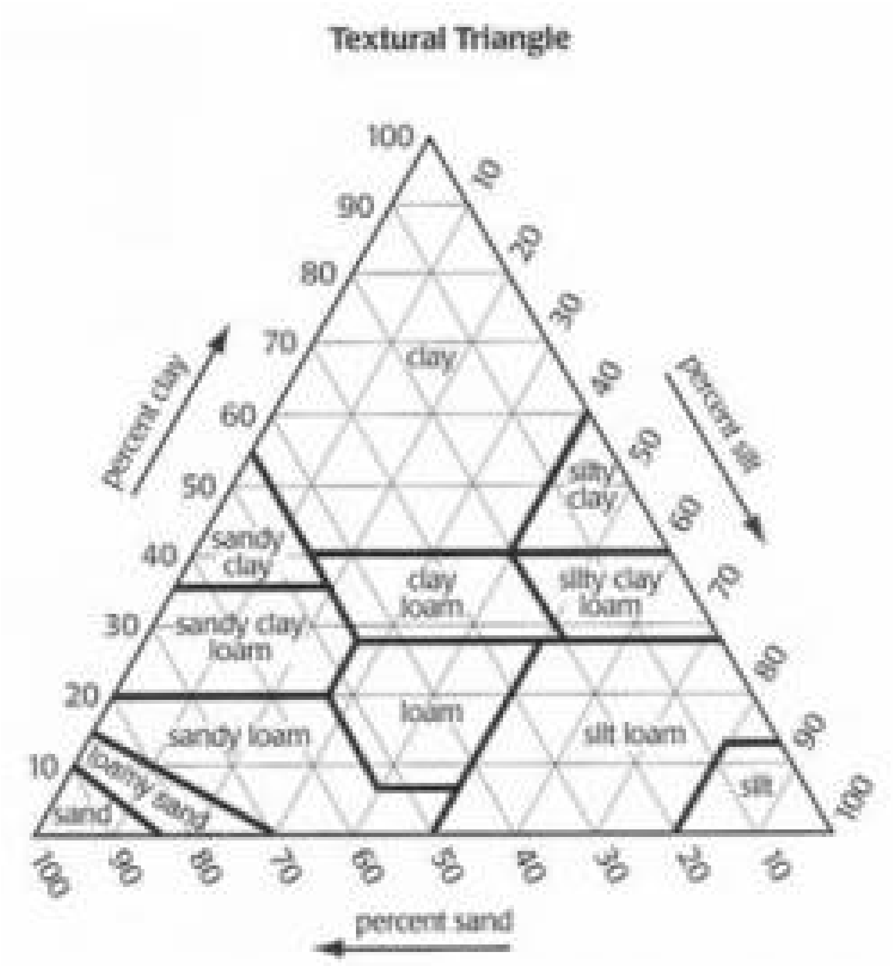


Fig. 15: The USDA Soil Texture Triangle.

The texture of a soil can be determined from its sand, silt, and clay content using a textural triangle. The triangle on the right (Figure 15) is the one created by the U.S. Department of Agriculture's Natural Resources Conservation Service and is primarily used in the United States. There are various textural triangles used throughout the world but most are similar. Percent clay in this triangle is read on the left-hand side of the triangle, the percent silt is read on the right hand side of the triangle, and the percent sand is on the bottom of the triangle. For example, if a soil contains 20 per cent clay, 40 per cent sand, and 40 per cent silt (total = 100%), then it is a loam.

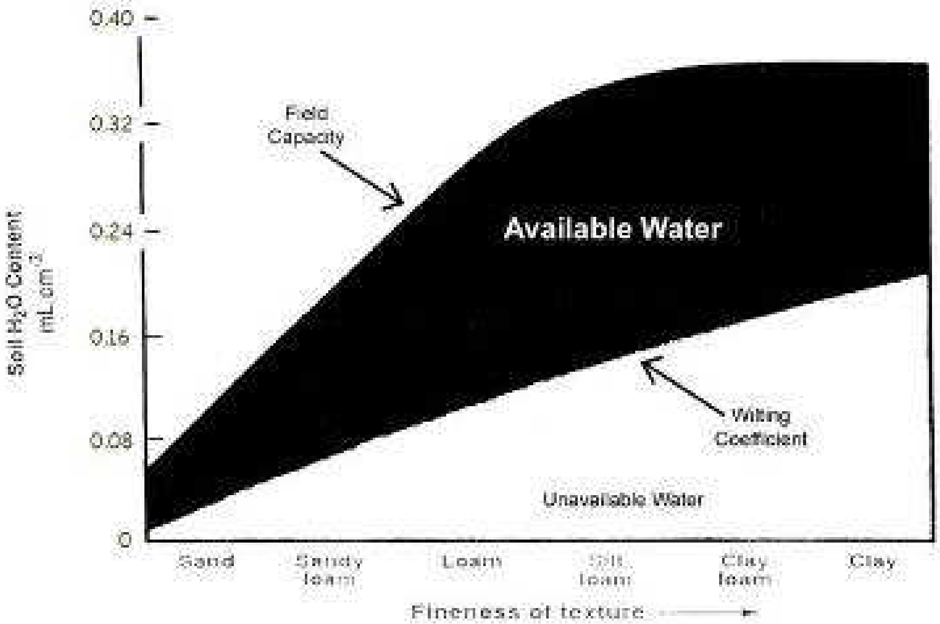


Fig. 16: A Plant's Available Water Holding Capacity for Soils with Different Textures.

The texture of a soil is important for soil water availability because it controls not only how well a soil can hold water but also how well water is absorbed into the soil. Any water that infiltrates into a soil does so primarily through large pores in the soil called "macro pores" that are created by plant roots, microorganisms, and physical processes such as freezing and thawing and drying and wetting. These processes help form conglomerations of soil particles called "aggregates" that are held together in part by organic molecules that originated from plants, animals, and microorganisms. Aggregates help form soil structure – which in turn helps maintain macro pores and good infiltration capacity. Good soil structure also improves soil aeration for both roots and microbes.

Once water has entered the soil it is held through capillary action by the small interparticle spaces called "micro pores." This is very similar to a paper towel absorbing spilled water. The course the texture, the fewer small spaces exist and the less water the soil can hold. An example might be water running through a jar of marbles, without being held. Alternatively, a very fine sponge will hold water until all the micro pores are filled, at which point excess water runs through. For a soil, this point is called the "water holding capacity" or "field capacity." Soils with different textures and levels of aggregation have very different water holding capacities. For trees to absorb water from a soil, it must be held at an energy level that trees can use. Sand is fairly coarse with limited micro pores, has a very poor water holding capacity versus clay that is a matrix of very fine pores. Although clay can hold the most water of all soil textures, the very fine micro pores hold water so tightly that plants have great difficulty extracting all of it. The point where water is held microscopically with too much energy for a plant to extract is called the “wilting coefficient,” and in general, water in such a state of energy is not available for most plants to extract. Thus, loams and silt loams are considered some of the most productive soil textures because they hold large quantities of water that is available for plants to use.

SELF-ASSESSTMENT EXERCISE (SAE)

Explain the meaning of Soil water availability
Discuss a typical soil profile
Explain the concept of soil-water availability

4.0 CONCLUSION

Available water capacity is the amount of water that a soil can store that is available for use by plants. It is the water held between field capacity and the wilting point adjusted downward for rock fragments and for salts in solution.

Of the water entering a soil profile, some will be stored within the rooting zone for plant use, some will evaporate and some will drain away from the plant root zone. Plant available water is the difference between field capacity (the maximum amount of water the soil can hold) and the wilting point (where the plant can no longer extract water from the soil) measured over 100 cm or maximum rooting depth. (Hunt and Gilkes, 1992).

5.0 SUMMARY

Soil water availability is the capacity of a soil to hold water that is available for plant use. A soil is simply a porous medium consisting of minerals, organic matter, water, and gases. The traditional definition of soil is: Soil is a dynamic natural body having properties derived from the combined effects of climate and biotic activities, as modified by topography, acting on parent materials over time.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the meaning of soil water availability
2. Discuss a typical soil profile
3. Explain the concept of soil-water availability

7.0 REFERENCE/FURTHER READING

Hunt, N. & Gilkes, B. (1992). Farm Monitoring Handbook. Published by University of Western Australia, Land Management Society, and National Dryland Salinity Program.

MODULE 4 MINERAL NUTRITION OF PLANTS: FUNCTIONS AND DEFICIENCY SYMPTOMS OF NUTRIENTS, NUTRIENT UPTAKE MECHANISMS

UNIT 1 MEANING OF MINERAL NUTRITION

CONTENTS

1.0 INTRODUCTION

Mineral nutrients are elements acquired primarily in the form of inorganic ions from the soil. Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the root systems of plants, so in a sense plants act as the "miners" of Earth's crust. The large surface area of roots and their ability to absorb inorganic ions at low concentrations from the soil solution make mineral absorption by plants a very effective process. After being absorbed by the roots, the mineral elements are translocate to the various parts of the plant, where they are utilised in numerous biological functions. Other organisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, often participate with mots in the acquisition of nutrients.

The study of how plants obtain and use mineral nutrients is called mineral nutrition.

2.0 OBJECTIVES

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

- explain the meaning of mineral nutrition
- outline the classification of essential elements into two groups
- discuss the criteria of essentiality of mineral elements
- classify plant nutrients based on their biochemical role and physiological function
- discuss the mineral availability shows an interesting dose effect
- list the specific roles of essential mineral elements
- explain the physiology of nutrient uptake

3.0 MAIN CONTENT

3.1 Meaning of Mineral Nutrition

The chemical compounds required by an organism are termed as nutrients

1. Nutrition may be defined as the supply and absorption of chemical compounds needed for plant growth and metabolism
2. For plant growth and metabolism, 17 elements are essential. They are C, H, O, N, P, K,
   Ca, S, Mg, Fe, Mn, Zn, B, Cu, Mo, Cl and Ni.

These essential elements are classified into two groups

1. Major elements (macro nutrients)
2. Minor elements (Micro nutrients) (Trace elements)

Major elements

The essential elements which are required by the plants in comparatively large amounts are called as major elements or macro nutrients. According to another definition minerals found in >1000 ppm concentration are macronutrients. They are C, H, O, N, P, K, Ca, S, Mg.

Minor elements

The essential elements which are required in very small amounts or traces by the plants are called as minor elements or micronutrients or trace elements. According to another definition minerals found in <100 ppm concentration are micronutrients. They are Fe, Zn, Mn, B, Cu and Mo. Si is now transferred from list of beneficial elements to essential elements.

Beneficial elements: (Na, Si and Co)

Sodium has beneficial effect, and, in some case, it is essential. There are some plant species, particularly the Chenopodiaceous plants and species adapted to saline conditions that take up this element in relatively high amounts. Na is also required for turnips, sugar beets and celery. The same is true for Si, which is an essential nutrient for rice. Cobalt is an essential element for the growth of the Blue green algae, but it has not been shown to be essential for other algae or for higher plants. It is also required by certain legumes to fix atmospheric nitrogen. Here, however the cobalt ion is necessary for the symbiotic bacteria present in the nodules associated with the roots.

3.1.1 Criteria of Essentiality of Mineral Elements

The term essential mineral element was proposed by Arnon and Stout (1939). According to them an element to be considered essential, three criteria must be met:

1. A given plant must be unable to complete its life cycle in the absence of mineral elements.
2. The function of the element must not be replaceable by another mineral element
3. The elements must be directly involved in plant metabolism. For e.g., as a component of an essential plant constituents or it must be required for a distinct metabolic step such as an enzyme reaction.

Based on the mobility, elements are also classified into three types.

1. Mobile elements: N, P, K, S and Mg
2. Immobile elements: Ca, Fe and B
3. Intermediate in mobility: Zn, Mn, Cu, Mo

3.1.2 Classification of Plant Nutrients Based on their Biochemical Role and Physiological Function

Essential elements are now classified according to their biochemical role and physiological function. Based on the biochemical behavior and physiological functions, plant nutrients may be divided into four groups.

Table 5: Nutrient Elements Uptake and Biochemical Function

Nutrient elements	Uptake	Biochemical function
1st group C, H, O, N, S	In the form of CO_2, HCO^-3, H_2O, O_2, NO_3, NH^+, 42 N2SO4, SO_2. The ions from the soil solution, the gases from the atmosphere.	Major constituents of the organic compounds of the plant. Essential elements of atomic groups which are involved in enzymatic processes. Assimilation by oxidation reduction reactions.
2nd Group P, B, Si	In the form of phosphates, boric acid or borate, silicate from the soil solution.	They are important in energy storage reactions or in maintaining structural integrity. Elements in this group are often present in plant tissues as phosphate, Borate and silicate esters in which the elemental group is bound to the hydroxyl group of an organic molecule (i.e., sugar- phosphates) (Esterification*). The phosphate esters are involved in energy transfer reactions.
3rd Group K, Na, Mg, Ca, Mn, Cl	In the form of cations from the soil solution except chlorine	Present in plant tissues as either free ions or ions bound to substances such as the pectic acids present in the plant cell wall. Of particular importance of their roles as enzyme cofactors and in regulation of osmotic potentials.

4th Group Fe, Cu, Zn, Mo	In the form of ions or chelates from the soil solution	Present predominantly in a chelated form Incorporated in prosthetic groups. Enable electron transport by valency change.

(Source: Taiz and Zeiger 2002)
*Esterification: Compounds formed by condensation of an acid and alcohol with elimination of water ADP + Pi = ATP

3.2 Mineral Deficiencies Produce Visible Symptoms

When minerals are deficient, the growth of the plant is stunted, or the plant shows other symptoms. The combination of symptoms observed for deficiency of a particular mineral can be traced to the roles that mineral plays in metabolism or physiology.

1. **Stunted growth** is a symptom for many deficiencies, especially stunted stems with nitrogen deficiency and stunted roots in phosphorus deficiency.
2. **Chlorosis** decreased chlorophyll synthesis or increased chlorophyll degradation, is observed with magnesium, nitrogen, and iron deficiencies. Magnesium is the central atom for the electron cloud of chlorophyll from which electrons flow through the light reactions.
3. **Necrosis**, dead spots or zones, is observed when magnesium, potassium or manganese deficiencies are present.
4. Colour changes such as excessive **anthocyanin production** are observed in stems with phosphorus deficiency. They generally pick up an intense purple Colour sometimes extending onto the leaves.

3.2.1 Mineral Availability Shows an Interesting Dose Effect:

The following graph demonstrates how deficiency reduces growth. As the mineral availability is increased, growth increases. As the mineral content continues to be increased there is no further increase in growth, but quality may be continuing to increase. This zone is called the luxury zone. However, continuing to increase the mineral concentration ultimately reaches toxic levels and growth is diminished.

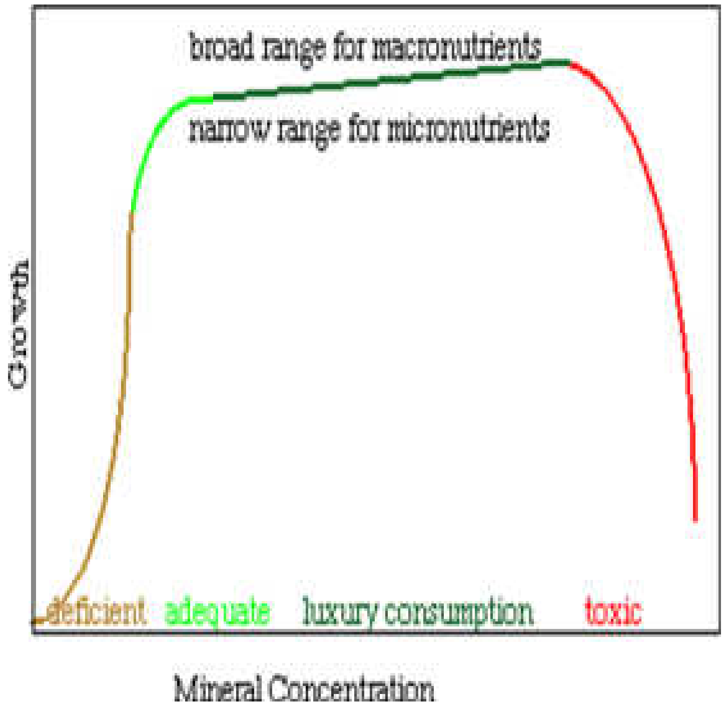


Fig. 16: Graph Showing Defiency Reduces Growth

The goal of a plant grower is to keep the plant in the sufficient to luxury zone but never to get as low as deficiency or as high as toxicity for any one of the macronutrients or micronutrients. The trouble with that goal knows how wide the luxury zone is in terms of concentrations. For minerals like boron, the zone is very narrow, and it is easy to achieve toxic levels or to be in deficiency. For minerals like phosphorus, the luxury zone is quite broad and large amounts can be given and the plants will respond nicely in spite of that. As a result, it is difficult to overdose plants on phosphorus.

3.2.2 Specific Roles of Essential Mineral Elements

A. The macronutrients

1. Nitrogen specific role

- Nitrogen is important constituent of proteins, nucleic acids, porphyries (chlorophylls & cytochromes) alkaloids, some vitamins, coenzymes etc. Thus, N plays very important role in metabolism, growth, reproduction and heredity. Deficiency symptoms
- Plant growth is stunted because protein content cell division and cell enlargement are decreased
- N deficiency causes chlorosis of the leave i.e., yellowing older leaves are affected first
- In many plants e.g., tomato, the stem, petiole and the leaf veins

become purple colored due to the formation of anthocyanin pigments.

2. Phosphorus

- It is important constituent of nucleic acids, phospholipids, coenzymes NADP, NADPH2 and ATP
- Phospholipids along with proteins may be important constituents of cell membranes
- P plays important role in protein synthesis through nucleic acids and ATP
- Through coenzymes NAD, NADP and ATP, it plays important role in energy transfer reactions of cell metabolism e.g., photosynthesis, respiration and fat metabolism etc.

Deficiency symptoms

- P deficiency may cause premature leaf fall
- Dead necrotic areas are developed on leave or fruits
- Leaves may turn to dark green to blue green Colour. Sometimes turn to purplish Colour due to the synthesis and accumulation of anthocyanin pigments.

3. Potassium Specific role:

- Although potassium is not a constituent of important organic compound in the cell, it is essential for the process of respiration and photosynthesis
- It acts as an activator of many enzymes involved in carbohydrate metabolism and protein synthesis
- It regulates stomata movement
- Regulates water balance Deficiency symptoms
- Mottled chlorosis of leaves occurs
- Neurotic areas develop at the tip and margins of the leaf
- Plants growth remains stunted with shortening of internodes.

4. Calcium

- It is important constituent of cell wall
- It is essential in the formation of cell membranes
- It helps to stabilise the structure of chromosome
- It may be an activation of may enzymes deficiency symptoms
- Calcium deficiency causes disintegration of growing meristematic regions of root, stem and leaves
- Chlorosis occurs along the margins of the younger leaves
- Malformation of young leaves takes place

5. Magnesium

- It is very important constituent of chlorophylls
- It acts as activation of many enzymes in nucleic acid synthesis and carbohydrate metabolism
- It plays important role in binding ribosomal particles during protein synthesis. Deficiency symptoms
- Mg deficiency causes mottled chlorosis with veins green and leaf tissues yellow or white appearing first on older leaves
- Dead neurotic patches appear on the leaves
- In cotton Mg deficiency leads o reddening of leaves and disorder is called as reddening in cotton.

6. Sulphur specific role

- It is important constituent of some amino acids (cystine, cysteine and methionine) with which other amino acids form the protein
- S helps to stabilise the protein structure
- It is also important constituent of vitamin i.e., biotin, thiamine and coenzyme A
- Sulfhydryl groups are necessary for the activity of many enzymes. Deficiency symptoms
- Deficiency causes chlorosis of the leaves
- Tips and margins of the leaf roll in ward
- Stem becomes hard due to the development of sclerenchyma.

B. Micronutrients:

1. Iron specific role:

- Important constituent of iron porphyrin proteins like cytochromes, peroxidases, catalases, etc.
- It is essential for chlorophyll synthesis
- It is very important constituent of ferredoxin which plays important role in photochemical reaction in photosynthesis and in biological nitrogen fixation.

Deficiency symptoms

Iron deficiency causes chlorosis of young leaves which is usually interveinal.

2. Zinc specific role:

- It is involved in the biosynthesis of growth hormone auxin (indole 3 acetic acid)
- It acts activator of many enzymes like carbonic anhydrase and alcohol dehydrogenase, etc.

Deficiency symptoms

- Zinc deficiency causes chlorosis of the young leaves which starts from tips and the margins
- The size of the young leaves is very much reduced. This disorder is called as 'little leaf disease'
- Stalks will be very short.

3. Manganese

- It is an activator of many respiratory enzymes
- It is also an activator of the enzyme nitrite reductase
- It is necessary for the evolution of oxygen (photolysis) during photosynthesis Deficiency symptoms
- The young leaves are affected by mottled chlorosis
- Veins remain green
- Small necrotic spots developed on the leaves with yellow strips

4. Copper specific role

- It is an important constituent of plastocyanin (copper containing protein)
- It is also a constituent of several oxidizing enzymes. Deficiency symptoms
- Copper deficiency causes necrosis of the tip of the young leaves
- It also causes die-back of citrus and fruit trees
- Also causes reclamation disease or white tip disease of cereals and leguminous plants.

5. Boron specific role

- Boron facilitates the translocation of sugars by forming sugar borate complex.
- It involves in cell differentiation and development since boron is essential for DNA synthesis
- Also involves in fertilization, hormone metabolism

Deficiency symptoms

- Boron deficiency causes death of shoot tip
- Flower formation is suppressed
- Root growth is stunted
- The other diseases caused by B deficiency is Heart rot of beet, Stem crack of celery, Brown heart of cabbage, Water core of turnip, Internal cork formation in apple, Hen and chicken in grapes.

6. Molybdeneum

- It is constituent of the enzyme nitrate reductase and thus plays an important role in nitrogen metabolism
- It is essential for flower formation and fruit set.

Deficiency symptoms

- Molybdenum deficiency causes interveinal chlorosis of older leaves
- Flower formation is inhibited
- Causes whiptail disease in cauliflower plants.

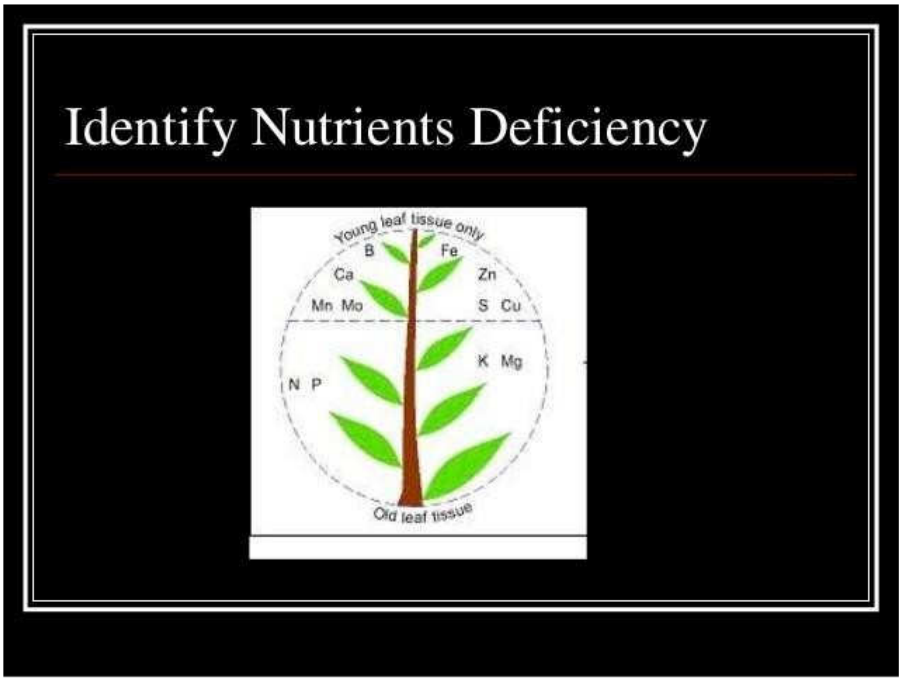
7. Chlorine:

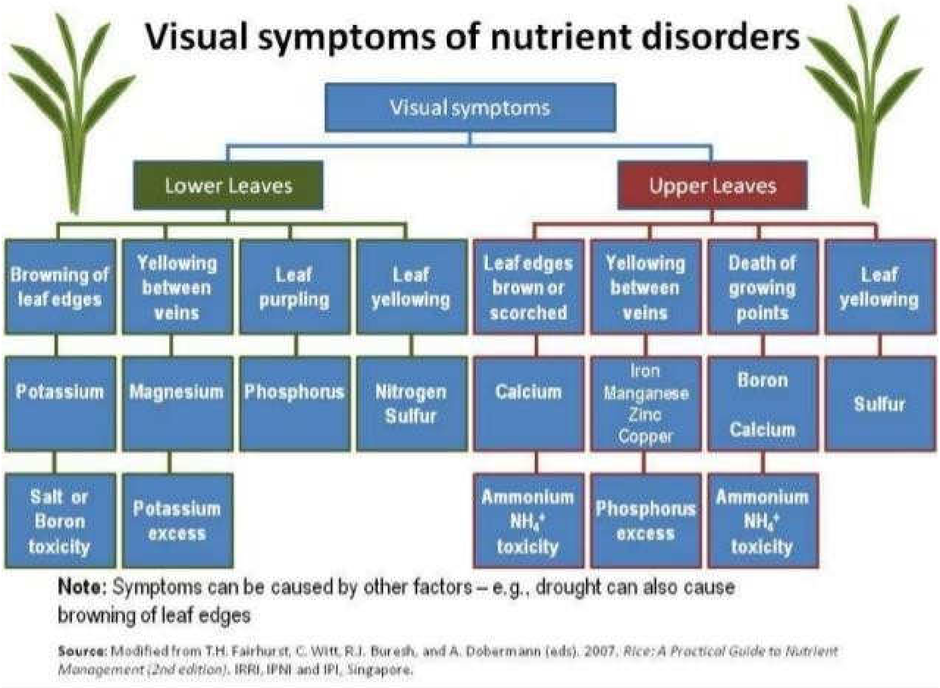
Specific role

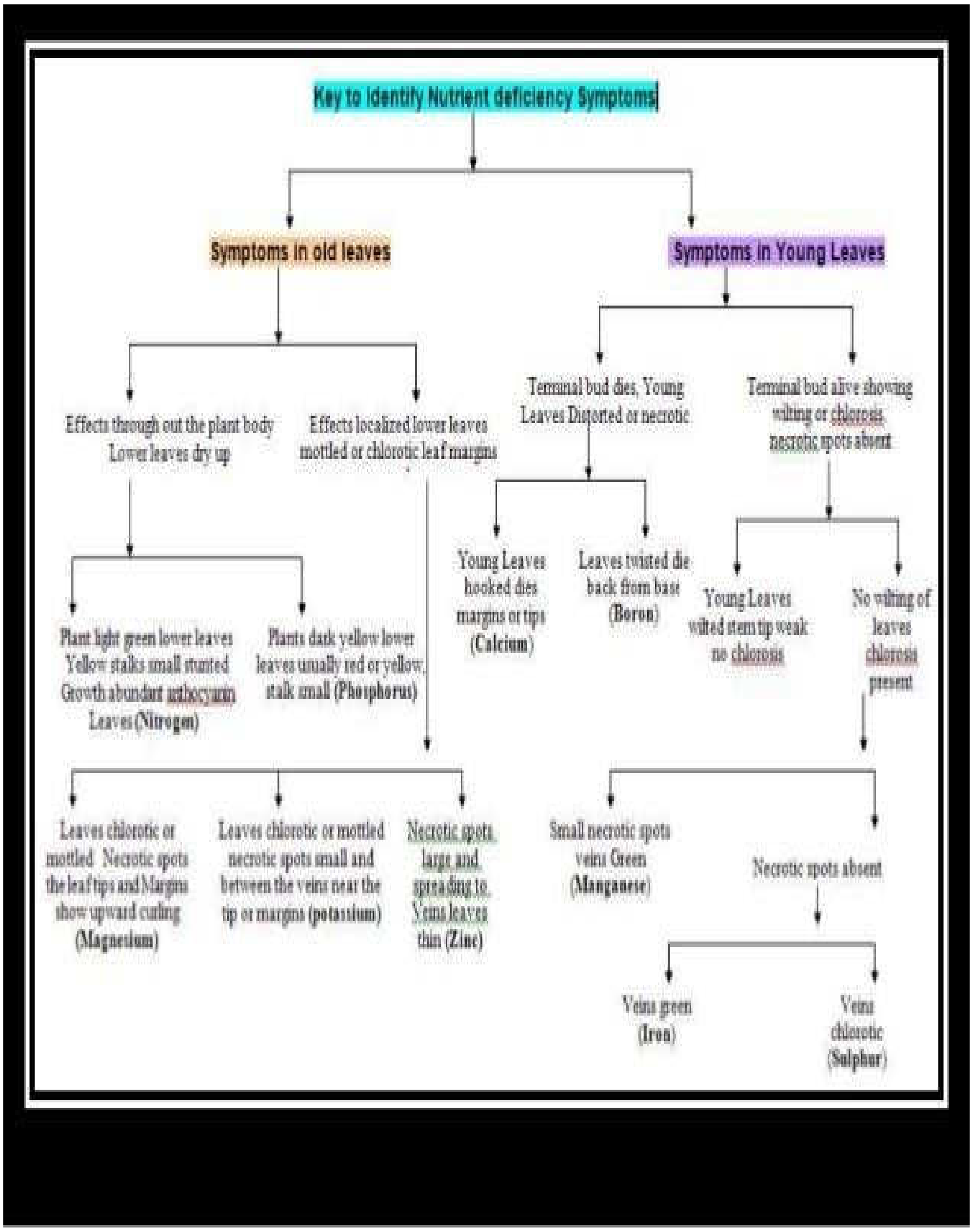
- Chlorine has been shown to be involved in the oxygen evolution in photosystem II in photosynthesis (Cl and Mn are important for this reaction)
- It raises the cell osmotic pressure
- Chlorine accelerates the activation of amylase which converts starch into soluble sugars

Deficiency symptoms

- Chlorosis of younger leaves and an overall wilting of the plant
- In some plant species, like tomato, leaves show chlorotic mottling, bronzing and tissue necrosis


Identify Nutrients Deficiency
Young leaf tissue only
B
Fe
Ca
Zn
Mn Mo
S Cu
K Mg
N P
Old leaf tissue


Visual symptoms of nutrient disorders
Visual symptoms
Lower Leaves
Upper Leaves
Browning of leaf edges
Yellowing between veins
Leaf purpling
Leaf yellowing
Leaf edges brown or scorched
Yellowing between veins
Death of growing points
Leaf yellowing
Potassium
Magnesium
Phosphorus
Nitrogen Sulfur
Calcium
Iron Manganese Zinc Copper
Boron Calcium
Sulfur
Salt or Boron toxicity
Potassium excess
Ammonium NH4+ toxicity
Phosphorus excess
Ammonium NH4+ toxicity
Note: Symptoms can be caused by other factors – e.g., drought can also cause browning of leaf edges
Source: Modified from T.H. Fairhurst, C. Witt, R.J. Buresh, and A. Dobermann (eds). 2007. Rice: A Practical Guide to Nutrient Management (2nd edition). IRRI, IPNI and IPI, Singapore.


Key to identify Nutrient deficiency Symptoms
Symptoms in old leaves
Symptoms in Young Leaves
Effects through out the plant body Lower leaves dry up
Effects localized lower leaves mottled or chlorotic leaf margins
Terminal bud dies, Young Leaves Distorted or necrotic
Terminal bud alive showing wilting or chlorosis necrotic spots absent
Young Leaves hooked dies margins or tips (Calcium)
Leaves twisted die back from base (Boron)
Young Leaves wilted stem tip weak no chlorosis
No wilting of leaves chlorosis present
Plant light green lower leaves Yellow stalks small stunted Growth abundant anthocyanin Leaves (Nitrogen)
Plants dark yellow lower leaves usually red or yellow, stalk small (Phosphorus)
Leaves chlorotic or mottled Necrotic spots the leaf tips and Margins show upward curling (Magnesium)
Leaves chlorotic or mottled necrotic spots small and between the veins near the tip or margins (potassium)
Necrotic spots large and spreading to Veins leaves thin (Zinc)
Small necrotic spots veins Green (Manganese)
Necrotic spots absent
Veins green (Iron)
Veins chlorotic (Sulphur)

DEFICIENCIES OF NUTRIENT ELEMENTS											
Symptoms	Suspected Element										
	N	P	K	Mg	Fe	Cu	Zn	B	Mo	Mn	OF
Yellowing of Younger Leaves					✓					✓	
Yellowing of Middle Leaves									✓		
Yellowing of Older Leaves	✓		✓	✓			✓				
Yellowing Between Veins				✓						✓	
Old Leaves Drop	✓										
Leaves Curl Over				✓							
Leaves Curl Under			✓			✓					✓
Younger Leaf Tips Burn								✓			
Older Leaf Tips Burn	✓						✓				
Young Leaves Wrinkle/Curl			✓				✓	✓	✓		
Necrosis			✓	✓	✓		✓			✓	
Leaf Growth Stunted	✓	✓									
Dark Green/Purple Leaf & Stems		✓									
Pale Green Leaf Color	✓								✓		
Molting							✓				
Spindly	✓										
Soft Stems	✓		✓								
Hard/Brittle Stems		✓	✓								
Growing Tips Die			✓					✓			
Stunted Root Growth		✓									
Wilting						✓					

3.3 Physiology of Nutrient Uptake

Mineral nutrients are found either as soluble fractions of soil solution or as adsorbed ions on the surface of colloidal particles. Various theories proposed to explain the mechanism of mineral salt absorption can be placed in two broad categories:

- Passive Absorption
- Active Absorption

Ion uptake is both active and passive:

After several decades of research on this process of ion uptake it is now believed that the process involves both passive and active uptake mechanisms.

Whether a molecule or ion is transported actively or passively across a membrane (casparian band, plasma membrane or tonoplast) depends on the concentration and charge of the ion or molecule, which in combination represent the electrochemical driving force.

Passive transport across the plasma membrane occurs along with the electrochemical potential. In this process ions and molecules diffuse from areas of high to low concentrations. It does not require the plant to expend energy.

Active transport, (in contrast, to passive transport) energy is required for ions diffusion against the concentration gradient (electro chemical potential). Thus, active transport requires the cell to expend energy.

3.3.1 Passive Transport Mechanism

A) Diffusion: Simple diffusion to membranes occurs with small, non-polar molecules (i.e., O_2, CO_2). In this process ions or molecules move from the place of higher concentration to lower concentration. It needs no energy.

B) Facilitated diffusion: For small polar species (i.e., H_2O, Ions and amino acids) specific proteins in the membrane facilitate the diffusion down the electrochemical gradient. This mechanism is referred to as facilitated diffusion.

a) Channel proteins: The specific proteins in the membrane form channels (channel proteins), which can open and close, and through which ions or H_2O molecules pass in single file at very rapid rates. A K^+ and NH_4^+ channel also operates by the same process of facilitated diffusion. In addition, Na^+ can also enter the cell by this process.

b) Transporters or Co-transporters or carriers: Another mechanism involves transporters or co-transporters responsible for the transport of ions and molecules across membranes. Transporter proteins, in contrast to channel proteins, bind only one or a few substrate molecules at a time. After binding a molecule or ion, the transporter undergoes a structural change specific to a specific ion or molecule. As a result, the transport rate across a membrane is slower than that associated with channel proteins.

Three types of transporters have been identified:

1. Uniporters: transport one molecule (i.e., glucose, amino acids) at a time down a concentration gradient.

2. Antiproters: catalyze movement of one type of ion or molecule against its concentration gradient. This is coupled with the movement of a different ion or molecule in the opposite direction. Examples of antiporter transport are H^{+}/Na^{+} and H^{+} $/Ca^{+2}$ transport into the vacuole.

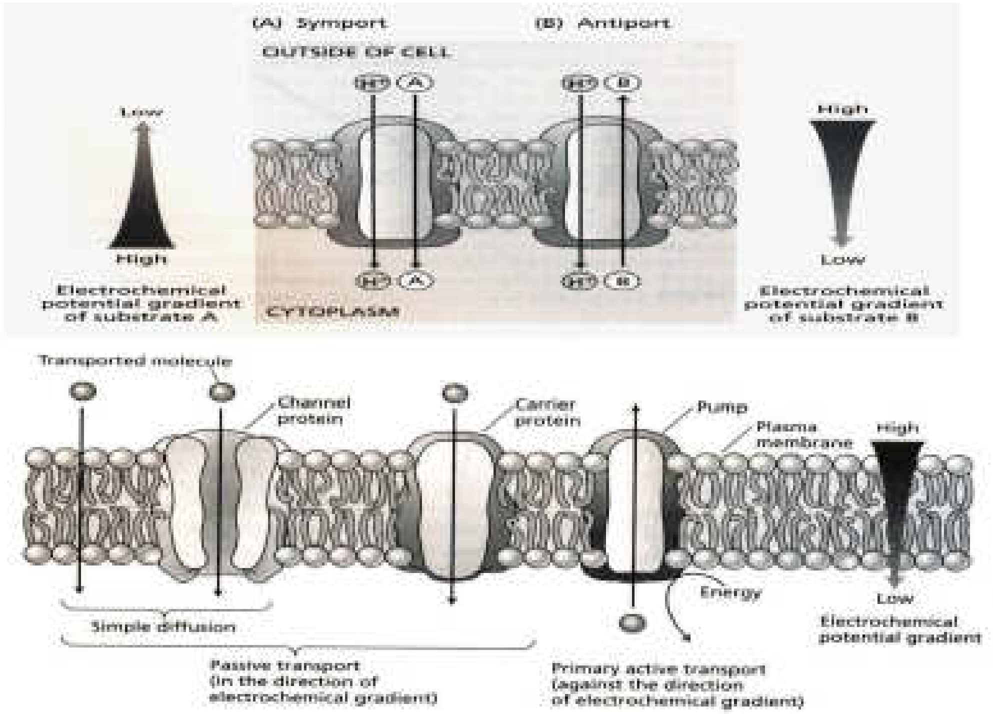
3. Symporters: catalyze movement of one type of ion or molecule against its concentration gradient coupled to movement of a different ion or molecule down its concentration gradient in the same direction. The high H^{+} concentration in the apoplast provides the energy for symporter transport of NO^{-} and the other anions.

Therefore, the energy for antiporter and symporter transport originates from the electric potential and/or chemical gradient of a secondary ion or molecule, which is often H^{+}.

3.3.2 Active Transport Mechanism:

Larger or more-charged molecules have great difficulty in moving across a membrane, requiring active transport mechanisms (i.e., sugars, amino acids, DNA, ATP, ions, phosphate, proteins, etc.). Active transport across a selectively permeable membrane occurs through ATP-powered pumps that transport ions against their concentration gradients. This mechanism utilises energy released by hydrolysis of ATP. The Na^{+}-K^{+} ATP pump transports K^{+} into the cell and Na^{+} out of the cell, another example is the Ca^{+2} -ATP pump.

Thus, it can be understood from the above discussion that the ion transport mechanisms operate both actively and passively. For some of the ions the uptake mechanism is active and for some others it is passive.



oln Taiz and Eduardo Zeiger 2006, Plant Physiology, Sinauer Associates, Inc. Publishers, Sunderland, Massachusetts.

SELF-ASSESSTMENT EXERCISE (SAE)

Explain the Meaning of Mineral nutrition
Outline the classification of essential elements into two groups
Discuss the Criteria of essentiality of Mineral Elements
Classification of plant nutrients based on their biochemical role and physiological function
Briefly discuss the Mineral availability shows an interesting dose effect
List the Specific roles of essential mineral elements
Explain the Physiology of Nutrient Uptake

4.0 CONCLUSION

Mineral nutrients are elements acquired primarily in the form of inorganic ions from the soil. Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the root systems of plants, so in a sense plants act as the "miners" of Earth's crust. The large surface area of roots and their ability to absorb inorganic ions at low concentrations from the soil solution make mineral absorption by plants a very effective process. After being absorbed by the roots, the mineral elements are translocated to the various parts of the plant, where they are utilised in numerous biological functions. Other organisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, often participate with mots in the acquisition of nutrients.

5.0 SUMMARY

The Meaning of Mineral nutrition and the criteria of essentiality of mineral elements classification of plant nutrients based on their biochemical role were discussed. Explain further was the physiological function mineral availability shows an interesting dose effect with specific roles of essential mineral elements and Physiology of Nutrient Uptake

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the Meaning of Mineral nutrition
2. Outline the classification of essential elements into two groups
3. Discuss the Criteria of essentiality of Mineral Elements Classification of plant nutrients based on their biochemical role and physiological function
4. Briefly discuss the Mineral availability shows an interesting dose effect
5. List the Specific roles of essential mineral elements
6. Explain the Physiology of Nutrient Uptake

7.0 REFERENCES/FURTHER READING

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MODULE 5 PHOTOSYNTHESIS: LIGHT AND DARK REACTIONS, C3, C4 AND CAM PLANTS

UNIT 1 MEANING AND CONCEPT OF PHOTOSYNTHESIS

CONTENTS

1.0 INTRODUCTION

Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that, through cellular respiration, can later be released to fuel the organism's metabolic activities. This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesised from carbon dioxide and water – hence the name photosynthesis, from the Greek phōs (φῶς), "light", and sun thesis (σύνθεσις), "putting together". In most cases, oxygen is also released as a waste product. Most plants, algae, and cyanobacteria perform photosynthesis; such organisms are called photoautotrophs. Photosynthesis is largely responsible for producing and maintaining the oxygen content of the Earth's atmosphere, and supplies most of the energy necessary for life on Earth.
Although photosynthesis is performed differently by different species, the process always begins when energy from light is absorbed by proteins called reaction centres that contain green chlorophyll pigments. In plants, these proteins are held

inside organelles called chloroplasts, which are most abundant in leaf cells, while in bacteria they are embedded in the plasma membrane. In these light-dependent reactions, some energy is used to strip electrons from suitable substances, such as water, producing oxygen gas. The hydrogen freed by the splitting of water is used in the creation of two further compounds that serve as short-term stores of energy, enabling its transfer to drive other reactions: these compounds are reduced nicotinamide adenine dinucleotide phosphate (NADPH) and adenosine triphosphate (ATP), the "energy currency" of cells.

2.0 OBJECTIVES

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

- Explain the Meaning and Definition of Photosynthesis
- Discuss the Definition of Absorption and Action Spectrum
- Give Meaning of Photochemical Reaction
- Explain the Concept of Emission of Radiant Energy in Photosynthesis
- Outline the Concept of Cyclic photophosphorylation

3.0 MAIN CONTENT

3.1 Meaning and Definition of Photosynthesis

Photosynthesis is the absorption of light energy and its conversion into chemical energy. During photosynthesis, CO2 and water transformed into simple carbohydrates and O2 is liberated into the atmosphere.

- The simple CH2O3 produced during photosynthesis are converted by additional metabolic process, into lipids, nucleic acids, proteins and other organic molecules.
- These organic molecules in turn, are elaborated into leaves, stems,
- roots, tubers, fruits, seeds and other tissues and organ system.
- Thus, the overall reaction of oxygenic photosynthesis can be represented as.

LIGHT
CHLORO
PHYLL

$$6CO_2 + 12\,H_2O \longrightarrow C_6H_{12}O_6 + 6\,H_2O + 6\,O_2\uparrow$$

This equation is frequently represented by the

$\longrightarrow$

simplified form:
CO_2 +2 H_2O (CH_2O) + H_2O + O_2

The photosynthetic process is carried out by three steps:

i. The absorption of light and retention of light energy.
ii. The conversion of light energy into chemical potential.
iii. The stabilization and storage of chemical potential.

Based on the three steps, the yield of a crop can be expressed by an equation Y = Q x I x E x H Q = Quantity of solar radiation received by the leaf or striking the leaf. I = Fraction of Q utilised by plants.

E = Overall photosynthetic efficiency of the canopy (i.e., efficiency of the conversion of solar energy to chemical energy) in terms of total dry matter produced by the plants.

H = Fraction of dry matter allocated to the harvested parts (Harvest index).

3.1.2 Light Phase of Photosynthesis

The absorption of radiant energy of green leaves is due to the presence of several pigments:

1. Chlorophyll a 2. Chlorophyll b 3. Carotenoids

Chlorophyll a and b account for the absorption of red light (600-700nm) and blue light (400 to 500 nm). The carotenoids also absorb in the blue region of the spectrum. In the absence of light chlorophyll 'a' synthesis is impaired. That is why plants grown in dark are usually lack chlorophyll 'a'. So, they are usually yellow in Colour and possess elongated growth habit. Their leaf development is strongly reduced. Plants displaying the characters are said to be etiolated plant. So a brief exposure of radiant energy of appropriate wavelength is sufficient to induce the formation of chlro 'a' in etiolated plants.

Photosynthesis is one of the most thoroughly studied photo-physiological reactions. Chlorophyll pigments absorb lights energy. But they chiefly absorb in the blue and red part of the spectrum. Apart from chlorophyll several leaf pigments participate in the absorption of radiant energy used in photosynthesis. But chlorophyll 'an' only participate directly in the conversion of light energy into chemical energy. Whereas the other pigments (accessory pigments) transfer their excitation energy to chlorophyll 'a'. The transfer of excitation energy between the pigments occurs by the process known as inductive resonance. This can be illustrated by an example. Consider two pigments A and B. A + radiant energy = A*

A pigment with the absorption of radiant energy is converted to an excited state. Where this excitation energy is transferred to another pigment B, then B gets excited. This is called inductive resonance. Inductive resonance normally occurs from accessory pigments to chlorophyll 'a' but not from chlorophyll 'a' to accessory pigments.

3.2 Definition of Absorption and Action Spectrum

Action Spectra: An action spectrum is the rate of a physiological activity plotted against wavelength of light.
Absorption Spectra: An absorption spectrum is a spectrum of radiant energy whose intensity at each wavelength is a measure of the amount of energy at that wavelength that has passed through a selectively absorbing substance e.

The absorption of radiation by a substance can be quantified with an instrument called a spectrophotometer. This is a device that produces a beam of monochromatic ("single-color") radiation that can be shifted progressively across the spectrum; passes the beam through a solution of the substance and measures the radiation that gets through.

The relationship between the action spectrum for photosynthesis and absorption of light by chlorophylls and other pigments (carotenoids) indicates that the pigments are involved in photosynthesis.

3.3 Meaning of Photochemical Reaction

In a photochemical event, only one above or one molecule is activated for each photon absorbed. Therefore, the number of excited molecules equals the number of photons absorbed. While observing the structure of a pigment molecule, nucleus possesses the protons and neutrons. Whereas electrons are seen at various distances away from the nucleus, the electrons have different energies, depending on the distance from the nucleus. Nearer the electron to the nucleus, greater is the pull or attraction of the nucleus on electrons. If a photon of appropriate energy strikes the pigment, the electron in an inner shell is raised to an outer shell and the pigment is said to be in an excited state. The excited molecule will participate in the chemical reaction (chlorophyll ‘a’) or it may transfer the excitation energy (accessory pigment) to the neighboring pigments molecule by resonance transfer. Otherwise, the excited molecule may return to the ground state by two processes.

1. By emitting the radiant energy (Emission of radiant energy) or
2. By dissipating the heat (Heat dissipation).

3.4 Concept of Emission of Radiant Energy in Photosynthesis

Chlorophyll molecules are capable of absorbing both red light and blue light. Red light is lesser energetic than blue light. Following the absorption of red light (660 nm), chlorophyll molecule attains the excited level called the first excited level. The lifetime of the excited molecule is quite short, often of the order of 10^{-10} to 10^{-8} s. When the energy is transferred to another pigment, excited chlorophyll returns to the ground state through the loss of energy by the emission of light. The emission of light within this short period of time ($10-^{10}$ to 10^{-8}S) is referred to as fluorescence. The red light at the wavelength of 700 nm has raised the electron to the first excited level, whereas more energetic blue light of shorter wavelength (400 nm) raised the electron to the second excited level. The life time of this excited molecule is long i.e., 10^{-2} to 10^{-1} seconds. Such long lived excited molecules have much greater probability of interacting with neighbouring molecules and participating in photochemical reaction or the energy of the long-lived molecule is emitted as light. This process is referred to as 'Phosphorescence'. The major difference between fluorescence and phosphorescence is that fluorescence occurs rapidly whereas the light emission by phosphorous is delayed. The excited chlorophyll molecule is involved in the transformation of radiant energy to chemical energy. As the result of the transformation of radiant energy, the chemical potentials such as ATP and NADPH are found besides releasing O_2.

ATP formation

Regarding ATP formation, it is generated during

1.) The oxidation of glucose to CO_2 and H_2O in mitochondria. This process is known as oxidative phosphorylation
2.) The formation of ATP by the absorption of radiant energy by the chlorophyll pigments is known as photophosphorylation.

ADP + inorganic phosphate (pi) $\longrightarrow$ Radiant energy ATP

Chloroplast

NADPH formation:

NADPH is formed by accepting electrons from water molecules and releasing O_2. $4H_2O$ Radiant Energy $O_2 + 4 (H^+ + e^-) + 2H_2O$ (Photolysis of water)

$4H_2O + 2\ NADP \xrightarrow{\text{Chloroplast}} 2NADPH + O_2 + 2H^+ + 2H_2O$

Therefore, the illuminated chloroplasts are capable of generating both ATP and NADPH through the following reaction.

RE

$2\ ADP + 4\ H_2O + 2Pi + 2NADP \longrightarrow 2\ ATP + 2NADPH + 2H_2O + O_2 + 2H$

Chloroplast

3.4.1 Reaction Scheme for ATP and NADPH Formation

Two pigment systems are involved:

1. Photo system I (PS I) (Photo system I contains chlorophyll 'a', 'b' and carotenes)
2. Photo system II (PS II) (Photo system II contains chlorophyll 'a', 'b' and xanthophylls) The two photo systems are connected by several intermediates:

1. Plastoquinone
2. Cytochrome
3. Plastocyanin

Non-cyclic electron transport and phosphorylation:

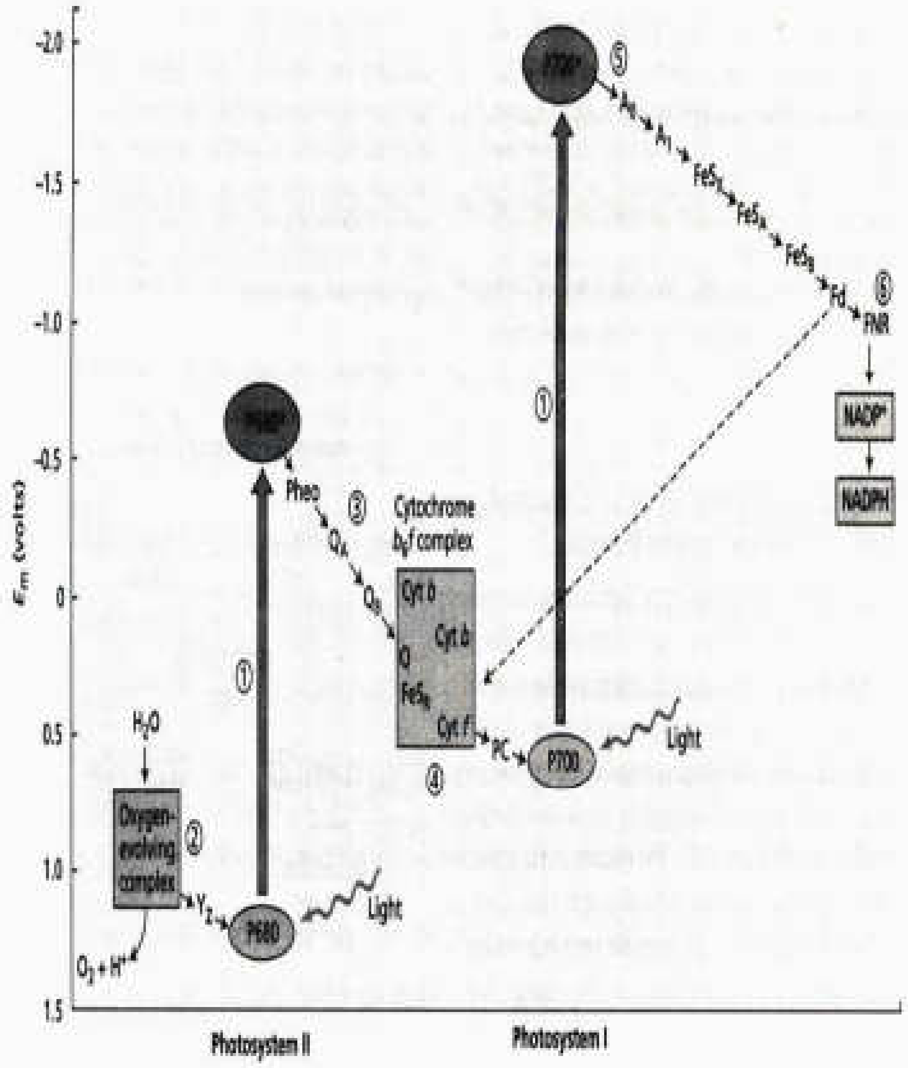


FIGURE Detailed Z scheme for O_2-evolving photosynthetic organisms. The redox carriers are placed at their midpoint redox potentials (at pH 7). (1) The vertical arrows represent photon absorption by the reaction center chlorophylls: P680 for photosystem II (PSII) and P700 for photosystem I (PSI). The excited PSII reaction center chlorophyll, P680*, transfers an electron to pheophytin (Pheo). (2) On the oxidizing side of PSII (to the left of the arrow joining P680 with P680*), P680 oxidized by light is re-reduced by Y_Z, that has received electrons from oxidation of water. (3) On the reducing side of PSII (to the right of the arrow joining P680 with P680*), pheophytin transfers electrons to the acceptors Q_A and Q_B, which are plastoquinones. (4) The cytochrome b_6f complex transfers electrons to plastocyanin (PC), a soluble protein, which in turn reduces $P700^+$ (oxidized P700). (5) The acceptor of electrons from P700* (A_0) is thought to be a chlorophyll, and the next acceptor (A_1) is a quinone. A series of membrane-bound iron–sulfur proteins (FeS_X, FeS_A, and FeS_B) transfers electrons to soluble ferredoxin (Fd). (6) The soluble flavoprotein ferredoxin–NADP reductase (FNR) reduces $NADP^+$ to NADPH, which is used in the Calvin cycle to reduce CO_2 (see Chapter 8). The dashed line indicates cyclic electron flow around PSI. (After Blankenship and Prince 1985.)

*

In 1960, Hill and Bendall proposed this scheme hill and Bendall scheme (Z scheme). This is the light requiring process in which electrons are removed from H_2O resulting in the evolution of O_2 as a byproduct and transfer of these electrons via a number of carriers to produce a strong, negative reducing potential with the subsequent formation of $NADPH_2$, a reducing agent with the potential of -0.34 V. Two ATP molecules can be simultaneously formed from two ADP and two pi, so that energy is stored in the form of this high energy compounds. The $NADPH_2$ and ATP are the 'assimilatory powers' required to reduce CO_2 to CH_2O.

The components of non-cyclic electron transport pathway are organized into three components that span the chloroplast membranes. These components are PS II complex, chlorophyll 'b' complex and PSI complex. Plastoquinone, plastocyanin and ferredoxin are the mobile carriers that shuttle electrons across the complexes. An electron is transferred from H_2O to NADP in almost 20 ms. Two different light reactions each occurring in different photosystem are required to raise the electrons from redox level of H_2O (+ 0.82V) to the redox level of $NADPH_2$ (-0.34V). Photosystem I have a predominance of chlorophyll 'a' with an absorption maximum at 680 nm (bluish green in Colour), whereas PS II the closely related chlorophyll 'b' which has its maximum absorption peak at 650 nm (Yellowish green in Colour).

3.5 Concept of Cyclic Photophosphorylation

The cyclic photophosphorylation operates when chloroplasts are illuminated with wave lengths of light greater than 680nm. Under these circumstances only photo system I is activated and electrons are not removed from H_2O. When the flow of electrons from H_2O is stopped, non-cyclic assimilation retarded, oxidized NADP is no longer available as an electron acceptor. Activation of photo system I by wave lengths of light greater than 680 nm causes electron to flow from P700 to chlorophyll molecule and Ferredoxin. Then the electrons instead of passing on to NADP return back to P700 via cyt b6-f complex, plastoquinone and plastocyanin.

Cyclic transport system is likely to result in the synthesis of ATP at two locations. One is between Fe-s protein and cyt-b6 complex and another between cyt-b6 and cytochrome f.

Significance

Evidence for the operation of cyclic electron transport in C3 plants *in vivo* is limited but it has been demonstrated under physiological conditions *in vivo* in C4 plants where there is an additional ATP requirement in their carbon fixation pathway. It may also play an important role in the synthesis of ATP required for protein synthesis during PS II repair, following photo inhibition.

Pseudo cyclic phosphorylation

Another source of generation of ATP is that electrons might be transferred from ferredoxin back to oxygen reducing it to water. It is possible that this process might also involve an electron transport chain and produce ATP. Here the electron that is cycled back to reduce molecular oxygen to water is not the same that is released from the water. Hence it is called as pseudo cyclic phosphorylation.

3.5.1 The Meaning of Dark Reaction (CO_2 fixation):

All photosynthetic eukaryotes, from most primitive algae to the most advanced angiosperms, reduce CO_2 to carbohydrates via the basic mechanism, the C3 photosynthetic carbon reduction (PCR) cycle. The PCR cycle is sometimes referred to as Calvin cycle in honour of its discovered, the American biochemist, Melvin Calvin.

In PCR cycle, CO_2 from atmosphere and water are enzymatically combined with a five-carbon acceptor molecule to generate two molecules of a three-carbon intermediate. These intermediates are reduced to carbohydrate using the photo chemically generated ATP and NADPH. The cycle is complete by regeneration of five carbon acceptor.

C3 PCR cycle involves three stages:

1. Carboxylation (Carboxylation of CO_2 acceptor, ribulose 1-5 bisphosphate to form two molecules of three phosphoglycerate, the first stable intermediate of the PCR cycle)
2. Reduction (Reduction on this 3 PGA to a carbohydrate in the form of glyceraldehyde 3 phosphate)
3. Regeneration (Regeneration of the CO_2 acceptor, ribulose, 1-5 bisphosphate from glyceraldehyde’s 3-phosphate)

3.5.2 Carboxylation of Ribulose Bisphosphate:

CO_2 enters the PCR cycle by reacting with ribulose 1,5-bisphosphate to yield two molecules of 3-phosphoglycerate, a reaction that is catalysed by the chloroplast enzyme ribulose bisphosphate carboxylate / oxygenase (Rubisco). Carboxylation of ribulose 1,5-bisphosphate, catalyzed by Rubisco proceeds in two stages: Carboxylation and hydrolysis.

1. Carboxylation involves the addition of CO_2 to carbon 2 (O_2) ribulose 1,5- bisphosphate to form an unstable enzyme bound intermediate 2 carboxy 3 keto arabinitol 1,5- bisphosphate, which undergoes hydrolysis to yield two molecules of stable product, 3-phosphoglycerate. Rubisco, the enzyme responsible for fixing 200 billion tons of CO_2 annually, is without doubt the world's most abundant enzyme. Rubisco accounts for some 40 per cent of the total soluble protein of most leaves. The concentration of Rubisco active sites within the chloroplast stroma is calculated to be about 4mM or about 500 times greater than the cone of one of its substrates CO_2. The molecular mass of Rubisco is 560 KDa. It is composed of eight large subunits each of which has an active site, and eight small subunits.

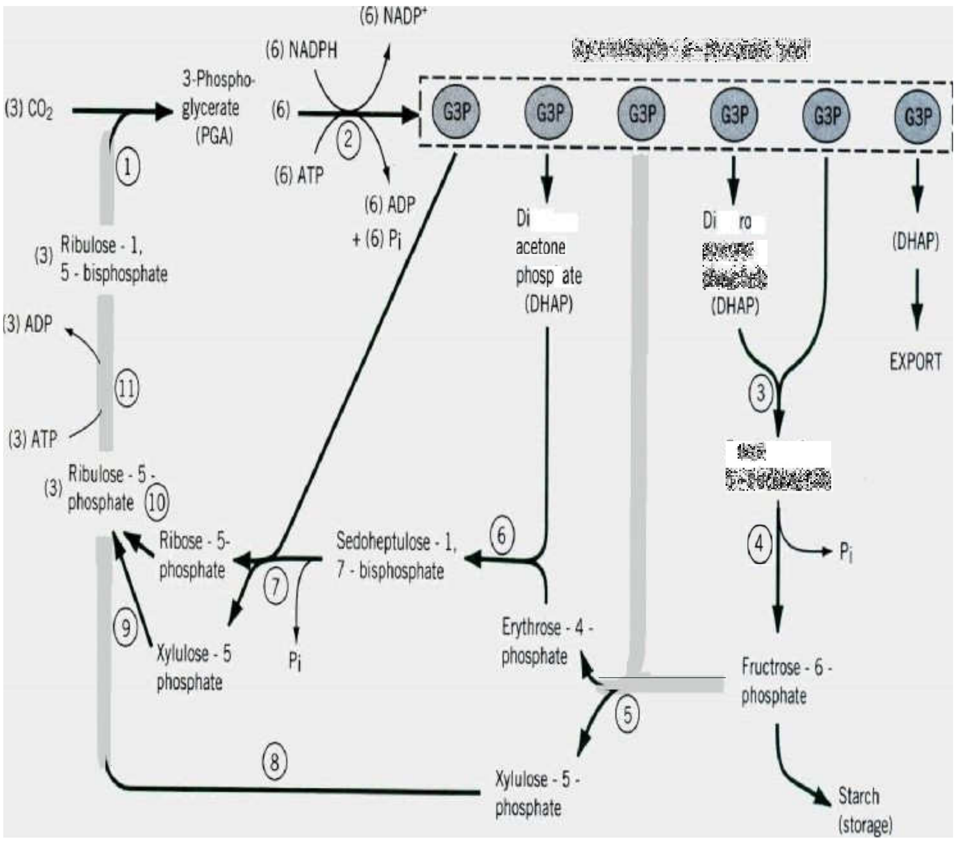
   The gene for the large submit is encoded by the chloroplast genome and this sub unit is synthesised by the chloroplast ribosomes. Gene for the small subunit is synthesised by cytosolic ribosomes, transported into the chloroplast and assembled there with large sub units for L8 S8 Rubisco molecules.

   The Reduction step of the C3 PCR cycle

   In this stage, the 3-phosphoglycerate formed as a result of the carboxylation of ribulose bisphosphate is first phosphorylate to 1-3 diphosphoglycerate by the ATP generated in the light reactions and is then reduced to glyceraldehyde's -3-phosphate, using the NADPH generated by the light reaction. The chloroplast enzyme NADP: glyceraldehyde's 3 phosphate dehydrogenase catalysis this step.

The regeneration of ribulose 1,5- Bisphosphate:

Continued fixation of CO_2 requires that the CO_2 acceptor, ribulose 1,5 bisphosphate, be consultancy regenerated. To avoid depleting the cycle of intermediates, 3 molecules of Ribulose 1-5, bisphosphate are formed by reshuffling the carbon from 5 molecules of triosephosphate. One molecule of glyceraldehyde's 3-phosphate is converted to dihydroxyacetone 3 phosphate. Dihydroxyacetone 3 phosphate then undergoes condensation with a molecule of glyceraldehyde 3 phosphate to give fructose 1,6 bisphosphate. This product is hydrolysed to fructose 6- phosphate. This compound reacts with third molecule of glyceraldehyde's 3-phosphate to give erythrose 4 phosphate and xylulose 5-phosphate. E4P then combines with a fourth molecule of triose phosphate to yield seven carbon sugar sedoheptulose 7 phosphate. This reacts with fifth molecule of glyceraldehyde's 3 phosphate and produces ribose 5-phoshate and xylulose 5 phosphate. The two molecules of xylulose 5-phosphate are epimerized to give ribulose 5- phosphate. Ribose 5phosphate is also isomerized to ribuloses 5 phosphate. Finally, ribulose 5- phosphate is phosphorylated with ATP, thus generating the CO_2 acceptor ribulose 1,5- bisphosphate.



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SELF-ASSESSTMENT EXERCISE (SAE)

1. Explain the meaning and definition of photosynthesis
2. Discuss the definition of absorption and action spectrum
3. Give meaning of photochemical reaction
4. Explain the concept of emission of radiant energy in photosynthesis
5. Outline the concept of cyclic photophosphorylation

4.0 CONCLUSION

Photosynthesis is a process used by plants and other organisms to convert light energy into chemical energy that, through cellular respiration, can later be released to fuel the organism's metabolic activities. This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesised from carbon dioxide and water – hence the name photosynthesis, from the Greek phōs (φῶς), "light", and sun thesis (σύνθεσις), "putting together".

5.0 SUMMARY

The unit showed the meaning and definition of photosynthesis and the definition of absorption and action spectrum. It also explained the meaning of photochemical reaction and the concept of emission of radiant energy in photosynthesis the concept of cyclic photophosphorylation

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the meaning and definition of photosynthesis
2. Discuss the definition of absorption and action spectrum
3. Give meaning of photochemical reaction
4. Eplain the concept of emission of radiant energy in photosynthesis
5. Outline the Concept of Cyclic photophosphorylation

7.0 REFERENCES/FURTHER READING

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MODULE 6 CROP GEOMETRY AND CULTURAL MANIPULATIONS.

UNIT 1 MEANING OF CROP GEOMETRY

CONTENT

INTRODUCTION

Crop geometry refers to the shape of the space available for individual plants. It influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Crop geometry is altered by changing inter and intra-row spacing (Planting pattern).

- Wider spaced crops have advantage under this geometry
- Plants which requires no restriction in all directions are given square geometry
- Usually perennial vegetations like trees/shrubs are under this arrangements

(i) Square planting - Square arrangements of plants will be more efficient in the utilization of light, water and nutrients available to the individual plants than in a rectangular arrangement.

(ii) Rectangular planting - Sowing the crop with seed drill, wider inter-row and closer intra-row and closer intra-row spacing leads to rectangularity. Rectangular arrangement facilitates easy interculti vation. Rectangular planting mainly suits annual crops, crops with closer spacing etc., the wider section (row) is given for irrigation, intercultural operation etc.

- It is an arrangement to restrict the endless growth habit in order to switch over from vegetation to the productive phase.
- This method accommodate high density planting It can facilitate intercropping also.

(iii) Triangular planting - It is a method to accommodate plant density under perennial/tree crops.

(iv) Miscellaneous planting - In rice and ragi transplanting is done either in rows or at random. Skipping of every alternate row is known as skip row planting. When one row is skipped the density is adjusted by decreasing inter-row spacing. When the inter row spacing is reduced between two rows and spacing between two such pair are increased then it is known as pairedrow planting. It is generally done to introduce an inter crop.

2.0 OBJECTIVES

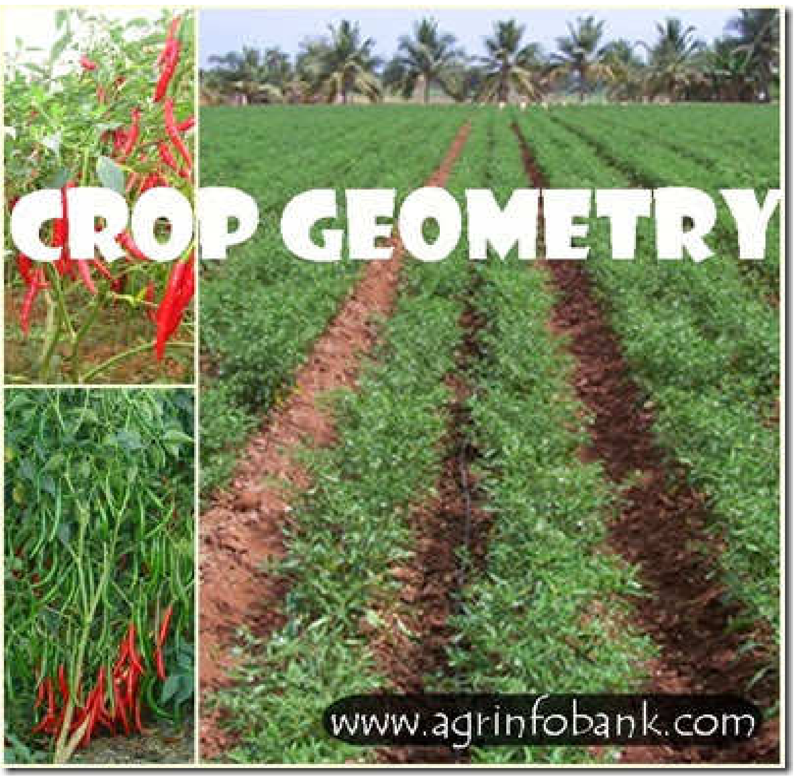
By the end this unit, you should be able to:

- define crop geometry
- mention the types of crop geometry
- explain cultural manipulations
- discuss the importance of cultural manipulations

1.0 MAIN CONTENT

3.1 Meaning and Definition of Crop Geometry

Crop geometry refers to the shape of the space available for individual plants. It influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Crop geometry is altered by changing inter and intra-row spacing (Planting pattern).



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- This method accommodates high density planting
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3.2 Importance and Types of Crop Geometry

The arrangement of the plants in different rows and columns in an area to efficiently utilise the natural resources are called crop geometry. Shape of the space available for individual plants, depends upon the, light interception. Rooting pattern and moisture extraction pattern plant population, crop yield while on other side yield may also reduce due to lesser plant population below optimum due to inability to intercept maximum available light by poor plant stand (Mahajan, 2010).

Planting pattern

Planting pattern influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Different planting patterns are followed to suit different weed control practices and cropping systems. Plant geometry refers to the shape of plant while crop geometry refers to the shape of space available for individual plants. Crop geometry is altered by changing inter and intra-row spacing.

Square planting

It is reasonable to expect that squares arrangement of plants will be more efficient in the utilisation of light, water and nutrients available to the individual’s than in a rectangular arrangement. In wheat, decreasing inter-row spacing below the standard 15-12 cm i.e., reducing rectangularity, generally increases yield slightly. In crops like Tobacco, inter cultivation in both directions is possible in square planting and helps in effective control of weeds. However, square planting is not advantageous in all crops. Groundnut sown with a spacing of 30x10cm (3.33 lakh/ha) gave higher pod yield than with same amount of population in square planting. Pod yield is reduced either by increasing rectangularity or approaching towards square planting.

Rectangular planting

Sowing the crop with seed drill is the standard practice. Wider inter-row spacing and closer intra-row spacing is very common for most of the crops, thus attaining rectangularity. This rectangular arrangement is adopted mainly to facilitate inter cultivation. Sometimes only inter-row spacing is maintained and intra-row spacing is not followed strictly and seeds are sown closely as solid rows.

Miscellaneous planting arrangements

Crops are sown with seed drills in two directions to accommodate more number of plants and mainly to reduce weed population. Crops like rice, finger millet are transplanted at the rate of two to three seedlings per hill. Transplanting is done either in rows or randomly. Skipping of every alternate row is skipped, and the population is adjusted by decreasing intra-row spacing, it is known as paired row planting. It is generally restored to introduce an intercrop.

Plant population and growth

A. High plant density brings out certain modifications in the growth of plants. Plant height increases with increase in plant population due to competition for light.

B. Sometimes it may happen that moderate increase in plant population may not increase but decrease plant height due to competition for water and nutrients but not for light.

C. Leaf orientation is also altered due to population pressure. The leaves are erect narrow and are arranged at longer vertical intervals under high plant densities. This is a desirable architecture.

3.3 Meaning of Cultural Manipulation

By cultural manipulation we will mean, in a broad sense, everything a farmer might do to increase crop yields per hectare, after he decides what to plant and buys the seed. With this restriction we leave out the agricultural economist and the plant breeder. When we limit our interest to yields per hectare, we introduce an element of area. This will include the crop canopy above the surface and the root system below it. Cultural manipulation also includes what the farmer might do to make best use of water, carbon dioxide, nitrogen, and essential mineral nutrients whether they occur naturally or otherwise. We will also include manipulations designed to make the most efficient use of radiant energy during the growing season. Finally, consideration of the length of the growing season introduces the concept of time as one of the objects of cultural manipulation.

Intraspecific Competition

I would like to start by referring to an experiment done in Lexington last summer for the prosaic purpose of evaluating 63 of the corn varieties (Zea Mays L.) most widely used in Kentucky. We will use it as a background to think together about whole plants growing in the field and about how they interact with each other and with their environment. This corn was planted in a design described in Biometrics (1962) by John NeIder, now occupying the position at R~thampstead made famous by R. A. Fisher. In Kentucky we call it a wagon wheel design for reasons that are obvious when you see it. Each wagon wheel contains 21 4-row plots and all varieties are replicated three times, hence nine wheels. The corn is planted in rows corresponding to the spokes of a wheel and the plants are set closer together in the row as we move toward the center of the wheel. Each plant is thus essentially in the center of a trapezoid that diminishes in area as we move toward the center of the wheel. The geometry stays constant, only the dimensions change. The planting rates go from 13,000 plants per hectare at the outside rim to a high of 107,000 plants per hectare at the last harvested radius. A cross section of the planting design is almost a history of corn planting practices. On the outside rim the corn is planted almost like it was 40 years ago when Dr. Kiesselbach was doing such fine pioneering work with corn here at Lincoln and when almost all corn was open pollinated. The population, 13,000 plants per hectare, was close to the average rate used then and the yields are strikingly similar. As we move toward the inside of the wheel we are progressing through 40 years of change in corn cultural practices. Near the center we reach the present and possibly even the future of corn cultural practices and problems. As planting rates change in our wheel so do the yields. The very best varieties yield 5,000 kg/ha on the outside radius and yields increase toward the center to as much as 15,000 kg/ha somewhere between the extremes of population studied. Many feel that the major thrust of research toward higher corn yields should be to push the population higher and higher. As we do so the difficulties to be overcome change in nature. It is well to think of the problems of yield in terms of things that occur in the test tube and under the microscope, but it is in the competitive struggle among plants that any changes must operate and survive. It is for this reason that I want to spend some time talking about what happens to plants growing at various positions within our wheel. As we move from the outside rim of the wheel toward the center, the yield per plant decreases in a very regular manner. Without bothering about a mathematical statement let us just say that if we plot the yield per plant as the ordinate against population per hectare as the abscissa on semilog paper we get a linear regression, a straight line that slopes downward (Duncan, 1958). From such a regression we can calculate the yield per unit of area at any rate of planting. The fact that the regression is linear indicates that there is a plant population at which a maximum yield per hectare would occur and we can of course estimate that maximum grain yield. This is why we plant our variety test in such a bizarre pattern. This is a good way to compare varieties. It lets us compare varieties on the basis of what each is capable of at its optimum population. It raises an interesting question about why the relationship between plant population and yield per plant should behave in such a beautifully mathematical manner, but this is outside the scope for this particular material.

A. Cooperative Interaction

Instead let us first consider the general height relationship. The height of the corn plants increased with increasing plant population to a maximum and then the average height decreased again. This observation is in agreement with a more general statement by Yoda, Kira, and Hozumi (1957) who observed that "When plants are experimentally exposed to shade, there is usually found a certain light intensity at which the plant attains its maximum (height)"-There were relatively large differences in this among the varieties we tested but all increased in height with increase in mutual shading. First appearance of the tassel and anthesis were observed at about the same time in all populations within most varieties so we can infer that the length of time to attainment of maximum height was not much affected by mutual shading. Thus the taller plants must have elongated at a more rapid rate than the shorter ones. This tendency of shaded plants to elongate more rapidly than unshaded ones were first reported by Hozumi, Koyama, and Kira (1955) as a result of their observations with corn. They noted that in closely spaced plants, the shorter plants had a higher elongation rate than the taller ones that were shading them. They gave the name "cooperative interaction" to this phenomenon because by reason of it the shorter plants tended to "catch up" in height with the taller ones. The results of this cooperative interaction were readily observable in the wagon wheels. The plant heights were more uniform at intermediate plant populations than at either the highest or lowest populations, and the difference in uniformity was statistically significant.

B. Competitive Interaction

Kira and his associate, however, noted no such tendency for shorter plants to increase faster in weight. It was quite the opposite. Shaded plants, as one would expect, gain weight more slowly than less shaded ones. With corn the effect of height difference on gain. In dry weight is closely related to plant density. By use of a modification of the computer simulation program mentioned earlier by Dr. R. S. Loomis and using plant descriptions taken from experiments conducted by Williams and Loomis in California, I estimated the effect of difference in height on average daily photosynthesis of corn. A plant 10 cm shorter than those surrounding it would be deficient in the production of dry matter at low populations by about 20 per cent, at high populations by almost 50 per cent. If the difference in height is increased to 30 cm the deficiency in dry matter production would increase to 40 and 80 per cent,
respectively . From this I think we can agree on several general propositions. One is that a corn plant shorter than its neighbours is at a considerable disadvantage. A second is that a difference in rate of

elongation such as Kira described that could reduce the height difference would reduce the penalty imposed by overshadowing. A third obvious conclusion is that the higher the population of plants the more severe the penalty imposed by height difference. As we move to higher planting rates, height differences produce larger effects. Another observation by Kira and his associates that is a corollary of the first is that beyond some degree of shading, that produces a maximum height, further shading must result in shorter plants and hence slower elongation rates. With these relationships in mind let us go back and slowly walk into our wagon wheel starting with our 1928-type plant populations. Here the plants are typically rather short and sturdy with several tillers, or suckers as grandfather called them. The plants are irregular in height and even more in yield of grain. The height irregularity is presumably due to genetic differences and the lack of enough competition to invoke Kira's cooperative interaction to hurry the shorter ones. The plants are irregular in grain yield per plant because some plants have one ear, some two, and some even three or four. In other low population experiments we have observed that the top or first ear is remarkably uniform from plant to plant within a variety. The difference in yield from plant to plant seems to be due to differences among plants in whatever impulse or stimulant or absence of repression is needed to cause a second or third ear to form. Among varieties the higher yielding at these low populations were those capable of forming the largest or the most ears. This takes us back in memory to the old state fairs in the Cornbelt where the corn shows were the big attraction and the prizes went to the big well-filled ears. These were closely related to yield in the early 1900's. Another characteristic of our low population corn I hadn't mentioned was that where our chemical weed control broke down, the weeds grew with astonishing vigor. It was easy to look at these and see why corn was cultivated three to five times in those days and checking was the popular way to plant it. As we move through increasing plant populations we lose the tillers and most of the second ears and weeds are much less aggressive. The plants look uniform in height because of the cooperative interaction and they get taller and ear height increases. This is the 6,000 to 8,000 kg/ha yield level which is easily realised with adequate fertilization and rainfall or irrigation. This is the corn of the late 1940's and early 1950's. The main problems were fertility and water. No one worried much about row widths and barren plants weren't much of a problem. Unfortunately we did not put any of the old, open-pollinated varieties in our wheels. I will do so next year and feel reasonably confident that we can get yields in excess of 6,000 kg/ha at these planting rates.

C. Plant Uniformity and Barrenness

As one moves to higher populations still, we encounter the problems of the present and get a look at those of the future. Plant heights become less uniform because our cooperative interaction no longer operates. All of the plants are shaded to nearly their maximum height and hence their maximum rate of elongation. A plant that germinates slowly or is slow in getting started is soon shaded beyond its maximum elongation rate. In consequence it grows more slowly than its neighbours. It is soon even more heavily shaded and hence grows more slowly still. It is thus suppressed and becomes a starved, spindly, barren plant. By doing everything possible to ensure uniformity one could probably avoid such suppressed plants, but only up to a point. When the maximum-height shading is reached for all plants, the equilibrium becomes unstable. Some plants must be suppressed. As stated by two famous Nebraskans, Clements and Weaver (1929), in their description of an experiment with sunflowers (Helianthus annuus L.), "in a crowded population a difference in height of as little as a millimeter could be decisive if it enabled one plant to get its leaf over its neighbors." We have stressed the competition for light, but an equally deadly competition must be going on under the soil. Shaded plants have an increased shoot/root ratio. The more shaded plant invests a decreased part of its resources in roots so its root system is smaller and shallower than its more favoured neighbors. Moisture or fertility stress can only add to the relative disadvantage and increase the probability of suppression. The nature of this double competition has been shown in many experiments, but possibly never more clearly than by Donald (1958) in his experiments in the 1950's. In the 63 varieties we observed, these suppressed plants were almost invariably barren. The ears formed contained only a few scattered kernels if any at all. More interesting was the fact that only plants that would be classified as suppressed by competition were barren. This might not have been the case under more normal field conditions where more reasons for barrenness might exist. In our plots there was ample pollen over a long period of time because of the number of varieties planted together. We also had a very favourable growing season with supplemental irrigation but I feel that the competitive interactions I have described are one of the. Important causes of barrenness in high-population corn, it has received surprisingly little attention in the agronomic literature. Barren plants are one of today’s serious problems in seeking higher yields and it is one not likely to get less important. A barren stalk intercepting light and using water and nutrients but giving nothing in return cannot but reduce grain yield. It should be pointed out, however, that grain yield in corn reaches a maximum and then declines as population continues to increase whether there are barren stalks or not. The effect of barren plants is to cause the yield maximum to occur at a lower plant population and to accelerate the rate of decrease in yield as populations continue to increase. As might be expected barrenness increases with stress. It would have been interesting to see what some of the old open pollinated varieties would have done at these much higher plant populations. Undoubtedly the increased variability among plants would have meant increasing numbers of plants would have been suppressed and hence barren. From this point of view, it seems obvious that one advantage of hybrid corn varieties is uniformity that permits higher plant populations. The greater uniformity of single-cross varieties might be one factor in their yield potential. Dr. Donald has written recently (1968) about the possibility of increasing plant yields by the breeding of crop ideotypes, defined as plants with model characteristics known to influence photosynthesis, growth, and grain production. One basic characteristic he notes is that ideal plants should have weak competitive ability. By this he means they should have characteristics that enable them to make the best possible use of their share of the environment without encroaching on environment allocated to neighboring plants. We will return again to this thoughtful observation but we can see in the tendency of corn plants to elongate when shaded the survival of a trait that in more primitive ancestors represented the thrust of green blades above competitors. In a field of crop plants where all plants have equal value the tendency to try to crowd out neighbouring plants is highly undesirable. In addition to mutual shading this elongation increases plant and ear height and decreases stalk strength. Both make the plant more likely to lodge. It has the less obvious effect of increasing the tendency to suppress individual plants at high plant populations. Elongation at a more rapid rate in response to shading may provide the mechanism for a certain improvement in height uniformity but this is small compensation for the additional stresses it imposes. The fact that there is relatively large variation in this tendency to elongate among varieties we have observed indicates that there is genetic variability for breeders to work with and probably that progress is already being made.

D. Planting Patterns

Our observations have stressed the potential loss of yield caused by lack of uniformity and the need for increased uniformity as plant population's increase. Some preventable causes of non-uniformity are obvious. Seeds should be uniform in germination time and should be planted uniformly. A more subtle influence on uniformity is in the pattern of planting. In our wheels each plant was in the center of a trapezoid, almost as well separated from neighbouring plants as possible for a given planting rate. This deferred competition among plants for light as well as for underground factors as long as possible. At critically high planting rates any lack of uniform plant distribution would mean localised high-density areas where plants would be shaded past the point of instability at which some plants must be suppressed no matter how uniform the initial conditions. The adverse effect of any lack of uniformity would be accentuated. This at least partially explains the current interest in narrow rows. As one decreases the distance between rows to some point, for a given plant population, the distribution of plants becomes more uniform. Our experiments have shown that the higher the plant population the greater the yield advantage of narrower rows. This is the usual conclusion from such experiments. The high planting rates necessary for higher yields in the future thus require more uniform planting patterns. The best planting pattern for any plant can be shown by rather rigorous mathematics to be equilateral or hexagonal as you choose to look at it. We might assume, therefore, that planting patterns of the future will tend toward this one. The present interest in narrower rows may be taken as a part of this trend. The problem of developing planting equipment that will place seed in a hexagonal pattern does not seem to me to be insuperable. A square pattern is almost as good and this was the common pattern for many years although the spacing was far too wide. Dr. Daynard and I have also shown by convincing mathematics with the aid of our computer that the worst way to distribute seed within a given area is with multiple seed hills. Quite a number of early experiments compared such hills with row plantings at the same population and usually showed small yield differences in favor of the rows. These were done at far lower than what we now consider high populations. At high rates the differences in favor of the row plantings are quite a bit higher as we learned in a small unpublished experiment two years ago. This is not to say that disease or insect control or other considerations might not favor other planting patterns but theory favours the hexagonal design.

E. Tillering

The disturbing fact is that tillering plants such as wheat [Triticum (aestivum L.) sp.] or rice (Oryza sativa L.) are essentially plants growing in multiple-plant hills which is, according to our computer, the worst way. Using somewhat different reasoning, Dr. Donald has selected as his ideotype for wheat a single-culm variety. This is not to say that a tillering plant might not have advantages in specific localities. Dr. Donald mentions the very obvious advantage of a tillering rice plant for Japanese conditions where the individual plants are usually set by hand. Scientists at the International Maize and Wheat Improvement Center in Mexico are interested in the development of a strongly tillering variety of corn which may have great advantage under some conditions. What I am asserting, with Dr. Donald, is that highest yields under very favourable conditions will probably result from no tillering plants. It is again a matter of plant geometry and of our ability to control it. F. Leaf

Area Index In summary of this discussion of the problems associated with the best use of space we may ask the question as to why high planting rates are required for high yields and if there is no limit to planting rates. If there is a limit, what determines it? The answer goes back, in part, to some of the points made by Dr. R. S. Loomis (see Chapter 4, this book) and his computer in describing the architecture of plant canopies. Higher plant populations are needed with a plant like corn in order to have high leaf area indices (LAI). Without high LAI values, the useful light cannot be intercepted at efficiently low levels of illumination. There is a limit to this, however, that is set by the leaf angles involved. With flat horizontal leaves a high LAI is a disadvantage because of excessive self-shading. As leaf angle increases so can LAL. The rate of planting required for maximum canopy photosynthetic rate and presumably yield with a given phenotype is set by the leaf area per plant and the angle or aspect of the leaves. There are obviously other considerations but these are fundamental and limiting. We can think about this in terms of Dr. Donald's idea that the ideal plant should be as noncompetitive as possible. With near vertical leaves it is possible for a plant to intercept light at low levels of illumination and hence more efficiently as far as the use of radiant energy is concerned. With such leaves the shading of neighboring plants is minimal. High yielding crops come from plants that are pacifists; that concentrate on productivity and minimise rivalry. In this context, a soybean plant (Glycine max L.) might be a good example of a plant with reprehensible social behaviour. It has a bush habit of growth that tends toward overshadowing neighbouring plants. For many varieties the leaves are large, relatively flat and placed close together. They thus intercept both direct sunlight and skylight at inefficiently high levels of illumination instead of dividing the light flux among many more leaves.

F. No-Tillage Planting

Let us continue by considering the underground environment and to some extent the use of water. In Kentucky and adjoining states there is considerable interest in a cultural method called "no-tillage." It is an awkward term to use in writing or speaking but no better one has evolved as yet. This year there were almost 40,000 ha (100,000 acres) planted in Kentucky by this method and more will be planted next year. What has brought it to the front is a better approach to an ancient problem, the control of weeds. The fact that weeds are easier to control in corn than in other crops probably explains why it is in wider use in this crop than others. Under this concept the grass sod or other ground cover is killed with herbicide mixtures and a 5-cm-wide (2-inch) seedbed prepared with a fluted coulter. Seeds are placed in this strip with only slightly modified planters. Results haven't been free of problems but there is solid reason for encouragement and for thinking it is much more than a passing agricultural fad. One that is most exciting to me is that our corn so planted has shown less wilting under moisture stress than corn in adjoining plots prepared conventionally. Apparently less water is lost from the soil during preparation, during the time when corn is too small to shade the soil surface, and possibly even after this when most visible radiation is being intercepted. There is a favourable effect on infiltration of rainfall also which may be a factor. At any rate, yields for no-tillage corn in Kentucky are as good as conventional tillage under very favourable conditions and consistently higher when there is moisture stress. While in Davis, California, I audited a class in tropical agriculture taught by Dr. W. A. Williams in which he discussed a comparable planting system in the steep hills of a remote part of Brazil. Here the farmer applied an ancient herbicide, fire, by burning the brush. He then planted his no-tillage corn-by a touch with the tip of his machete that made a mark just large enough to allow him to insert and cover a grain of corn. The farmer didn't know anything about scientific agriculture but he knew that the less he disturbed the surface of the soil the fewer weeds he would have. The process may sound a bit crude but it may embody the fundamental principles of the best cultural manipulation of soil for the future. As we think about no-tillage systems and see how well they work we must ask the question, why do we plow in the first place? Observations of no-tillage systems suggest to me that what we refer to as soil preparation has little to do with improving the environment for root development. Corn yields without plowing are just as good, usually better, and sometimes quite a bit better than with conventional tillage. Apparently in our part of the country the major reason for plowing is to control weeds. Dr. DeWit has talked about similar results with crops other than corn in Holland, so it isn't too local a conclusion. A huge tractor pulling four or five bottom plows is a lot of machinery just to kill weed

SELF-ASSESSMENT EXERCISE

Discuss extensively the concept of Crop geometry in Agricultural production
Discuss the concept of cultural manipulation based on Duncan's theory.

4.0 CONCLUSION

Crop geometry refers to the shape of the space available for individual plants. It influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Crop geometry is altered by changing inter and intra-row spacing (Planting pattern). By cultural manipulation we will mean, in a broad sense, everything a farmer might do to increase crop yields per hectare, after he decides what to plant and buys the seed. With this restriction we leave out the agricultural economist and the plant breeder. When we limit our interest to yields per hectare, we introduce an element of area. This will include the crop canopy above the surface and the root system below it. Cultural manipulation also includes what the farmer might do to make best use of water, carbon dioxide, nitrogen, and essential mineral nutrients whether they occur naturally or otherwise.

5.0 SUMMARY

Crop geometry refers to the shape of the space available for individual plants. It influences crop yield through its influence on light interception, rooting pattern and moisture extraction pattern. Crop geometry is altered by changing inter and intra-row spacing (Planting pattern). By cultural manipulation we will mean, in a broad sense, everything a farmer might do to increase crop yields per hectare, after he decides what to plant and buys the seed. With this restriction we leave out the agricultural economist and the plant breeder. When we limit our interest to yields per hectare, we introduce an element of area. This will include the crop canopy above the surface and the root system below it. Cultural manipulation also includes what the farmer might do to make best use of water, carbon dioxide, nitrogen, and essential mineral nutrients whether they occur naturally or otherwise.

6.0 TUTOR-MARKED ASSIGNMENT

1. Discuss extensively the concept of crop geometry in agricultural production
2. Discuss the concept of cultural manipulation based on Duncan's theory.

7.0 REFERENCES/FURTHER READING

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