COURSE GUIDE

CRP 502
PLANT GROWTH AND DEVELOPMENT

Course Team: Dr. Godwin Adu Alhassan (Course Writer) - NOUN
Dr. Aliyu J. A. (Course Editor) - ABU, Zaria
Prof. Grace Jokthan (Programme Leader) - NOUN
Dr. Aliyu Musa (Course Coordinator) - NOUN

NATIONAL OPEN UNIVERSITY OF NIGERIA

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

Lagos Office
14/16 Ahmadu Bello Way
Victoria Island
Lagos

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

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INTRODUCTION

Plant Growth and Development (CRP 502) is one semester and two credit course. It is available to all students offering crop production in their final year of Bachelor of Agriculture degree programme. The course will consist of 18 units, which involves good knowledge in the natural sciences.

Have you ever thought about where and how the structures like roots, stems, leaves, flowers, fruits and seeds arise and in an orderly sequence? You have also seen that trees continue to increase in height or girth over a period of time. However, the leaves, flowers and fruits of the same tree not only have limited dimensions but also appear and fall periodically and some time repeatedly. All plant organs are made up of a variety of tissues; is there any relationship between the structure of a cell, a tissue, an organ and the functions they perform? Can the structure and the function of these be altered? All cells of a plant are descendants of the zygote. The question is, then, why and how do they have different structural and functional attributes? How do plants feed, who supplies their food, and what happens to the source of supply as plants grow? These questions and many more will be answered as you study this course.

Plant development is the sum of two processes: growth and differentiation. To begin with, it is essential and sufficient to know that the development of a mature plant from a zygote (fertilized egg) follow a precise and highly ordered succession of events. During this process a complex body organization is formed that produces roots, leaves, branches, flowers, fruits, and seeds, and eventually they die.

WHAT YOU WILL LEARN IN THIS COURSE

The overall aim of this course of study is to understand the mechanism and processes involved in plant growth and development beginning from fertilisation, seed formation and dormancy. You will also study and know how carbohydrates are formed in plants and their movement and storage (translocation and sinks). There are some factors that affect these processes and mechanisms ranging from the environment and the soil which influences growth and development and the eventual yields. There are some natural growth regulators which are used to fasten or slow down plant growth and development. What roles do plant organs like the leaf, stem, flowers, roots, fruits and seeds play in our daily lives? All these and others will be adequately explained during the course of this study.

COURSE AIMS

The course aims to provide you with an understanding of plant growth and development and the factors that affect these processes. It also aims to provide you with solutions to solving the problems (factors) associated with plant growth and development in the field.

COURSE OBJECTIVES

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

- explain processes involved in seed germination and dormancy
- discuss principle of juvenility and senescence
- describe translocation and respiration in plants
- explain what roles do environmental resources play in plant growth and development
- analyse the importance of water and water stress in plants
- discuss the significance of light and solar radiation
- state the roles of nutrients in plant growth and development
- examine reproduction in plants (sexual and asexual reproduction)
- list stages involved in plant growth
- appraise the mechanisms in plant growth and development
- draw and explain the sigmoid growth curve
- explain the factors influencing plant growth and development
- discuss the principle of photosynthesis, plant growth and partitioning of assimilates
- identify yield limiting factors and yield components
- list growth regulators
- analyse the measurements in plant growth
- explain in detail plant growth analysis
- identify the roles of various plant organs.

WORKING THROUGH THIS COURSE

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

This course should take you a total of 18 weeks to complete. From the listed components of the course, you should be able to allocate your time to each unit in order to successfully complete the course on time.

In addition to spending quality time to read, I would advise that you avail yourself the opportunity of attending the tutorial sessions with your facilitators. This will give you the opportunity to compare notes with your colleagues and seek explanations where necessary.

COURSE MATERIALS

The main components of the course are:

1. Course guides
2. Study units
3. References/further reading
4. Assignments (TMA)

STUDY UNITS

Module 1 Seed Germination and Dormancy, Role Of Environmental Resources On Plant Development

Unit 1 Seed Germination and Dormancy
Unit 2 Juvenility and Senescence
Unit 3 Translocation and Respiration in Plants
Unit 4 Role of Environmental Resources
Unit 5 Water and Water Stress in Plants
Unit 6 Light and Solar Radiation
Unit 7 Role of Plant Nutrients
Unit 8 Sexual and Asexual Reproduction

Module 2 Plant Growth Stages and Factors Influencing Plant Growth and Development

Unit 1 Plant Growth Stages-Induction, Initiation, Differentiation,

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 assignments will account for 30% of the total course mark.

TUTOR- MARKED ASSIGNMENT

CRP 502 involves a lot of reading and study hours. There are tutor marked assignments at the end of every unit which you are expected to do. You are expected to go through the study units very carefully so that you can attempt the self-assessment exercises. You will be assessed on the different aspects of the course but only three of them will be selected for continuous assessment. Send the completed assignments (when due) together with the tutor-marked assignment form to your tutorial facilitator. Make sure you send in your assignment before the stated deadline.

FINAL EXAMINATION AND GRADING

The modalities for the final examination for CRP 502 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 exercises. 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 502 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 assignments 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

In this course, you will study some of the factors which govern and control these developmental processes. These factors are both intrinsic (internal) and extrinsic (external) to the plant. Plant growth is regarded as one of the most fundamental and conspicuous characteristics of a living being. Growth is an irreversible permanent increase in size of an organ or its parts or even of an individual cell. Generally, growth is accompanied by metabolic processes (both anabolic and catabolic), that occur at the expense of energy. This process of growth to maturity and senescence is very interesting in our study of nature. I wish you happy reading.

MAIN COURSE

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MODULE 1 SEED GERMINATION AND DORMANCY, ROLE OF ENVIRONMENTAL RESOURCES ON PLANT DEVELOPMENT

UNIT 1 SEED GERMINATION AND DORMANCY

CONTENTS

1.0 INTRODUCTION

With the seeds, the independence of the next generation of plants begins. Seeds have to germinate and get established to produce the next set of seeds. Nature has it that there are different periods allowed for seeds to initiate the process of germination. The failure of an intact viable seed to complete germination under favourable condition is what is called dormancy. These two critical phenomena of seed dormancy and germination are controlled by factors which will be elucidated in this unit of study.

2.0 OBJECTIVES

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

- discuss what is seed germination
- identify conditions or factors necessary for germination
- explain the meaning of seed dormancy
- examine the importance of seed dormancy
- describe how to break seed dormancy.

3.0 MAIN CONTENT

3.1 Seed Germination

Every seed contains an embryo which is the new plant in miniature. It is structurally and physiologically equipped for its role as it is well provided with enough food reserves to sustain the growing seedling until it establishes itself as a self-sufficient, autropic organism. Germination commences with the uptake of water by the dry seed-imbibitions, and is completed when a part of the embryo, usually the radicle, extends to penetrate the structures that surround it. Uptake of water by a mature dry seed is in three phases. Phase one is with a rapid initial uptake followed by a plateau phase (phase two). The third phase will only take place with further uptake of water only after germination is completed, as the embryonic axes elongate. Because dormant seeds do not complete germination, they cannot enter phase three.

The influx of water into the cells of dry seeds during phase one results in temporary structural perturbations, particularly to membranes, which lead to an immediate and rapid leakage of solutes and low molecular weight metabolites into the surrounding imbibition solution. Upon imbibition, the quiescent dry seed rapidly resumes metabolic activity. The structures and enzymes necessary for this initial resumption of metabolic activity are generally assumed to be present within the dry seed, having survived, at least partially intact, the desiccation phase that terminates seed maturation. Reintroduction of water during imbibitions is sufficient for metabolic activities to resume, with turnover or replacement of components occurring over several hours as full metabolic status is achieved. The time for events to be completed varies from several hours to many weeks, depending on the plant species and the germination conditions. With few exceptions, radicle extension through the structures surrounding the embryo is the event that terminates germination and marks the commencement of seedling growth.

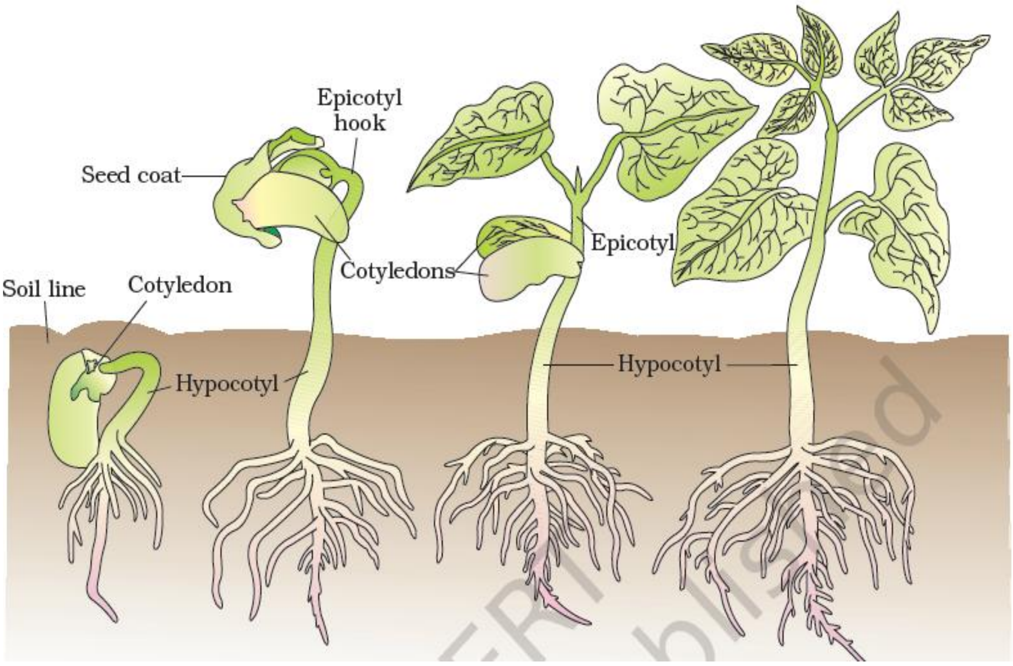

Fig. 1: Stages in seed germination

3.1.1 Conditions for Germination

Several factors influence seed germination. They include:

1) External factors such as water, oxygen and suitable temperature
2) Internal factors such as seed dormancy due to internal conditions

Water is crucial to seed germination. A dormant seed is generally dehydrated and contains hardly 6-15% water in its living cells. The active cells, however, require about 75-95% of water for carrying out their metabolism. Therefore, the dormant seeds must absorb external water to become active and show germination. Besides providing the necessary hydration for the vital activities of protoplasm, water softens the seed coats, causes their rupturing, increases permeability of seeds, and converts the insoluble food into soluble form for its translocation to the embryo. Water also brings in the dissolved oxygen for use by the growing embryo. The seed must go through imbibition to activate root growth. However, too much water can be harmful to a germinating seed. When a plant is still growing underground, during root formation, it relies on the stored food inside the seed, and oxygen from the environment to make energy. If the soil is too saturated with water, there will not be enough oxygen for the plant to survive.

Temperature is also an important factor. Moderate warmth is necessary for the vital activities of protoplasm. Some seeds germinate when it is cold, while others only germinate when the weather reaches warm temperatures. Other seeds only germinate after extreme temperatures, such as after a fire in the grasslands. Though germination can take place over a wide range of temperature (5-40°C), the optimum for most of the crop plants is around 25-30°C. The germination in most cases stops at 0°C and 45°C.

Oxygen is necessary for respiration which releases the energy needed for growth. Germinating seeds respire very actively and need sufficient oxygen. The germinating seeds obtain this oxygen from the air contained in the soil. It is for this reason that most seeds sown deeper in the soil or in water-logged soils (i.e. oxygen deficient) often fail to germinate due to insufficient oxygen. Ploughing and hoeing are **cultural methods** that aerate the soil and facilitate good germination.

Seed dormancy due to internal conditions. In some plants the embryo is not fully mature at the time of seed shedding. Such seeds do not germinate till the embryo attains maturity. The freshly shed seed in certain plants may not have sufficient amounts of growth hormones required for the growth of embryo. These seeds require some interval of time during which the hormones get synthesised.

The seeds of almost all the plants remain viable or living for a specific period of time. This viability period ranges from a few weeks to many years. Seeds of Lotus have the maximum viability period of 1000 years. Seeds germinate before the ending of their viability periods. In many plants, the freshly shed seeds become dormant due to various reasons like the presence of hard, tough and impermeable seed coats, presence of growth inhibitors and the deficiency of sufficient amounts of food, minerals and enzymes, etc.

3.2 Seed Dormancy

Seed dormancy is generally an undesirable characteristic in agricultural crops, where rapid germination and growth are required. However, some degree of dormancy is advantageous, at least during seed development. This is particularly true for cereal crops because it prevents germination of grains while still on the ear of the parent plant (pre-harvest sprouting), a phenomenon that results in major losses. Thus, dormancy is an adaptive trait that optimises the distribution of germination over time in a population of seeds.

Crop species have ostensibly removed most dormancy mechanisms present in the seeds of their wild ancestors, although under adverse environmental conditions, dormancy may reappear. By contrast, weed seeds frequently mature with inherent dormancy mechanisms that allow some seeds to persist in the soil for many years before completing germination. Virtually all the cellular and metabolic events that are known to occur before the completion of germination of non-dormant seeds also occur in imbibed dormant seeds; indeed, the metabolic activities of the latter are frequently only subtly different from those of the former. Hence, a dormant seed may achieve virtually all of the metabolic steps required to complete germination, yet for some unknown reason, the embryonic axis (i.e., the radicle) fails to elongate.

3.2.1 What 1s Dormancy?

Despite the fact that many researchers study dormancy, there is no unambiguous definition of the phenomenon, perhaps because it is manifest and broken in different ways in different species. For the sake of simplicity, seed dormancy is regarded here as the failure of an intact viable seed to complete germination under favourable conditions. The seeds of some species are prevented from completing germination because the embryo is constrained by its surrounding structures. This phenomenon is known as coat enhanced dormancy; embryos isolated from these seeds are not dormant. In other species, a second category of dormancy is found in which the embryos themselves are dormant (embryo dormancy). Since dormancy is regulated at different developmental phases, in interaction with environmental factors, it is difficult to detect when the genetic and physiological differences are established. This difficulty arises because all dormancy assays are based on seed germination, which is the result of the balance between the degree of dormancy and the capacity of the embryo to overcome dormancy.

3.2.2 Importance of Seed Dormancy

There are advantages of dormancy in agriculture. These include:

1. Perennation: Seed dormancy allows seeds to pass through drought, cold and other unfavourable conditions.
2. Dispersal: It is essential for dispersal of seeds. The period of dormancy of seed is essential for seeds to be found in other locations, thus help in the natural distribution process.
3. Germination under favourable conditions: Seeds germinate only when sufficient water is available to leach out inhibitors and soften the seed coats. Where the conditions for germination are not favourable, the seed remains intact, thus prolonging their self-life. Dormancy under this condition has helped in the study of the conditions necessary for germination.
4. Storage: It is because of dormancy that human beings are able to store grains, pulses and other edibles for making them available throughout the year and transport to the areas of shortfall or where there are better prices for these crops.

3.2.3 Breaking of Seed Dormancy

There are two types of breaking seed dormancy, natural and artificial.
In nature seed dormancy is broken automatically due to:

(i) Development of growth hormones to counter growth inhibitors,
(ii) Leaching of germination inhibitors,
(iii) Maturation and after-ripening of embryo
(iv) Weakening of impermeable and tough seed coats by microbial action, abrasion, passage through digestive tract of animals, etc.

Artificial Breaking of Seed Dormancy involves:

1. Scarification: Hard, impermeable seed coat is weakened or ruptured by filing, chipping, hot water and chemical treatments.
2. Stratification: Seeds are moistened and exposed to oxygen for variable period at low or high temperature. There is also mechanical stratification e.g. the use of sandpaper, hammer, knife.
3. Counteracting Inhibitors: Inhibitors are destroyed by dipping seeds in KNO_3, thiourea, ethylene chlorohydrin and gibberellin.
4. Shaking and Pressure: Vigorous shaking and hydraulic pressure are used to weaken seed coats.

4.0 CONCLUSION

With the seed, the independence of the next generation of plants begins. Because the function of a seed is to establish a new plant, it may seem peculiar that dormancy, an intrinsic block to germination, exists. But it may not be advantageous for a seed to germinate freely, even in seemingly favourable conditions. Seed dormancy is generally an undesirable characteristic in agricultural crops, where rapid germination and growth are required. However, some degree of dormancy is advantageous, at least during seed development.

5.0 SUMMARY

During the course of our study of this unit, we have been able to explain what is seed and the processes involved in seed germination. What are the conditions or factors that affect seed germination? Also, we were able to explain the term ‘seed dormancy’ with insight into the causes of seed dormancy, its importance in agriculture and food security. We equally explained the processes and methods available for breaking dormancy or approaches to reduce dormancy period in seeds.

6.0 TUTOR-MARKED ASSIGNMENT

1. Why is a seed called a miniature plant?
2. Explain the process of seed germination.
3. List the factors necessary for seed germination.
4. Explain dormancy in seeds.
5. List the importance of dormancy to man.
6. How can you attempt to break dormancy in seeds?

7.0 REFERENCES/FURTHER READING

Chandrasekaran, B.; Annadurai, K. & Somassundaram, E. (2016). *A Text Book of Agronomy*. New Delhi, India: New Age International Publishers.

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UNIT 2 JUVENILITY AND SENESCENCE

CONTENTS

1.0 INTRODUCTION

During the life cycle of a plant, it undergoes some noticeable morphological changes from the embryonic phase to juvenile and maturity. These are phases of growth and development which is eventually followed by senescence and death. After death the plant is said to have completed its life cycle. The juvenile phase in some species has a distinctive morphology of leaves, stems, and other structures which are no longer present when the plant becomes mature. Once the plant reaches maturity, flowering can be induced by appropriate external signs. The change from mature to senescent conditions typically involves the deterioration of many synthetic reactions leading to the death of the plant, thereby completing the cycle.

2.0 OBJECTIVES

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

- explain what is called juvenility, maturity and senescence
- discuss the morphological changes in plants as they grow to maturity.

3.0 MAIN CONTENT

Most plant start development from seed germination through the various growth stages to maturity. Most characteristics change gradually during the period preceding the mature phase, and usually no distinct concurrent change in any one characteristic is apparent at the time the ability to flower is attained. Phase change is of considerable theoretical importance relative to morphogenetic control and differentiation. Physiological characteristics such as seasonal leaf retention and stem pigmentation, ability to form adventitious roots and buds, partitioning of photosynthates into main stem or branches, disease resistance and unfavourable weather resistance changes are characteristics that occur during development in plants and these vary from species to species.

3.1 Juvenility

In the development of all woody plants from seed, there is a so-called juvenile phase lasting up to 30 - 40 years in certain forest trees, during which flowering does not occur and cannot be induced by the normal flower-initiating treatments or conditions. In time, however, the ability to flower is achieved and maintained under natural conditions; at this stage, the tree is considered to have attained the adult or sexually mature condition. The juvenile phase of plant development can be defined as an initial period of growth when apical meristems will not typically respond to internal or external conditions to initiate flowers. The length of the juvenile period can be influenced by environmental as well as genetic factors. This phase is characterised by exponential increases in size; absence of the ability to shift from vegetative growth to reproductive maturity leading to the formation of flowers once the plant reaches maturity, flowering can be induced by appropriate external signs. The change from mature to senescent conditions typically involves the deterioration of many synthetic reactions leading to the death of the plant, thereby completing the cycle. This transition from the juvenile to the mature phase could also be referred to as ontogenetic aging or meristem aging.

3.1.1 Morphological Characters of Juvenility

As the plant grows steadily through the years to maturity, you are likely going to see morphological changes in the plants external features like the shapes of the leaves and the length of the branches and other signs indicating maturity and flowering. Associated with this transition are progressive changes in morphological and developmental attributes including leaf cuticular characteristics, bark characteristics, leaf shape and thickness, phyllotaxis, plastochron, thorniness, and shoot orientation, branch number and branching pattern, tracheid width and length, shoot growth vigor and other physiological characteristics such as seasonal leaf retention and stem pigmentation, ability to form adventitious roots and buds, partitioning of photosynthates into main stem or branches, disease resistance and unfavourable weather resistance. Changes in such characteristics during development vary from species to species. Most characteristics change gradually during the period preceding the mature phase, and usually no distinct concurrent change in any one characteristic is apparent at the time the ability to flower is attained.

3.2 Maturity and Senescence

Attainment and maintenance of the ability or potential to flower is the only consistent criterion available to assess the termination of the juvenile period. Once the plant attains this ability to flower, flowering will continue to occur so long as all other requisite environmental conditions are met. If they are not, flowering will be delayed even though the plant is now capable of flowering. Thus, flowering can indicate that the plant has reached the phase of sexual maturity, but may not indicate when the transition occurred. Conversely, lack of flowering may not mean that the plant is still in the sexually immature, juvenile phase. However, for individual species, a specific character such as thorniness or anthocyanin formation may be correlated with ability to flower and thus be useful as an indicator of the termination of the juvenile period. Once the sexually mature phase is attained, it is relatively stable. Reversion to the juvenile condition does not generally occur as a result of asexual propagation such as cuttage or graftage involving a single bud and a small piece of stem.

4.0 CONCLUSION

Juvenility is part of the ageing process in woody plants. Commencement of flowering can indicate that the plant has reached the phase of sexual maturity though lack of flowering may not necessarily mean that the plant is still in the sexually immature, juvenile phase.

5.0 SUMMARY

During the life cycle of a plant, it undergoes some noticeable morphological changes from the embryonic phase to juvenile and maturity. These are phases of growth and development which is eventually followed by senescence and death. After death the plant is said to have completed its life cycle. The juvenile phase of plant development is the initial period of growth when apical meristems will not typically respond to internal or external conditions to initiate flowers. As the plant grows steadily through the years to maturity, you are likely going to see morphological changes in the plants external features like the shapes of the leaves and the length of the branches and other signs indicating maturity and flowering. Attainment and maintenance of the ability or potential to flower is the only consistent criterion available to assess the termination of the juvenile period.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define juvenility.

2. List some morphological characters of plants within the juvenile phase to maturity.

7.0 REFERENCES/FURTHER READING

Allsopp, A. (1965). “Heteroblastic Development in Cormophytes.” In: W. Ruhland (Ed.). *Encyclopedia of Plant Physiology Xvii*. Berlin: Springer, pp 1172-1221.

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UNIT 3 TRANSLOCATION AND RESPIRATION IN PLANTS

CONTENTS

1.0 INTRODUCTION

When plants create nutrients in their leaves, how do materials get to the rest of the plant? When you eat, how does the food get to where it should go. Of course, plants don't consume food the way we do. Instead, they create food in their leaves during photosynthesis by transforming water and carbon dioxide into carbohydrates which they can use for energy. Since photosynthesis only occurs in the leaves, that means plants have to have some way of transporting these sugars into other areas of the plant that need it, such as the stems, roots, and flowers. This transport of materials from the leaves to other parts of the plant is known as **translocation**. All living organisms need energy for carrying out daily life activities, be it absorption, transport, movement, reproduction or even breathing.

Before this process of energy release takes place, two basic and fundamental reactions have to occur, photosynthesis and respiration. But in this unit we will treat translocation and respiration.

2.0 OBJECTIVES

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

- discuss what is translocation
- examine the organs responsible for translocation
- explain the meaning of respiration
- identify the factors influencing respiration in plants.

3.0 MAIN CONTENT

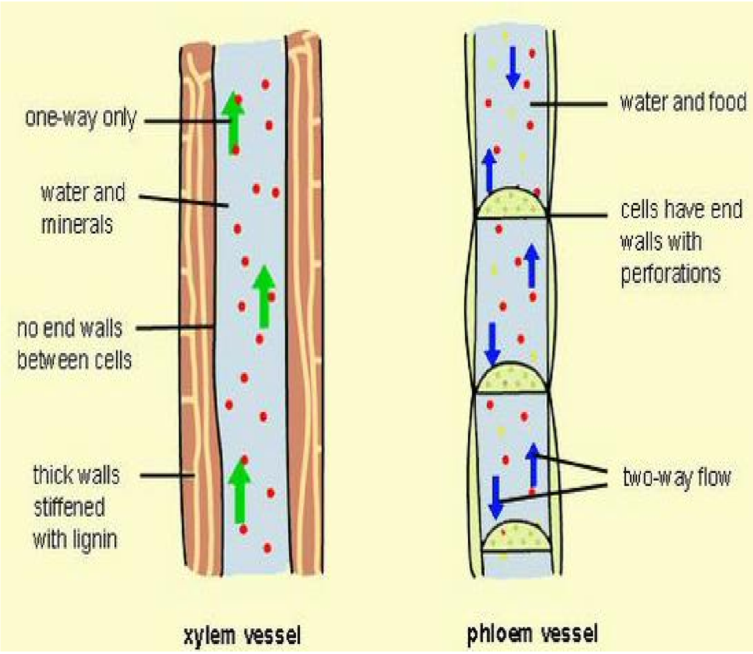
How exactly do the sugars and other materials get from the leaves into the areas where they are needed? These materials start in the leaves, which are known as sugar sources because they have an abundance of sugar following photosynthesis. First they have to move into the phloem, and this is accomplished either of the two ways. In some plants, it is directly transported into the phloem using sugar transport proteins. In others, it makes its way in through small openings in the phloem cell walls, and is then converted into larger forms so that it cannot move back out. With either method, the result is a buildup of sugar in the plant body system. The phloem moves the sugars into sugar sinks, or areas where there is a lack of sugar, such as the stems and flowers.

3.1 Translocation

When photosynthesis takes place within the leaves, plants have to device ways of transporting (translocation) the manufactured complex sugars called carbohydrates to others areas of need and possible storage in the plant such as the stems, roots, and flowers. We must remember that in green plants too, not all cells, tissues and organs photosynthesise except cells that contain chloroplasts. But all the organs, tissues and cells that are not green, need food for oxidation. Hence, food has to be translocated to all non-green parts too. This transport of materials from the leaves to other parts of the plant is known as **translocation**.

3.1.1 The Phloem and Xylem Transport Tubes

The nutrients the plant creates can't simply stream through the leaves to the other parts of the plant. They are moved through special tubes that run all throughout the plant, known as **phloem**. These long, continuous tubes extend from the leaves into every part of the plant, and new phloem are added as the plant grows, so the flow of nutrients is never interrupted. Phloems are not hollow, open tubes. Within the phloem are **xylem**, which are special types of tissue that carry water and dissolved nutrients throughout the phloem. The phloem is really a series of long, connected cells containing xylem. The connecting walls of the phloem cells look like a sieve, allowing materials to pass through uninhibited. These materials start in the leaves, which are known as sugar **sources** because they have an abundance of sugar following photosynthesis. The phloems move the sugars into sugar **sinks**, or areas where there is a lack of sugar, such as the stems and flowers. So how exactly do the sugars and other materials get from the leaves into the areas where they are needed? First they have to move into the phloem, and this is accomplished in one of the two ways. In some plants, it is directly transported into the phloem using sugar transport proteins. In others, it makes its way in through small openings in the phloem cell walls, and is then converted into larger forms so that it cannot move back out.



3.2 Respiration

Respiration takes sugar either directly from photosynthesis or from breakdown of storage compounds like starch or lipids (oils), and uses its stored chemical energy to make energy currency (ATP). The whole process of respiration can be divided into several different steps. The first part is called glycolysis which literally means sugar splitting. This occurs in the cytoplasm of the cell and does not use oxygen and produces a small amount of ATP. Glycolysis also serves as the central primary metabolic pathway on which most other secondary metabolic pathways depend. This means that crucial plant biomolecules such as proteins, lipids, starch, cellulose, DNA, RNA, chlorophyll, other pigments, plant hormones, and many others are all intricately related with metabolic flux through glycolysis. The other parts of respiration occur in specialized organelles called mitochondria. This is where the bulk of the ATP is released in processes requiring oxygen. All the energy required for 'life' processes is obtained by oxidation of some macromolecules that we call 'food'. Only green plants and cyanobacteria can prepare their own food by the process of photosynthesis where they trap light energy and convert it into chemical energy that is stored in the bonds of carbohydrates like glucose, sucrose and starch.

3.2.1 Importance of Respiration in Plant Productivity

During seed germination, seed storage proteins, carbohydrates and lipids must all be broken down to support the germinating seedling. Aerobic respiration is a crucial part of these processes. Timing is important before seeds are planted since temperature and moisture are essential for germination. The reason for this is that respiration increases substantially with increased temperature. If the soil temperature is too cold, respiration will be too low to metabolise seed storage reserves, and the seed cannot germinate. The fact that respiration increases with temperature also has a profound effect on adult plant productivity. When it is very hot, many plants grow very slowly because of reduced productivity. This usually results from lack of water to support transpiration and CO_2 uptake. As temperature and light availability increase, photosynthetic output eventually plateaus because the chloroplasts have a finite light absorption capacity. On the other hand, the rate of respiration keeps increasing as it gets hotter, which burns more and more carbohydrate. The more respiration increases, the less net photosynthetic product. The effect of high temperature on respiration is most severe at night when there is no photosynthesis. If nighttime when temperatures are very high, all the carbohydrate made by the plant during the day can be used up in respiration and there may be no net growth.

3.2.2 Factors Influencing Respiration in Plants

At this level we will limit ourselves to identifying and discussing ten factors that influence or affect respiration in plants. They are:

1. Type and age of plant tissue
2. State of respiring protoplasm
3. Temperature
4. Hydration of tissues
5. Light
6. Oxygen
7. Carbon dioxide
8. Inorganic salts
9. Mechanical stimulation
10. Wounding as a respiration stimulator

Type and age of plant tissue: The respiratory rate depends upon the age and the nature of the tissues, since it is concerned with energetic activities. Young tissues, like the actively growing regions of the plant, have higher respiratory rate than the old or matured tissues.

In a mature tissue there is breakdown of the integrated system of energy transfer and further increase in age is associated with an increase in senescence. During senescence, proteins breakdown thereby releasing some substrates for respiration. This normally results in an increase in respiratory rate with more production of CO_2 for a brief period. This marks the collapse of the cellular organisation and cells die. The respiratory rate also varies with the type of tissues depending mostly on their metabolic status and relative availability of non-metabolic or structural components and their accessibility to oxygen.

State of respiring protoplasm: The rate of respiration depends upon the developmental stage of protoplasm. In the actively growing regions of the plant, cells are relatively rich in protoplasm with high enzymatic activity. As these regions grow, numerous synthetic processes are taking place which require energy and this is supplied by respiration.

Thus, the rate of respiration is very high in these tissues. In the mature plant organ where growth has ceased, protoplasm abounds in inert matter and metabolic processes gradually decrease. Here the rate of respiration is also low. The inert matter also increases with the age of plant cells. Evidently the rate of respiration is connected with growth.

Temperature: Temperature significantly affects the rate of respiration as it does other enzymatic processes. Lower temperature limits of respiration of a plant that lies below 10°C which are conditioned by the freezing of the tissues. Within certain limits, an increase in temperature increases respiratory rate rapidly. With temperatures in excess of 33°C, the process of respiration which was initially very intense, soon begins to decrease and after few hours becomes weaker than at temperatures of about 20-25°C and even lower.

Hydration of tissues: The percentage of bound water in the seeds is 16% and their rate of respiration is low. With an increase in the moisture content up to 16% the respiration also increases slightly but beyond this, rise in respiration is very rapid.

The increase in respiration due to increase in water content may either be because of water which makes the respiring cells turgid; the hydrolysis of carbohydrates to soluble sugars; accelerating the action of respiratory enzymes; acting as a medium in which oxygen diffuses into the respiring protoplasm or the water concentration of the cell membranes would reduce the permeability to oxygen and CO_2, the former acting as a deficient factor and the latter as a retarding factor. Tissues saturated with water have low rate of respiration. In the wilted leaves the rate of respiration rises because starch is converted into sugar which serves as a respiratory material.

Light: Light is not essential for respiration and indirectly affects the respiratory rate. It increases respiration by raising the temperature of the green plant and also increases the amount of photosynthetic material required for respiration. In some green tissues, it has an inhibitory effect. Red light has a greater retarding effect than blue light. In some instances, red light may increase respiration**.**

Oxygen: The presence of oxygen is essential for the Krebs cycle. Oxygen is the terminal acceptor of electron in the electron transport system. In general, at low O_2 concentrations both aerobic and anaerobic respirations occur in the plant.

As the oxygen concentration increases from zero, the rate of aerobic respiration increases. In most of the plants the rate falls with an increase in oxygen concentration. In germinating rice grain, the increase in the rate of aerobic respiration is linear over a range of oxygen concentration.

Carbon Dioxide: Increasing the CO_2 concentration of air depresses respiration. Normally, inhibition of respiration is only there if the CO_2 concentration increases too high over the normal. The anaerobic respiration in the germinating pea seeds is inhibited by about 50% carbon dioxide in the air. This is helpful in maintaining the dormant state of the seeds. Relative changes in the carbon dioxide concentration does affect stomatal closure and opening. Stomata get closed under the environment with high concentrations of carbon dioxide and this may thus cause inhibition of respiration. In leaf respiration, the effect of CO_2 concentration is indirect one that is through the closure of stomata which limit a gaseous exchange. This may result in increasing the internal concentration of CO_2 considerably and in this way limit respiration.

Inorganic Salts: The rate of respiration increases when a plant or a tissue is transferred from water to a salt solution. The amount by which the respiration is increased over normal has been called salt respiration. This process has been linked with absorption of salts and ions, which have high requirement of energy supplied by respiration.

Mechanical Stimulation: Leaf respiration increases by handling, stroking or bending of leaves. Response to handling decreases if it is repeated over a period of time. It has been observed that shearing stress, gives more of stimulation to respiration and almost very little effect by compression or tension. It has also been reported that sound waves stimulate respiration but no conclusive evidence has so far been given.

Wounding as a Respiration Stimulator: Wounding of a plant organ stimulates respiration in that organ. It initiates meristematic activity in the region of the wound resulting in the development of “wound callus”. Perhaps the increase in respiration is due to an increased availability of respiratory substrate in wounded tissues. Further evidences for the stimulation of respiration in response to wounding are associated with the rapid oxidation of phenolic compounds, the increase in the normal process of glycolysis and oxidative catabolism in wounded tissue and the reversion of certain cells to meristematic state, followed by callus formation to heal the wound which will have high rate of respiration to those of resting or mature tissues.

4.0 CONCLUSION

All living organisms need energy for carrying out their daily life activities, be it absorption, transport, movement, reproduction or even breathing. These series of biological activities are made possible through the release of energy which is influenced by a number of factors.

5.0 SUMMARY

When photosynthesis takes place within the leaves, plants have to device ways of transporting (translocation) the manufactured complex sugars called carbohydrates to others areas of need and possible storage in the plant such as the stems, roots, and flowers. The nutrients the plant creates can't simply stream through the leaves to the other parts of the plant. They are moved through special tubes that run all throughout the plant, known as phloem. These long, continuous tubes extend from the leaves into every part of the plant, and new phloem are added as the plant grows, so the flow of nutrients is never interrupted. The manufacture of starch and its movement through the xylem and phloem are made possible through respiratory activities of the plant. The energy ‘box’ of the living cell is the ATP. ATP is released in processes requiring oxygen (respiration) and this is influenced by series of factors.

6.0 TUTOR-MARKED ASSIGNMENT

1. What is the relationship between respiration and plant productivity?
2. Describe the xylem and phloem vessels in plants.
3. List 10 factors influencing the rate of respiration in plants.

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UNIT 4 ROLE OF ENVIRONMENTAL RESOURCES

CONTENTS

1.0 INTRODUCTION

The world population is steadily increasing each year creating demand for more food to feed the people adequately. Environment is the primary factor that influences plant growth and development and has also the greatest effect on crop distribution on the earth. Crop production is practiced over a wide range of agro ecosystem ranging from very wet to very dry regions and across temperate to tropical and semi-arid zones of the world. The effects and interrelationships between the climatic factors like temperature, rainfall, solar radiation CO_2 concentration etc. determine the type of crops cultivated in the various regions.

In this unit, we will be considering the most important environmental factors that affect crop growth and development.

2.0 OBJECTIVES

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

- identify the environmental resources that influence crop growth, development and distribution
- discuss the relationships between climatic factors that determine the type of crops grown in the various regions.

3.0 MAIN CONTENT

Weather elements over the years determine the type of climate which influences the type of plants/crops cultivated. These elements of weather are fundamental to crop growth. The rate of growth of roots, stem and leaves depends on the rate of photosynthesis which in turn depends on light, temperature, moisture and carbon dioxide concentration. In this unit we will explain the climatic factors which affect crop growth and production. We will also be considering the most important environmental factors that affect crop growth and development. These factors include:

- Light
- Water
- Temperature
- Wind
- Soil salinity and sodicity

3.1 Light

The primary source of light is the sunshine. The production of sugars by plants takes place only in the presence of sunlight. In regions of poor sunshine, photosynthetic activity and growth of plants are limited. Abundant sunshine, adequate rainfall and fertile soils promote luxuriant growth of plants as witnessed in the tropical regions.

3.2 Water (Rainfall)

For survival of life all living organisms require water. Adequate rainfall or water availability is the most important environmental factor that limits growth and survival. Apart from rainfall, there are rivers, lakes, wells that supply irrigation water to supplement rainfall water. These sources also depend on rains for water supply. Thus rain is the only source of water to crops, either directly or indirectly. Rainfall received by plants at the desired quantity and at the right time is an invaluable gift from nature. Insufficient rains limit plant growth, while heavy rains are equally not good for crops. Heavy rainfall causes erosion and leaching and at times creates water logged conditions in the field. Water logged situations do not permit aeration of soils leading to poor growth and development.

3.3 Temperature

Temperature influences a number of physiological activities in plants ranging from photosynthesis, respiration, evapo-transpiration and activities of soil micro-organisms. There is an optimum range of temperature that is the most favourable for these processes and activities as any deviation will affect them. Temperature conditions in Nigeria are mostly favourable for plant growth and development.

3.4 Humidity

This is linked to rainfall. High humidity of the atmosphere reduces transpiration in plants and evaporation of soil moisture. Low humidity on the other hand increases water requirements of plants thus increasing the cost of crop production through irrigation. High humidity of the atmosphere reduces plant resistance to fungal diseases in some cases and encourages pest outbreak in some locations.

3.5 Wind

Wind helps in the pollination of crops, reduces atmospheric temperature. But it has its harmful effects. Excessive wind promotes loss of water from soils through evaporation and transpiration thus more requirements from irrigation water. Strong winds interfere with fruit setting and promotes fruit falling in fields especially orchards. Matured cereal crops are always logged during strong winds leading to losses and increased cost of harvesting. Top soils are sometimes lost to wind especially in semi-arid zones.

3.6 Soil Salinity and Sodicity

Soluble salts are formed by the weathering of rocks and when they are not completely leached as in arid regions, the salts move down to the lower layers with the peculating rain water and move up to the surface again with the capillary rise of moisture. As a result of up and down movements of soluble salts the concentration in the different layers therefore varies from time to time. This is salinity. In soil sodicity, soluble salts formed by weathering that are not completely leached out of the soil but remained concentrated within the surface layers. When the soluble salts like sodium, becomes the prominent base in the clay complex, sodicity condition will set in. Upon saturation through moisture, the Na ion in the double ionic layer round the clay forms sodium hydroxide thereby creating an alkaline reaction to the soil solution. The sodium hydroxide combines with the carbon dioxide of the soil air and forms sodium carbonate and this raises the pH of the soil to as high as 10 at times. These two soil conditions are not conducive for plant growth and development. To grow crops under this condition requires high level of soil conditioning and amelioration.

4.0 CONCLUSION

From our study so far we have been able to identify a number of environmental resources that influence plant growth and development in a particular location and region. These include weather elements and edaphic factors that are extreme. These climatic factors should be seen as interrelated for the over benefit of our crops. Alarming variations in weather elements are very critical in our study of climate change. This is the most serious environmental problem facing humanity now.

5.0 SUMMARY

Crop production is practiced over a wide range of agro ecosystems ranging from very wet to very dry regions and across temperate to tropical and semi-arid zones of the world. The effects and interrelationships between the climatic factors like temperature, rainfall, solar radiation salinity and alkalinity of soils determine the type of crops cultivated in the various regions of the world. Each of these weather elements and soil types has ranges that are favourable for plant growth and development. Extreme conditions call for concern in our study of climate change and its effects on our environmental resources that are necessary for our survival.

6.0 TUTOR MARKED ASSIGNMENT

1. List the weather elements that affect our climate.
2. What do you understand by sodic soils?
3. Which regions of the world are you likely to find saline soils?

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UNIT 5 WATER AND WATER STRESS IN PLANTS

CONTENTS

1.0 INTRODUCTION

Influence of global warming all over the world is creating unusual weather phenomena often in the form of water deficit or in the form of floods and water logging. Drought is worst of these two due to the prolonged exposure of plants to a water deficient condition. Through the evolutionary mechanism, plants have developed their innate mechanism to combat water stress. But not all plants are capable in withstanding water stress and their response to the stress also varies. Even in the highly tolerant species of plants, tolerance comes through changes in the molecular and physiological mechanisms that make plants morphologically adaptable to water deficits. However, they have to pay the price of such tolerance in the form of reduced photosynthesis leading to lower biomass yields often caused by the conservative water management scheme adopted by plants. It helps plants to reduce water loss and to maximise available water uptake while making sure that maximum utilisation of physiologically available water. The adaptation in this form came from genetic machineries that help plants to produce enzymes, proteins and synthesise molecules suitable in various means to combat water shortages. This unit will expose us to the understanding of the importance of water to crops, causes and effects of water stress and plants response to water stress.

2.0 OBJECTIVES

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

- discuss the importance of water to crops
- explain the causes of water stress

- examine the effects of water stress in plants
- explain the responses of plants to water stress.

3.0 MAIN CONTENT

Water stress is an important environmental constraint on crop productivity, both quantitative and qualitative. Water is a vital element for the growth of plants. It is the most important factor that determines the growth and development of organisms. Drought stress is one of the major factors associated with limitations in growth of most plants. Plants stressed under a water deficit show a decrease in photosynthesis, which is correlated to decreased growth and increased incidence of early senescence in plants. Scarcity of water has a direct effect on plants at physiological, morphological, and molecular levels. All biochemical and physiological processes depend upon the availability of water.

3.1 Importance of Water to Plants

Plants at their vegetative growth stages contain 80-90 per cent water, which keeps them turgid and erect. Under normal atmospheric condition there is always evaporation or transpiration of moisture from the leaves and tender portions of plants. Plants make up the lost water by absorbing same from the soil. The presence of water in plants helps in regulating the temperature of plants. When sunshine is severe, transpiration increases and effectively prevents the rise of temperature in the plant system. The soil moisture contains nutrients necessary for plant growth and development. Water in essence is necessary for the following functions in plants:

a) Providing moisture that constitutes the plant materials.
b) Meeting the transpiration, respiration and photosynthetic requirements of plants.
c) Regulating the temperature of the plant system.
d) Serving as medium for dissolving nutrients present in the soil thus meeting the various physiological requirements of growing plants. When plants are supplied with sufficient water, there will be improvements in growth and final yields.

3.2 Causes of Water Stress

Plants experience water stress either when the water supply to their roots becomes limiting or when the transpiration rate becomes intense. Water stress is primarily caused by the water deficit, i.e. drought or high soil salinity. In case of high soil salinity and also in other conditions like flooding and low soil temperature, water exists in soil solution but plants cannot uptake it – a situation commonly known as ‘physiological drought'. Drought occurs in many parts of the world every year. This is more frequent in the arid and semi-arid climates. Regions with adequate but non-uniform precipitation also experience water limiting environments. Since the dawn of agriculture, mild to severe drought has been one of the major factors limiting production of field crops. Consequently, the ability of plants to withstand such stress is of immense economic importance. All plants have tolerance to water stress, but the extent varies from species to species.

3.3 Effects of Water Stress on Plants

Drought is an abiotic stress. Its effect on plants is multidimensional in nature, and it affects plants at various levels of their organisation. In fact, under prolonged drought, many plants will dehydrate and die. Water stress in plants reduces the plant-cell's water potential and turgor. Drought does not only affects plant-water relations through the reduction of water content, turgor and total water, it also affects stomatal closure, limits gaseous exchange, reduces transpiration and arrests carbon assimilation (photosynthesis) rates.

Negative effects on mineral nutrition (uptake and transport of nutrients) and metabolism leads to a decrease in the leaf area and alteration in assimilate partitioning among the organs. Alteration in plant cell wall elasticity and disruption of homeostasis and ion distribution in the cell has also been reported. Synthesis of new protein associated with the drought response is another outcome of water stress on plants. Under water stress, cell expansion slows down or ceases, and plant growth is retarded.

However, water stress influences cell enlargement more than cell division. Plant growth under drought is influenced by altered photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and hormones. Drought creates an imbalance between light capture and its utilisation, which inhibits the photosynthesis in leaves.

3.4 Plant Responses to Water Stress

Plants adapt themselves to drought conditions by various physiological, biochemical, anatomical, and morphological changes, including transitions in gene expression. The physiology of plants' response to drought at the whole plant level is highly complex and involves deleterious and/or adaptive changes. This complexity is due to some factors such as plant species and variety, the dynamics, duration and intensity of soil water depletion, changes in water demand from the atmosphere, environmental conditions, as well as plant growth and the phenological state in which water deficit is developed. Plants' strategies to cope with drought normally involve a mixture of stress avoidance and tolerance strategies. Early responses of plants to drought stress usually help the plant to survive for some time. The acclimation of the plant to drought is indicated by the accumulation of certain new metabolites associated with the structural capabilities to improve plant functioning under drought stress. The main aspects of plant responses to water involve the maintenance of homeostasis (ionic balance and osmotic adjustment),

3.5 Plants Resistance to Water Stress

Plants optimise the morphology, physiology and metabolism of their organs and cells in order to maximise productivity under the drought conditions. The reactions of the plants to water stress differs significantly at various organisational levels depending upon intensity and duration of stress as well as plant species and its stage of development. Stress resistance in plant is divided into two categories, including stress tolerance and stress avoidance.

Drought avoidance is the ability of plant to maintain high tissue water potential under drought conditions, while drought tolerance is a plant's stability to maintain its normal functions even at low tissue water potentials. Drought avoidance is usually achieved through morphological changes in the plant, such as reduced stomatal conductance, decreased leaf area, development of extensive root systems and increased root/shoot ratios. On the other hand, drought tolerance is achieved by cell and tissue specific physiological, biochemical, and molecular mechanisms, which include specific gene expression and accumulation of specific proteins. The dehydration process of drought-tolerant plants is characterised by fundamental changes in water relation, biochemical and physiological process, membrane structure, and ultrastructure of sub cellular organelles. Some plants are able to cope with arid environments by mechanisms that mitigate drought stress, such as stomatal closure, partial senescence of tissues, reduction of leaf growth, development of water storage organs, and increased root length and density, in order to use water more efficiently.

4.0 CONCLUSION

Changes in the climatic condition all over the world under the influence of global warming are creating unusual weather phenomena often in the form of water deficit or in the form of floods and water logging. Not all the plants are equally capable in withstanding water stress or water surplus as their responses vary, most at times leading to reduced photosynthesis and resulting in lower biomass yields.

5.0 SUMMARY

Plants at their vegetative growth stages contain 80-90 per cent water, which keeps them turgid and erect. Plants experience water stress either when the water supply to their roots becomes limiting or when the transpiration rate becomes intense. As a result, cell enlargement decreases leading to growth inhibition and reproductive failure. Plants optimise the morphology, physiology and metabolism of their organs and cells in order to maximise productivity under deficit conditions.

6.0 TUTOR-MARKED ASSIGNMENT

1. Do plants need enough water?
2. State three reasons why plants need water.
3. Under what condition can we say the plant is water stress?
4. List the effects of water stress in plants that you know.
5. List some morphological characters that plant devise to cope with water stress.

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UNIT 6 LIGHT AND SOLAR RADIATION

CONTENTS

1.0 INTRODUCTION

Most terrestrial plants grow by selective absorption of natural light from the sun. Sunshine is important in plant growth because the heat and the light required by all growing plants are supplied by solar radiation. The solar radiation ranges from infrared to ultraviolet. Not all the radiation reaches earth's surface, because the ultraviolet wavelengths, that are the shorter wavelengths, are absorbed by gases in the atmosphere, primarily by ozone. Direct solar radiation has wavelengths ranging from 300 to 3,000 nm, and is divided into three bands: ultraviolet radiation, visible radiation and infrared radiation. The wavelengths of visible radiation for humans are in the range from 380 to 780 nm, and the peak of the visibility curve (photopic vision) is at 555 nm. While heat cannot entirely replace light in this process, light can in large measure replace heat. The quality and the quantity of the sun-light transmitted to growing plants are both dependent upon atmospheric conditions, as well as upon the season of the year. They vary from place to place and from month to month.

Of the various weather elements, sunshine, directly through radiation, and indirectly through its effect upon air temperatures, influences the distribution of crops. This is because it furnishes the required energy for certain chemical activities within growing plants, as well as promotes evaporation from the foliage. Abundant sunshine is required of most plants. In this unit you will be made to understand solar radiation and the energy content, energy balance and effects of solar radiation on plant growth and development.

2.0 OBJECTIVES

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

- discuss what is solar radiation and its constituents
- explain the concept of energy balance
- identify the effects of solar radiation on plants
- examine the effect of clouds on solar radiation
- identify the types of radiation.

3.0 MAIN CONTENT

Radiant energy from the Sun is the major source of energy for terrestrial life. Practically all the energy for all the physical and biological processes occurring on the Earth arise in the form of solar radiation. Radiation is the ultimate of all the changes and motion of the atmosphere and it is the single most important control of climate. It is a meteorological element of highest important. Radiation from the Sun comes in forms of short-wave electromagnetic radiation. The shortwave radiation is referred to as short-wave incoming radiation. The outgoing radiation from the soil is called the long-wave terrestrial radiation.

3.1 Energy Balance

Solar radiation is the set of electromagnetic radiation emitted by the Sun. The Sun behaves almost like a black body which emits energy according to Planck's law at a temperature of 6000 K. Solar radiation ranges goes infrared to ultraviolet. Not all the radiation reaches Earth's surface, because the ultraviolet wavelengths, that are the shorter wavelengths, are absorbed by gases in the atmosphere, primarily by ozone. The atmosphere acts as a filter to the bands of solar spectrum, and at its different layers as solar radiation passes through it to the Earth's surface, so that only a fraction of it reaches the surface. The atmosphere absorbs part of the radiation, reflects and scatters the rest some directly back to space, and some to the Earth, and then it is irradiated. All of these produce a thermal balance, resulting in radiant equilibrium cycle. The net radiation is the difference between total incoming and outgoing radiations and is a measure of the energy available at the ground surface. It is the energy available at the Earth’s surface to drive the processes of evaporation, air and soil heat fluxes as well as other smaller energy consuming processes such as photosynthesis and respiration.

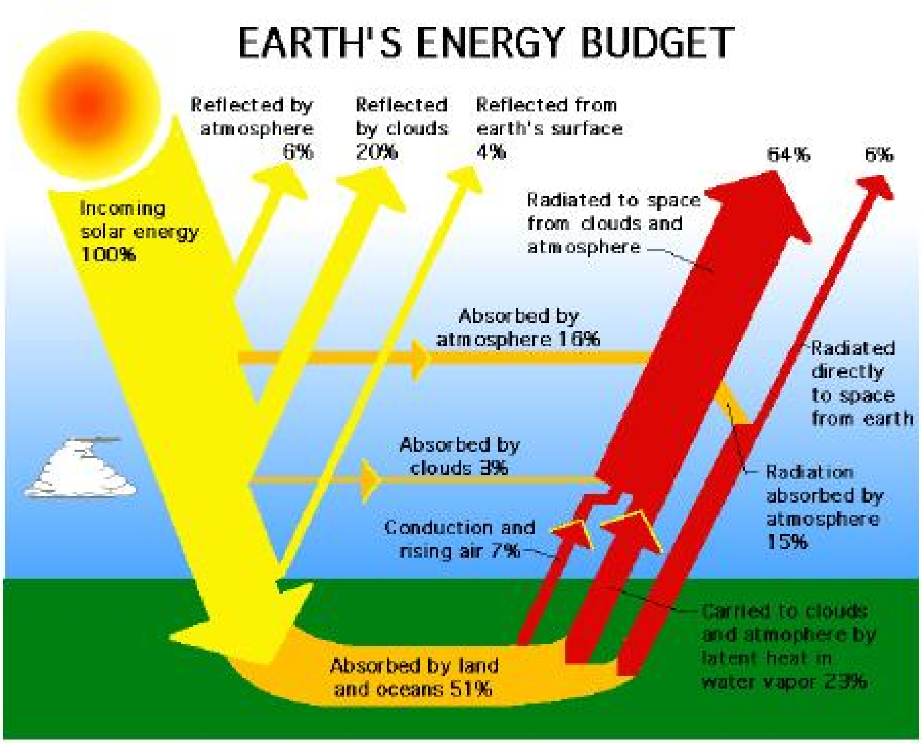

Figure x: Effects of clouds on the Earth's Energy Budget. This image is from a NASA site

3.2 Energy Wavelengths

Depending on the type of radiation, it is known that the 324 Wm-2 reaching the Earth in the upper atmosphere (1400 Wm-2 is the solar constant), 236 Wm-2 are reissued into space infrared radiation, 86 Wm-2 are reflected by the clouds and 20 Wm-2 are reflected by the ground as short-wave radiation. But part of the re-emitted energy is absorbed by the atmosphere and returned to the earth surface, causing the "greenhouse effect". The average energy that reaches the outside edge of the atmosphere from the sun is a fixed amount, called solar constant. This energy contains between 200 and 4000 nm wavelengths and it is divided into ultraviolet radiation, visible light and infrared radiation.

Ultraviolet radiation:
Ultraviolet radiation consists of shorter wavelengths band (360 nm). It has a lot of energy and interacts with the molecular bonds. These waves are absorbed by the upper atmosphere, especially by the ozone layer.

Visible Light:
This radiation band corresponds to the visible area with wavelengths between 360 nm (violet) and 760 nm (red), it has a great influence on living beings.

Infrared radiation:

This consists of wavelengths between 760 and 4000 nm. It corresponds to the longer wavelengths and it has little energy associated with it. Its absorption increases molecular agitation, causing increase in temperature.

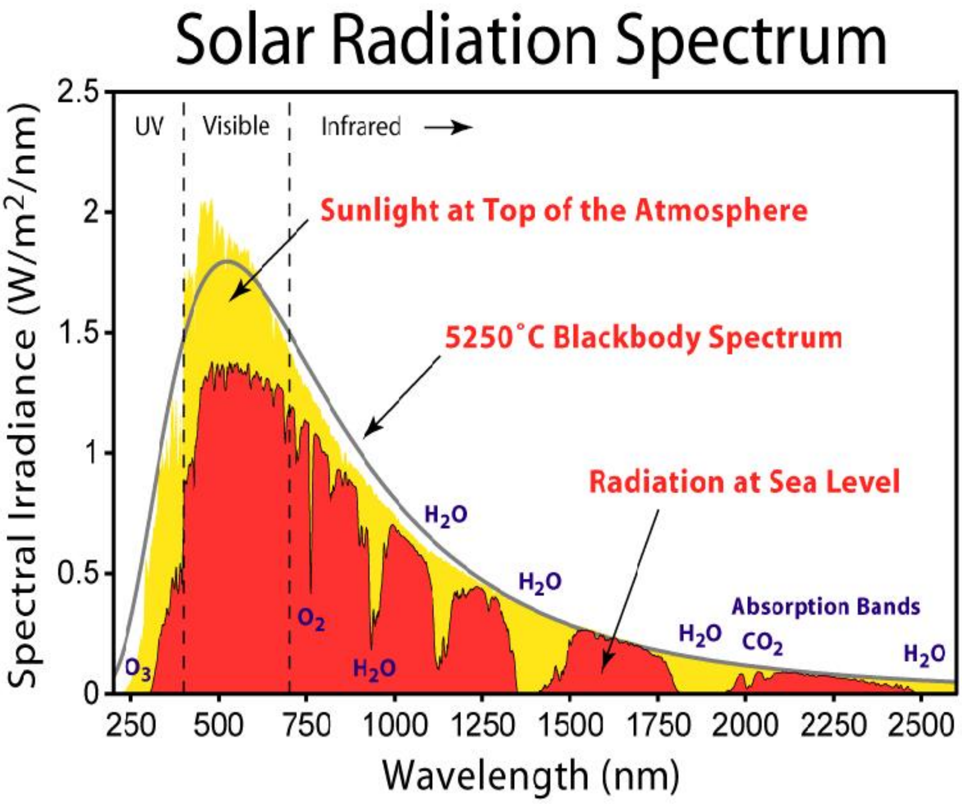

Fig. 1: Spectrum of solar radiation above the atmosphere and sea level (Source: Global Warming Art project)

3.3 Types of Radiation

Solar radiation on the earth can be classified as:

- **Direct radiation:**
- This radiation comes directly from the sun without any change in its direction. This type of radiation is characterized by projecting defined shadow onto the objects that intersect.
- **Diffuse radiation:**
- This radiation comes from all over the atmosphere as a result of reflection and scattering by clouds, particles in the atmosphere, dust, mountains, trees, buildings, the ground itself, and so on.

- **Global radiation:**
  This is the total radiation. It is the sum of the two radiations above. On a clear day with a clear sky, the direct radiation is predominant above the diffuse radiation.

3.4 Effects of cloud on Solar Radiation

1. Plants are able to use only a portion of the solar radiation spectrum. This portion is known as "photosynthetically active radiation (PAR)" and is estimated to be about 43% to 50% of total radiation.
2. Amount of PAR available to a crop is reduced proportionately to cloud cover.
3. On a cloudy and partly cloudy day, PAR will be reduced by 50% and 25% respectively and by over 60% on rainy days.
4. It is not surprising, then, that cloudy, rainy periods have significant effect on crop development and yield.

3.5 Instruments Used to Measure Solar Radiation

The instruments used to measure solar radiation include:

a) Bellanis pyranometer or solarimeter
b) Sunshine recorder
c) Line spectrum sensor
d) Photometer
e) Lux meter measures the light intensity

3.6 Effects of Solar Radiation on Crops

Crop production is exploitation of solar radiation. One of the most important factors that influence plants development is the solar radiation intercepted by the crop. Solar radiation brings energy to the metabolic process of the plants. The principal process is the photosynthetic assimilation using water, CO_2 and light energy. A part of this, energy is used in the evaporation process inside the different organs of the plants, and also in the transpiration through the stomata.

Photosynthesis is a chemical process that converts carbon dioxide into organic compounds, especially sugars, using the energy from sunlight. Depending on how carbon dioxide is fixed the plants can be grouped into three types: C3, C4, and CAM.

The C3 plants are usually the more superior plants, which are the temperate weather crops (wheat, barley and sunflower, etc.).

The C4 category are species from arid weather or hotter or tropical weathers (corn, sugar or sorghum). The C3 types are generally considered less productive than C4. One difference lies in the fact that photorespiration is very active in C3 plants. The photorespiration makes plants increase the oxygen consumption when they are illuminated by the sun, and this is very important for agriculture in temperate zones. In a hot day with no wind, the CO_2 concentration in the plant decreases considerably for photosynthesis consumption. Therefore, the relationship between carbon and oxygen decreases, and the CO_2 fixation increases the photorespiration. Crops like rice critically requires light 25 days prior to flowering while for barley, it is at flowering period.

4.0 CONCLUSION

Radiant energy from the Sun is the major source of energy for terrestrial life. Practically all the energy for all the physical and biological processes occurring on the Earth arises in the form of solar radiation. The productivity of a crop depends on the ability of plant cover to intercept the incident radiation. Of the various weather elements, sunshine, directly through radiation, and indirectly through its effect upon air temperatures, influences the distribution of crops.

5.0 SUMMARY

Most terrestrial plants grow by selective absorption of natural light from the sun. Sunshine is important in plant growth because the heat and the light required by all growing plants are supplied by solar radiation.

6.0 TUTOR-MARKED ASSIGNMENT

1. What do you understand by energy balance?
2. What is the effect of cloud cover on solar radiation?
3. With reference to solar radiation, does the tropical region has any advantage over the temperate region with respect to productivity of crops?
4. Differentiate between C3 crops and C4 crops.

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UNIT 7 ROLE OF PLANT NUTRIENTS

CONTENTS

1.0 INTRODUCTION

Plants, like all other living things, need nutrients for their growth and development. Plants require 16 essential elements as nutrients. Nutrients like carbon, hydrogen, and oxygen are derived from the atmosphere and soil water. The remaining 13 essential elements (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, zinc, manganese, copper, boron, molybdenum, and chlorine) are supplied either from soil minerals and soil organic matter or by organic or inorganic fertilisers. For plants to utilise these nutrients efficiently, light, heat, and water must be adequately supplied. Cultural practices and control of diseases and insects also play important roles in crop production with respect to nutrient uptake. Each type of plant is unique and has an optimum nutrient range as well as a minimum requirement level. Below this minimum level, plants start to show nutrient deficiency symptoms. Excessive nutrient uptake can also cause poor growth because of toxicity. Therefore, the proper amount of application and the placement of nutrients are important. This unit will describe the essential nutrients, the chemical forms in which they are available to plants, their function in plants, symptoms of their deficiencies, and recommended nutrient levels.

2.0 OBJECTIVES

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

- list the names of macro and micro nutrients for plants
- discuss the functions of nutrients in plants
- examine the symptoms of nutrient deficiencies in plants
- identify the individual nutrient levels for various crops.

3.0 MAIN CONTENT

There is a large number of elements in nature out of which 16 are important for the proper growth and development of crop plants. Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus, Potash, Calcium, Magnesium and Sulfur are called macro or major nutrients and required in comparatively large amounts. Iron, Copper, Zinc, Boron, Molybdenum, Manganese and Chloride are the micro or minor nutrients which required in smaller quantities for vegetative and reproductive growth of crop plants. C, H and O contribute the 85-90 % of the total plant content. N gives dark-green colour to crop plants and it increases the vegetative growth of crop plants. It is most important for preparation of starch in leaves and production of amino acids. P is the constituent of certain nucleic acids, phosphatides, chromosomes and "coenzymes”. P works as a catalyst in about 60 enzymatic systems of the plants and regulates the water in plants and reduces the negative effects of salts in the plants. Ca is the important constituent of plant cell wall and it promotes early root growth and development. Micro nutrients are always required in very little amounts but play a very important role in the physiological processes of the crop plants.

3.1 Important Nutrients and Their Sources

There are 17 most important nutrients for plants. Plants must obtain the following mineral nutrients from their growing medium. These elements stay beneath the soil as salts and are consumed by plants as ions. The macronutrients are consumed in larger quantities; hydrogen, oxygen, nitrogen and carbon contribute to over 95% of a plants' entire biomass on a dry matter weight basis. Micronutrients are present in plant tissue in quantities measured in parts per million, ranging from 0.1 to 200 ppm, or less than 0.02% dry weight. Most soil conditions across the world can provide plants with nutrients and are therefore adapted to that climate and soil with sufficient nutrition for a complete life cycle, without the addition of nutrients as fertilisers. However, if the soil is cropped it may be necessary to artificially modify fertility with the application of fertilisers to promote vigorous growth and increase or sustain yield. This is done because, even with adequate water and light, nutrient deficiency can limit growth and crop yield.

The table below gives the list of important plant nutrients, their categories and sources of supply to plants.

Table 1: Categories of nutrients for plant growth and development

Category	Name of nutrient	Source of supply
Macro-nutrient	Carbon Hydrogen Oxygen	Air and water
Primary macro-nutrient	Nitrogen Phosphorus Potassium	Soil
Secondary and tertiary macro-nutrients	Sulphur Calcium Magnesium	Soil
Micro-nutrients	Iron Molybdenum Boron Copper Manganese Sodium Zinc Nickel Chlorine Cobalt Aluminum Silicon Vanadium selenium	Soil

3.2 Plant Nutrient, Form Available to Plants, Functions and Deficiency Symptoms

3.2.1 Nitrogen

Symbol: N; available to plants as nitrate (NO3 –) and ammonium (NH4 +) ions.

Nutrient functions

- N is biologically combined with C, H, O, and S to create amino acids, which are the building blocks of proteins. Amino acids are used in forming protoplasm, the site for cell division and thus for plant growth and development.
- Since all plant enzymes are made of proteins, N is needed for all of the enzymatic reactions in a plant.

- N is a major part of the chlorophyll molecule and is therefore necessary for photosynthesis.
- N is a necessary component of several vitamins.
- N improves the quality and quantity of dry matter in leafy vegetables and protein in grain crops.

Deficiency symptoms

- Stunted growth may occur because of reduction in cell division.
- Pale green to light yellow color (chlorosis) appearing first on older leaves, usually starting at the tips.

Depending on the severity of deficiency, the chlorosis could result in the death and/or dropping of the older leaves. This is caused by the translocation of N from the older to the younger tissues.

- Reduced N lowers the protein content of seeds and vegetative parts. In severe cases, flowering is greatly reduced.
- N deficiency causes early maturity in some crops, which results in a significant reduction in yield and quality.


Severe nitrogen deficiency in citrus.
Nitrogen deficient corn; yellowing proceeds down the midrib of older leaves.

3.2.2 Phosphorus

Symbol:
P; available to plants as orthophosphate ions ($HPO4^{2-}$, $H2PO4^{-}$).

Nutrient functions

- In photosynthesis and respiration, P plays a major role in energy storage and transfer as ADP and ATP (adenosine di- and triphosphate) and DPN and TPN (di- and triphosphopyridine nucleotide).
- P is part of the RNA and DNA structures, which are the major components of genetic information.

- Seeds have the highest concentration of P in a mature plant, and P is required in large quantities in young cells, such as shoots and root tips, where metabolism is high and cell division is rapid.
- P aids in root development, flower initiation, and seed and fruit development.
- P has been shown to reduce disease incidence in some plants and has been found to improve the quality of certain crops.

Deficiency symptoms

- Because P is needed in large quantities during the early stages of cell division, the initial overall symptom is slow, weak, and stunted growth.
- P is relatively mobile in plants and can be transferred to sites of new growth, causing symptoms of dark to blue-green coloration to appear on older leaves of some plants. Under severe deficiency, purpling of leaves and stems may appear.
- Lack of P can cause delayed maturity and poor seed and fruit development.

Phosphorus deficient corn; lower leaves become reddish-purple

3.2.3 Potassium

Symbol: K; available to plants as the ion K^+

Nutrient functions

- Unlike N and P, K does not form any vital organic compounds in the plant. However, the presence of K is vital for plant growth because K is known to be an enzyme activator that promotes metabolism K assists in regulating the plant's use of water by controlling the opening and closing of leaf stomata, where water is released to cool the plant.
- In photosynthesis, K has the role of maintaining the balance of electrical charges at the site of ATP production.

- K promotes the translocation of photosythates (sugars) for plant growth or storage in fruits or roots.
- Through its role assisting ATP production, K is involved in protein synthesis.
- K has been shown to improve disease resistance in plants, improve the size of grains and seeds, and improve the quality of fruits and vegetables.

Deficiency symptoms

- The most common symptom is chlorosis along the edges of leaves (leaf margin scorching). This occurs first in older leaves, because K is very mobile in the plant.
- Because K is needed in photosynthesis and the synthesis of proteins, plants lacking K will have slow and stunted growth.
- In some crops, stems are weak and lodging is common if K is deficient.
- The size of seeds and fruits and the quantity of their production is reduced.

Potassium deficient tomato leaves have chlorotic and necrotic spotting.

Potassium deficient banana; older leaves become chlorotic, then necrotic, and the tip of the midrib bends downward.

3.2.4 Calcium

Symbol: Ca; available to plants as the ion Ca^{2+}

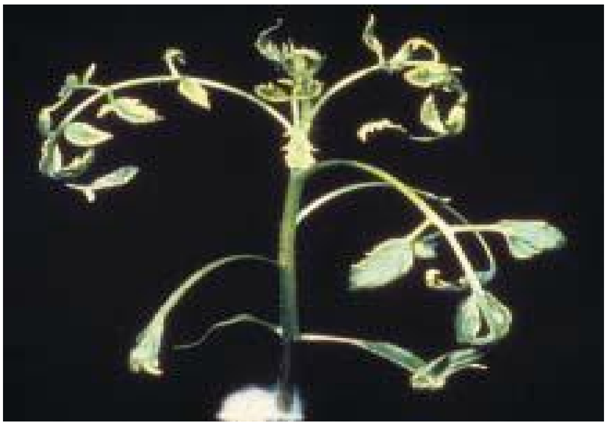
Nutrient functions

- Ca has a major role in the formation of the cell wall membrane and its plasticity, affecting normal cell division by maintaining cell integrity and membrane permeability.
- Ca is an activator of several enzyme systems in protein synthesis and carbohydrate transfer.
- Ca combines with anions including organic acids, sulfates, and phosphates. It acts as a detoxifying agent by neutralizing organic acids in plants.
- Ca is essential for seed production in peanuts.

- Ca indirectly assists in improving crop yields by reducing soil acidity when soils are limed.

Deficiency symptoms

- Ca is not mobile and is not translocated in the plant, so symptoms first appear on the younger leaves and leaf tips. The growing tips of roots and leaves turn brown and die.
- Ca deficiency is not often observed in plants because secondary effects of high acidity resulting from soil calcium deficiency usually limit growth, precluding expressions of Ca deficiency symptoms.
- Without adequate Ca, which in the form of calcium pectate is needed to form rigid cell walls, newly emerging leaves may stick together at the margins, which causes tearing as the leaves expand and unfurl. This may also cause the stem structure to be weakened.
- In some crops, younger leaves may be cupped and crinkled, with the terminal bud deteriorating.
- Buds and blossoms fall prematurely in some crops.



Calcium deficient tomato;
young leaves become twisted and cupped

3.2.5 Magnesium

Symbol: Mg; available to plants as the ion Mg^{2+}

Nutrient functions

- The predominant role of Mg is as a major constituent of the chlorophyll molecule, and it is therefore actively involved in photosynthesis.
- Mg is a co-factor in several enzymatic reactions that activate the phosphorylation processes.
- Mg is required to stabilize ribosome particles and also helps stabilize the structure of nucleic acids.
- Mg assists the movement of sugars within a plant.

Deficiency symptoms

- Because Mg is a mobile element and part of the chlorophyll molecule, the deficiency symptom of interveinal chlorosis first appears in older leaves. Leaf tissue between the veins may be yellowish, bronze, or reddish, while the leaf veins remain green. Corn leaves appear yellow striped with green veins, while crops such as potatoes, tomatoes, soybeans, and cabbage show orange-yellow colour with green veins.
- In severe cases, symptoms may appear on younger leaves and cause premature leaf drop.
- Symptoms occur most frequently in acid soils and soils receiving high amounts of K fertiliser or Ca.

Magnesium deficient sweet potato leaves become reddish-purple.

3.2.6 Sulfur

Symbol: S; available to plants as the sulfate ion, $SO4^{2-}$

Nutrient functions

- S is essential in forming plant proteins because it is a constituent of certain amino acids.
- It is actively involved in metabolism of the B vitamins biotin and thiamine and co-enzyme A.
- S aids in seed production, chlorophyll formation, nodule formation in legumes, and stabilising protein structure.

Deficiency symptoms

- Younger leaves are chlorotic with evenly, lightly colored veins. In some plants (e.g., citrus) the older leaves may show symptoms first. However, deficiency is not commonly found in most plants.
- Growth rate is retarded and maturity is delayed.
- Plant stems are stiff, thin, and woody.
- Symptoms may be similar to N deficiency and are most often found in sandy soils that are low in organic matter and receive moderate to heavy rainfall.

Sulfur deficient sorghum; young leaves are uniformly chlorotic.

3.2.7 Boron

Symbol: B. Available to plants as borate, H3BO3

Nutrient functions

- B is necessary in the synthesis of one of the bases for RNA formation and in cellular activities.
- B has been shown to promote root growth.
- B is essential for pollen germination and growth of the pollen tube.
- B has been associated with lignin synthesis, activities of certain enzymes, seed and cell wall formation, and sugar transport.

Deficiency symptoms

- Generally, B deficiency causes stunted growth, first showing symptoms on the growing point and younger leaves. The leaves tend to be thickened and may curl and become brittle.
- In many crops, the symptoms are well defined and crop-specific, such as:
- Peanuts: hollow hearts
- Celery: crooked and cracked stem
- Beets: black hearts
- Papaya: distorted and lumpy fruit
- Carnation: splitting of calyx
- Chinese cabbage: midribs crack, turn brown
- Cabbage, broccoli, and cauliflower: pith in hollow stem

Boron deficient papaya fruits develop bumps

Boron deficient tomato leaves are chlorotic, with some curling

3.2.8 Copper

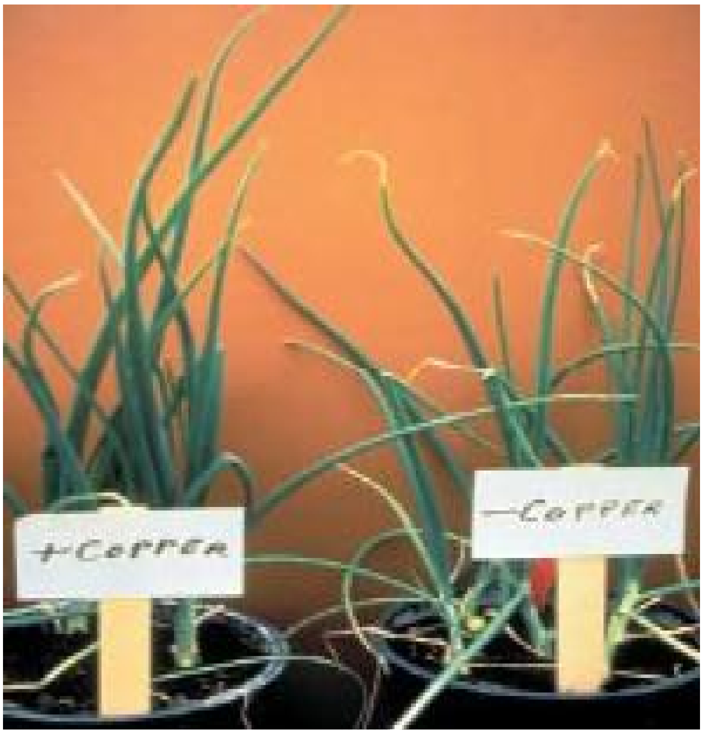
Symbol: Cu; available to plants as the ion Cu^{++}

Nutrient functions

- Cu is essential in several plant enzyme systems involved in photosynthesis.
- Cu is part of the chloroplast protein plastocyanin, which forms part of the electron transport chain.
- Cu may have a role in the synthesis and/or stability of chlorophyll and other plant pigments.

Deficiency symptoms

- Reduced growth, distortion of the younger leaves, and possible necrosis of the apical meristem.
- In trees, multiple sprouts occur at growing points, resulting in a bushy appearance. Young leaves become bleached, and eventually there is defoliation and dieback of twigs.
- In forage grasses, young leaf tips and growing points are affected first. The plant is stunted and chlorotic.



Copper deficient onion leaves have white tips and twist in spirals or right angles

3.2.9 Chlorine

Symbol: Cl; available to plants as the chloride ion, Cl^-

Nutrient functions

- Cl is essential in photosynthesis, where it is involved in the evolution of oxygen.
- Cl increases cell osmotic pressure and the water content of plant tissues.
- Cl is found in many bacteria and fungi.
- Cl reduces the severity of certain fungal diseases, e.g., take-all disease of wheat.

Deficiency symptoms

- Chlorosis of younger leaves and wilting of the plant.
- Deficiency seldom occurs because Cl is found in the atmosphere and rainwater.

Chlorine deficient tomato; leaf edges roll upward

3.2.10 Iron

Symbol: Fe; available to plants as Fe^{2+}, Fe^{3+}

Nutrient functions

- Fe is essential in the heme enzyme system in plant metabolism (photosynthesis and respiration). The enzymes involved include catalase, peroxidase, cytochrome oxidase, and other cytochromes.
- Fe is part of protein ferredoxin and is required in nitrate and sulfate reductions.
- Fe is essential in the synthesis and maintenance of chlorophyll in plants.
- Fe has been strongly associated with protein metabolism.

Deficiency symptoms

- Interveinal chlorosis in younger leaves. The youngest leaves may be white, because Fe, like Mg, is involved in chlorophyll production.
- Usually observed in alkaline or over-limed soils.

Iron deficient soybean; young leaves have interveinal chlorosis.

3.2.11 Manganese

Symbol: Mn; available to plants as Mn^{2+}, Mn^{3+}

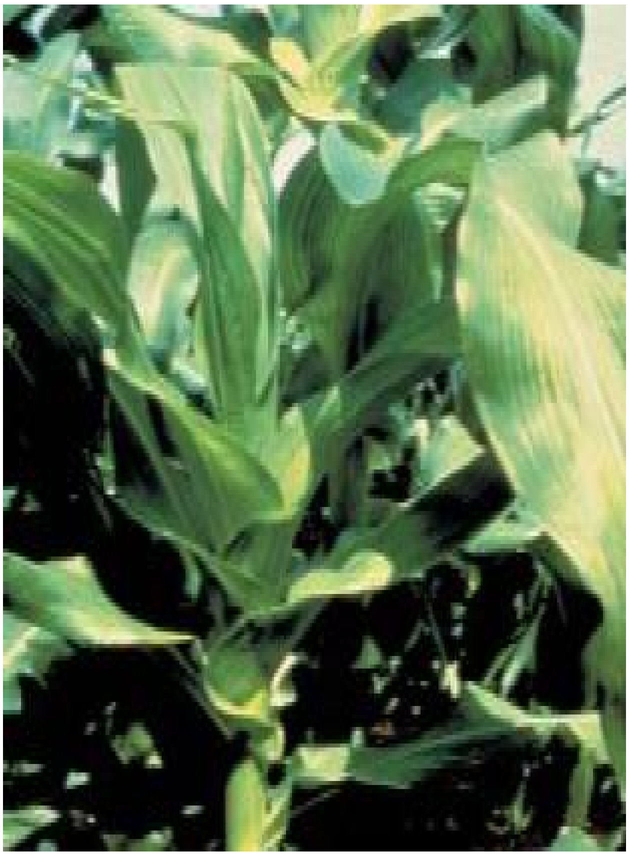
Nutrient functions

- Mn primarily functions as part of the plant enzyme system, activating several metabolic functions. It is a constituent of pyruvate carboxylase.

- Mn is involved in the oxidation-reduction process in photosynthesis.
- Mn is necessary in Photosystem II, where it participates in photolysis.
- Mn activates indole acetic acid oxidase, which then oxidizes indole acetic acid in plants.

Deficiency symptoms

- Symptoms first appear as chlorosis in young tissues.
  Unlike Fe chlorosis symptoms, in dicots Mn chlorosis shows up as tiny yellow spots.
- In monocots, greenish-grey specks appear at the lower base of younger leaves. The specks may eventually become yellowish to yellow-orange.
- In legumes, necrotic areas develop on the cotyledons, a symptom known as marsh spots.



Manganese deficient corn; young leaves are olive-green and slightly streaked

3.2.12 Molybdenum

Symbol: Mo; available to plants as molybdate, MoO_4

Nutrient functions

- Mo is a necessary component of two major enzymes in plants, nitrate reductase and nitrogenase, which are required for normal assimilation of N.
- Mo is required by some soil microorganisms for nitrogen fixation in soils.

Deficiency symptoms

- Deficiency symptoms resemble those of N because the function of Mo is to assimilate N in the plant. Older and middle leaves become chlorotic, and the leaf margins roll inwards.
- In contrast to N deficiency, necrotic spots appear at the leaf margins because of nitrate accumulation.
- Deficient plants are stunted, and flower formation may be restricted.
- Mo deficiency can be common in nitrogen-fixing legumes.

Molybdenum deficient onion leaves show wilting and dieback

Molybdenum deficient tomato leaves have interveinal chlorosis

3.2.13 Zinc

Symbol: Zn; available to plants as Zn^{++}

Nutrient functions

- Zn is required in the synthesis of tryptophan, which in turn is necessary for the formation of indole acetic acid in plants.
- Zn is an essential component of several metallo-enzymes in plants (variety dehydorgenases) and therefore is necessary for several different function in plant metabolism.
- The enzyme carbonic anhydrase is specifically activated by Zn.
- Zn has a role in RNA and protein synthesis.

Deficiency symptoms

- Interveinal chlorosis occurs on younger leaves, similar to Fe deficiency. However, Zn deficiency is more defined, appearing as banding at the basal part of the leaf, whereas Fe deficiency results in interveinal chlorosis along the entire length of the leaf.
- In vegetable crops, colour change appears in the younger leaves first. The new leaves are usually abnormally small, mottled, and chlorotic.
- In citrus, irregular interveinal chlorosis occurs with small, pointed, mottled leaves. Fruit formation is significantly reduced.

- In legumes, stunted growth with interveinal chlorosis appears on the older, lower leaves. Dead tissue drops out of the chlorotic spots.

Zinc deficient corn. Young leaves have interveinal, chlorotic stripes on both sides of midrib

4.0 CONCLUSION

Most soil conditions across the world can provide plants with nutrients and are therefore adapted to that climate and soil type with sufficient nutrition for a complete life cycle, without the addition of nutrients as fertilisers. However, if the soil is cropped it may be necessary to artificially modify fertility with the application of fertilizers to promote vigorous growth and increase or sustain yield. This is done because, even with adequate water and light, nutrient deficiency can limit growth and crop yield.

5.0 SUMMARY

Plants, like all other living things, need nutrients for their growth and development. Plants require 16 essential elements. Each type of plant is unique and has an optimum nutrient range as well as a minimum requirement level. Below this minimum level, plants start to show nutrient deficiency symptoms. Excessive nutrient uptake can also cause poor growth because of toxicity. Therefore, the proper amount of application and the placement of nutrients are important.

6.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between macro and micro nutrients necessary for plant growth.
2. List six macro nutrients.
3. List eight micro nutrients.
4. Describe deficiency symptoms in plants associated with the following nutrients:
   a. Nitrogen
   b. Phosphorus
   c. Potassium
   d. Boron
   e. Zinc
   f. Iron
   g. Calcium

7.0 REFERENCES/FURTHER READING

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UNIT 8 SEXUAL AND ASEXUAL REPRODUCTION

CONTENTS

1.0 INTRODUCTION

Reproduction is a fundamental feature of all known life. Each individual organism exists as a result of reproduction. Reproduction is essential for 'Continuity of Life' and without it, all life will cease to exist. This unit is based on reproduction in plants.

Reproduction (or procreation or breeding) is the biological process by which new individual organisms – "offspring" – are produced from their "parents".

There are two forms of reproduction in plants, Asexual and Sexual. In asexual reproduction, an organism can reproduce without the involvement of another organism; while sexual reproduction typically requires sexual interaction of two specialised organisms, which typically involves a male fertilising a female of the same species to create offspring whose genetic characteristics are derived from those of the two parental organisms.

2.0 OBJECTIVES

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

- discuss the meaning of reproduction
- identify the two types of reproduction in plants
- examine types of asexual reproduction
- describe the development processes in seed and fruit production
- explain the differences between sexual and asexual reproduction.

3.0 MAIN CONTENT

Plant reproduction is the process by which plants generate new individuals, or offspring. Reproduction is either sexual or asexual. Sexual reproduction is the formation of offspring by the fusion of gametes. Asexual reproduction is the formation of offspring without the fusion of gametes. Sexual reproduction results in offspring that is genetically different from the parents. Asexual offspring are genetically identical except for mutation. In higher plants, offspring are packaged in a protective seed, which can be long lived and can disperse the offspring some distance from the parents. In flowering plants (angiosperms), the seed itself is contained inside a fruit, which may protect the developing seeds and aid in their dispersal.

3.1.1 Sexual Reproduction- Seed Development

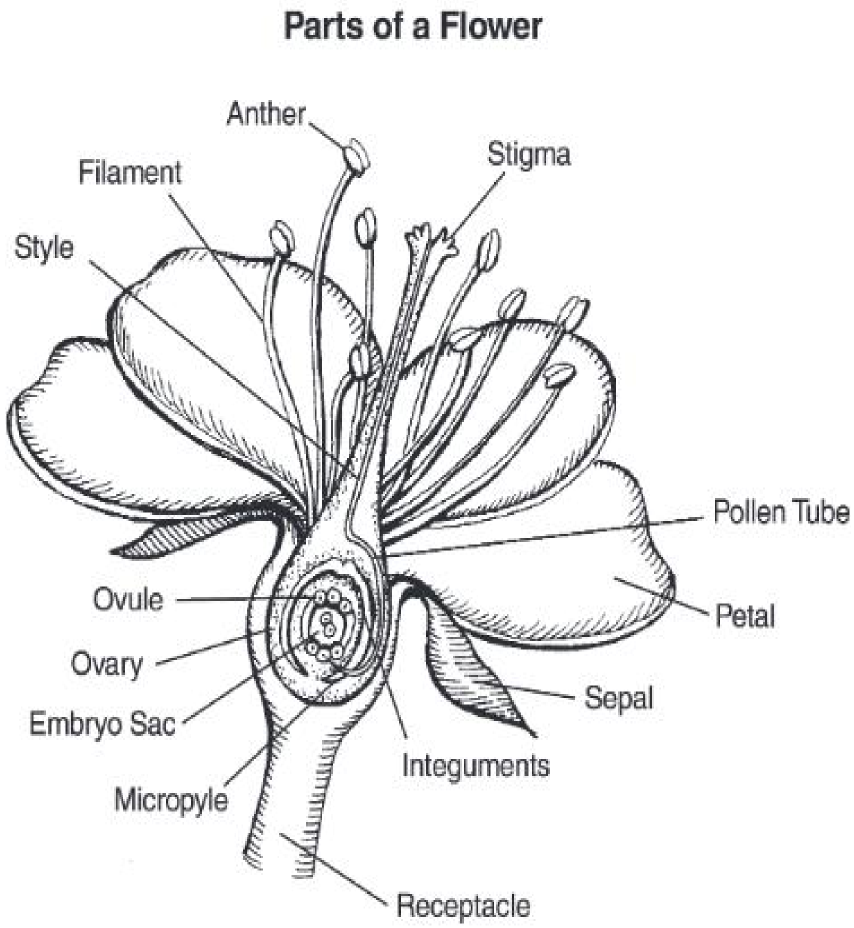
Sexual reproduction in plants results from fertilisation, the union, of gametes (cells that have undergone meiosis) from two genetically different plants. Meiosis reduces the number of chromosomes in half producing gametes. Fertilisation recombines gametes from different individuals, producing a zygote, which develops into either spores or seeds. The main purpose of sexual reproduction is the rearrangement of genes in the next generation. This serves to increase the genetic diversity of the population, enhancing the evolutionary viability of the species in the face of changing environmental factors.

All plants have a life cycle that consists of two distinct forms that differ in size and the number of chromosomes per cell. In flowering plants, the large, familiar form that consists of roots, shoots, leaves, and reproductive structures (flowers and fruit) is diploid and is called the sporophyte. The sporophyte produces haploid microscopic gametophytes that are dependent on tissues produced by the flower. The reproductive cycle of a flowering plant is the regular, usually seasonal, cycling back and forth from sporophyte to gametophyte. The flower produces two kinds of gametophytes, male and female. The female gametophyte arises from a cell within the ovule**,** a small structure within the ovary of the flower. The ovary is a larger structure within the flower that contains and protects usually many ovules. Flowering plants are unique in that their ovules are entirely enclosed in the ovary. The ovary itself is part of a larger structure called the carpel, which consists of the stigma, style, and ovary. Each ovule is attached to ovary tissue by a stalk called the funicle. The point of attachment of the funicle to the ovary is called the placenta.

The male gametophyte is the mature pollen grain. Pollen is produced in the anthers, which are attached at the distal end of filaments. The filament and anther together constitute the stamen, the male sex organ. Through chemical recognition, the pollen tube changes its direction of growth and penetrates through the placenta to the ovule. Here the tube reaches the embryo sac lying close to the micropyle, and sexual fertilization takes place. It involves union of both male and female 'gametes' and leads to restoration of the number of chromosomes to form a Diploid Zygote, which then develops into the offspring. The resulting genetic composition has characteristics of both the parent plants from which it is derived.

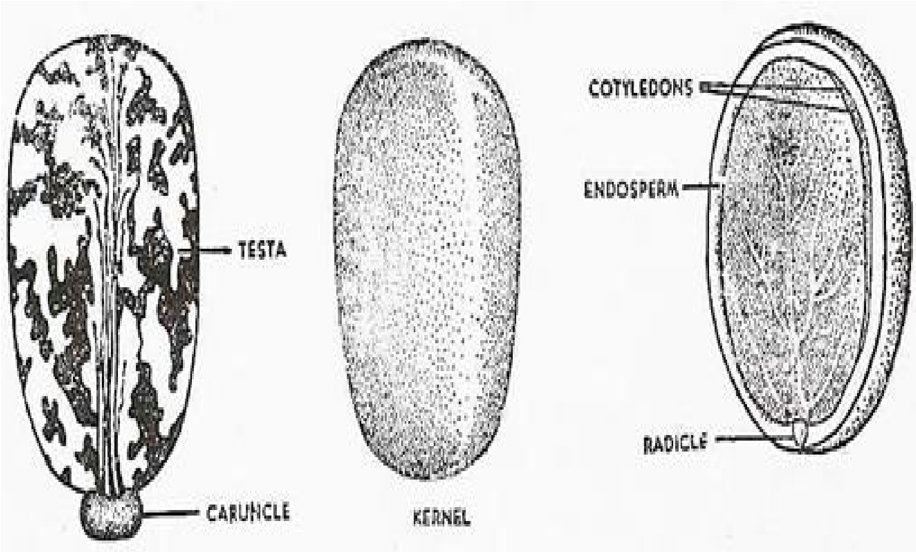
After fertilisation, the diploid zygote develops into the embryo, and the triploid endosperm cells multiply and provide nutrition. The testa usually shows a scar called the hilum where the ovule was originally attached to the funicle. In some seeds a ridge along the testa called the raphe shows where the funicle originally was pressed against the ovule. The micropyle of the ovule usually survives as a small pore in the seed coat that allows passage of water during germination of the seed.

The embryo consists of the cotyledon(s)**,** epicotyl, and hypocotyl. The cotyledons resemble small leaves, and are usually the first photosynthetic organs of the plant. The portion of the embryo above the cotyledons is the epicotyl, and the portion below is the hypocotyl. The epicotyl is an apical meristem that produces the shoot of the growing plant and the first true leaves after germination. The hypocotyl develops into the root. Often the tip of the hypocotyl, the radicle, is the first indication of germination as it breaks out of the seed. Flowering plants are classified as monocotyledons or dicotyledons (most are now called eudicots) based on the number of cotyledons produced in the embryo. Common monocotyledons include grasses, sedges, lilies, irises, and orchids; common dicotyledons include sunflowers, roses, legumes, and all nonconiferous trees. The endosperm may be consumed by the embryo, as in many legumes, which use the cotyledons as a food source during germination. In other species the endosperm persists until germination, when it is used as a food.

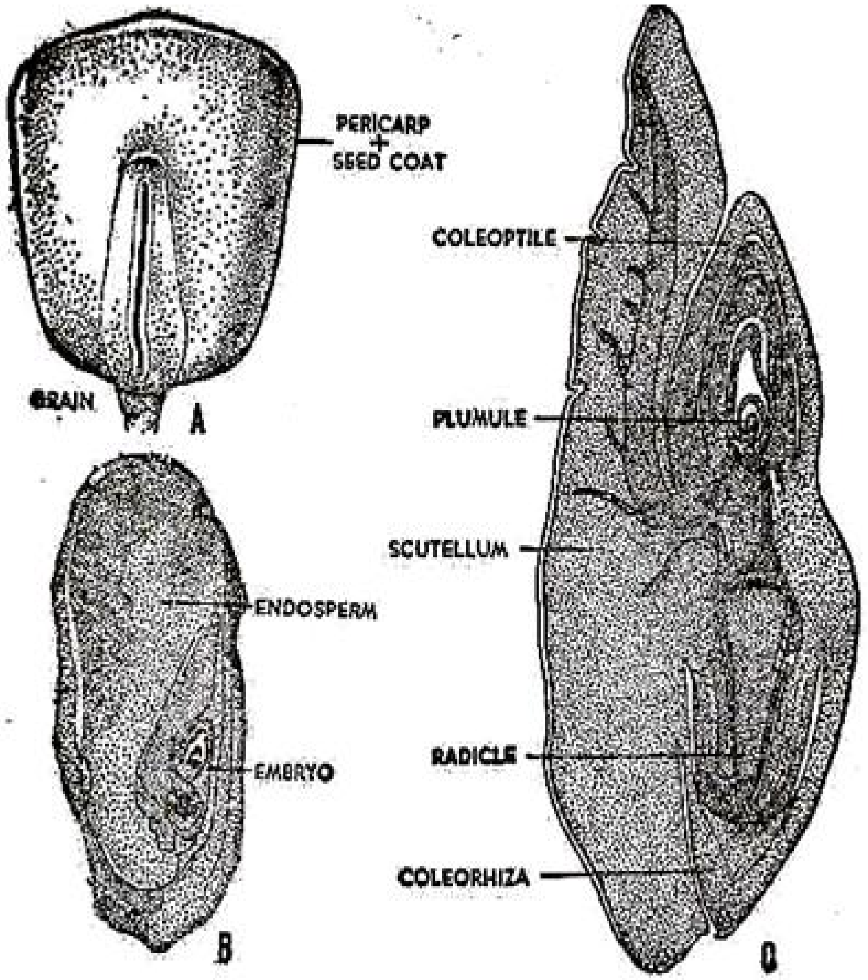


3.1.2 Sexual Reproduction-Fruit Development

The fruit of a flowering plant is the mature ovary. As seeds mature, the surrounding ovary wall forms a protective structure that may aid in dispersal. The surrounding ovary tissue is called the pericarp and consists of three layers. From the outside to inside, these layers are the exocarp, mesocarp, and endocarp. The exocarp is usually tough and skinlike. The mesocarp is often thick, succulent, and sweet. The endocarp, which surrounds the seeds, may be hard and stony, as in most species with fleshy fruit, such as mango.

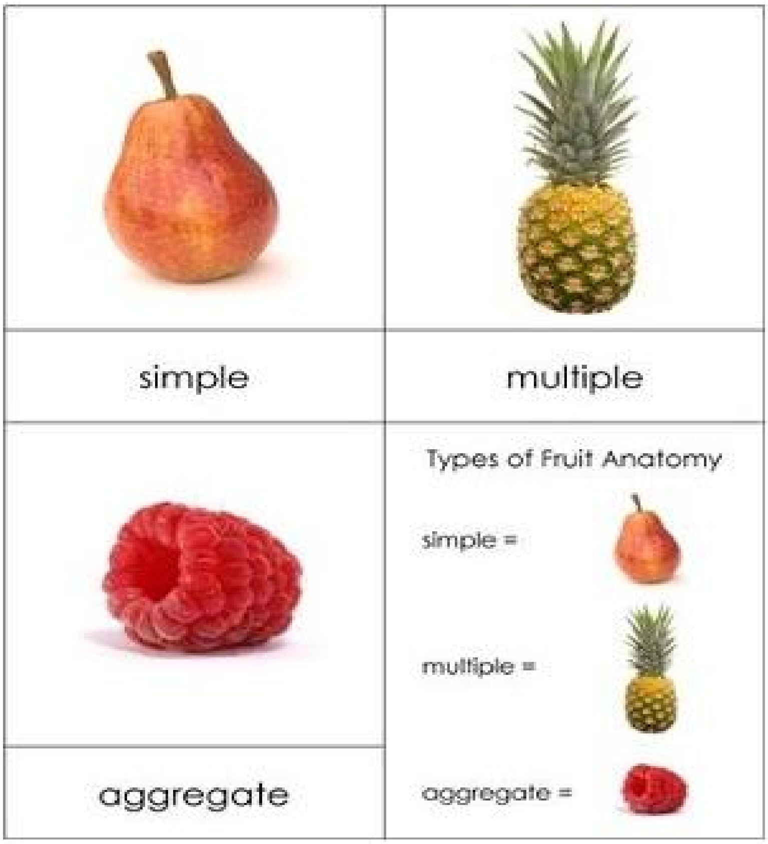


Structure of castor oil seed



Structure of maize grain: A-Seed; B-Same cut length wise; C-Embryo enlarged

A fruit is termed simple if it is produced by a single ripened ovary in a single flower (apples, oranges). An aggregated fruit is a cluster of mature ovaries produced by a single flower (blackberries, strawberries). A multiple fruit is a cluster of many ripened ovaries on separate flowers growing together in the same inflorescence (pineapple). A simple fruit may be fleshy or dry. A fleshy simple fruit is classified as a berry (grape, tomato, papaya), pepo (cucumber, watermelon, pumpkin), hesperidium (orange), drupe (apricot), or pome (apple). Dry simple fruits have a dry pericarp at maturity. They may or may not dehisce, or split, along a seam to release the seeds. A dehiscent dry fruit is classified as legume or pod (pea, bean), silique or silicle (mustard), capsule (poppy, lily), or follicle (milkweed, larkspur, columbine). An indehiscent dry fruit that does not split to release seeds is classified as an achene (sunflower, buttercup, sycamore), grain or caryopsis (grasses such as corn, wheat, rice, barley), schizocarp (carrot, celery, fennel), winged samara (maple, ash, elm), nut (acorn, chestnut, hazelnut), or utricle (duckweed family). Some fruiting bodies contain non-ovary tissue and are sometimes called pseudocarps. The sweet flesh of apples and pears, for example, is composed not of the pericarp but the receptacle, or upper portion, of the flowering shoot to which petals and other floral organs are attached.



Fruiting bodies of all kinds function to protect and disperse the seeds they contain. Protection can be physical (hard coverings) or chemical (repellents of seed predators). Sweet, fleshy fruits are attractive food for birds and mammals that consume seeds along with the fruit and pass the seeds intact in their fecal matter, which can act as a fertilizer. Dry fruits are usually adapted for wind dispersal of seeds, as for example with the assistance of wing-like structures or a fluffy pappus that provides buoyancy. The diversity of fruiting bodies reflects in part the diversity of dispersal agents in the environment, which select for different fruit size, shape, and chemistry.

3.1 Asexual Reproduction

The ability to produce new individuals asexually is common in plants. In asexual reproduction, new plants are produced that are genetically identical clones of the parent plant, and without the contribution of genetic material from another plant. Asexual reproduction in plants can be further divided into two: Vegetative reproduction and apomixis.

- **Vegetative Reproduction in Plants:**

When a vegetative piece of the original plant such as root, stem or leaf is involved in producing an offspring, it is known as 'Vegetative Reproduction in Plants.' It is often known as a process of 'Survival' and expansion of biomass. Below are examples of vegetative reproduction.

Budding
Budding is a form of asexual reproduction in which a new organism develops from an outgrowth or bud due to cell division at one particular site. The new organism remains attached as it grows, separating from the parent organism only when it is mature, leaving behind scar tissue. For example: Yeast is a single-celled organism which reproduces by this mode.

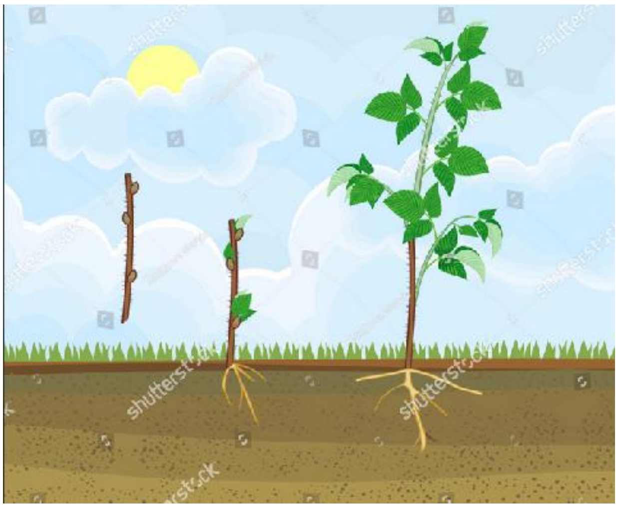
Fragmentation
Fragmentation in plants is a form of asexual reproduction or cloning in which an organism is split into fragments. Each of these fragments develops into mature, fully grown individuals that are clones of the original organism. Fragmentation is the mode of reproduction in Algae such as Spirogyra.

Spore Formation
The term 'Sporogenesis' is used to refer to the process of reproduction in plant via spores. Reproduction via spores involves the spreading of the spores by water or air. Reproductive spores grow into multi-cellular haploid individuals or sporelings. Each spore is covered by a hard protective outer covering to withstand unfavorable conditions such as high temperature and low humidity, thus enabling survival for a long time. Once conditions are favourable, a spore germinates and develops

into a new individual. The plant organisms which reproduce by this method are fungi on bread, certain types of moss and ferns, etc.

Vegetative Propagation

Vegetative Propagation is a type of asexual reproduction in which new plants are produced from roots, stems, leaves and buds. Since reproduction is through the vegetative parts of the plant, it is known as **v**egetative propagation**.**



Vegetative propagation using cuttings- productivity is dependent on environment

3.3 Differences between Sexual and Asexual Reproduction

The most important differences between the mechanisms of sexual and asexual reproduction in plants are tabulated below:

s/n	Sexual reproduction	Asexual reproduction
1	Both male and female parent plants are required	Reproduction occurs through a single parent plant
2	It can occur in only bisexual plants	It occurs in unisexual plants
3	Morphologically developed plants use sexual mechanism	Morphologically underdeveloped plants use asexual mechanism
4	Fully developed reproductive parts such as anther and pistil are present	Reproductive parts are not present
5	The original parent continues to exist after process of reproduction	In most methods, original parent ceases to exist after process of reproduction
6	The characteristics of the offsprings are derived from both the parent plants.	The characteristics of the offsprings are identical to parent plant
7	Seeds are required to produce new plants	No requirement of seeds

4.0 CONCLUSION

Reproduction in plants occurs through either asexual or sexual mechanisms. A study of these mechanisms is of utmost importance in the science of Agriculture, Horticulture and Floriculture. Healthy crops can be cultivated on the basis of this knowledge, and with scientific agricultural practices they will lead to higher yields.

5.0 SUMMARY

Reproduction is a fundamental feature of all known life; each individual organism exists as the result of reproduction. There are two forms of reproduction: Asexual and Sexual. The productivity of crops arising from sexual reproductive method is usually influenced by both the environment and the genetic composition. Fruits and seeds are the main products of sexual reproduction while in asexual reproduction, vegetative reproduction and **a**pomixis are common products. Vegetatively propagated plants are clones and therefore their differences in growth can only be ascribed to environmental effects instead of genetic differences.

6.0 TUTOR MARKED ASSIGNMENT

1. Explain the process of fertilisation in plants.
2. What is asexual reproduction?
3. Give examples of vegetative propagation.
4. How is a fruit formed?
5. List the major differences between sexual and asexual reproduction in plants.

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MODULE 2 PLANT GROWTH STAGES AND FACTORS INFLUENCING PLANT GROWTH AND DEVELOPMENT

UNIT 1 PLANT GROWTH STAGES-INDUCTION, INITIATION, DIFFERENTIATION, DEVELOPMENT, BLOOMING, FLOWERING AND SENESCENCE

CONTENTS

1.0 INTRODUCTION

Plant development is the general term for changes in form brought about through growth and differentiation. Because post-mitotic expansion processes in plants are largely driven by water, growth is not necessarily associated with increase in dry mass. Differentiation is the change in structure and function that results in cell, tissue and organ specialisation. The capacity to reverse the process of differentiation is a characteristic of the plastic nature of plant development. Senescence and development interact at different levels. Senescence is part of the programme that specifies cell fate. It is triggered differentially in tissues and organs, resulting in complex anatomies and morphologies that change and adapt over time. It is the means by which resources are recycled from obsolete body parts to new developing structures. Finally, variations on the senescence programme theme have been shaped by evolution to give rise to a diversity of structures within the angiosperm lifecycle.

2.0 OBJECTIVES

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

- define induction and differentiation in flowering plants
- identify factors that affect induction and differentiation in flowering plants
- describe the process of plant senescence
- explain what death means in plants.

3.0 MAIN CONTENT

3.1 Flower Bud Initiation and Differentiation

Flower bud formation requires a series of changes in the differentiation pattern of apical or axillary buds. Flower bud development is a process with high level of complexity characterised by two distinct physiological phases:

a) Bud initiation and
b) Floral bud development.

Internal and external signals have a fine regulatory function on the timing of flowering. This is also termed the `irreversibility' stage, to indicate a condition of the bud, which has only one ontogenic possibility, that of developing into a flower bud, or not to undergo any further development. When the irreversibility stage is overcome, the bud is to be considered `induced' to flower, and the next phase begins, termed `differentiation'; which is merely an anatomical phase, during which the typical tissues of flower structures are formed, and which is concluded immediately before anthesis.

The transition between the juvenile and adult phase is characterised by changes in meristerm sensitivity to internal and external signals of flower induction. At maturity, buds become competent to respond to induction. Once a meristerm has been determined to be productive, it follows its program even in the absence of inducing stimuli. On the other hand, the capacity to respond to induction signals for reproductive development depends on the physiological state of the plant or some plant part. The time of flower induction is harder to detect, mostly because the modifications involved are of a physiological nature, and therefore not detectable microscopically. In addition, this phase has a duration that does not depend so much on the length of the process in the individual bud, but takes place gradually at different times in different parts of the canopy, in both deciduous and evergreen species.

3.1.1 Factors Affecting Induction and Differentiation

This can be broadly divided into two: environmental and internal factors.

1. Environmental factors

a) Time of the year: Under common natural conditions, flowering of seed plants takes place after the formation of vegetative organs or, more precisely, after they have passed the young age or juvenile stage. In many plants, the duration of the juvenile period depends on their sensitivity to photoperiodic and thermal induction.

b) Photoperiodism: Day length, as an astronomic phenomenon, has proved to be the most reliable and accurate signal informing plants when they must flower and propagate and when they must be ready to survive unfavorable environmental conditions. As a result of the photoperiodic effect, leaves become physiologically transformed, which are biophysical and biochemical in nature. These transformations result in the formation of certain metabolites, some of which, under favorable day-length conditions, are necessary for flowering.

c) Intensity and quality of light: Since in the total absence of light flower induction cannot take place, because leaves are the main seat of the events leading to flower induction. The sun provides the energy required for various physiological functions of plants. Excessive cloud cover lowers the quality and intensity of light and the temperature of the plant environment.

d) Moisture conditions. Moisture is central to the growth and performance of plants. Insufficient moisture supplies to flowering plants causes flower abortion and pre-mature drops of formed buds.

e) Mineral nutrition: The role of nutrients in flowering plants is very important. Sugars formed in the process of photosynthesis and nitrogenous compounds introduced through plant's roots were considered of primary importance in Klebs's theory which showed that all conditions essential for flowering are also favorable for photosynthesis and consequently for the accumulation of carbohydrates in plant organs.

2. **Genetic factors**
Genetic factors find their expression in the very division of plants into perennial and annual, winter and spring, late and early.

3.3 Plant Senescence

Senescence is a terminal stage of plant development. It often, but not invariably, ends in the death of cells, tissues, organs or the whole plant. At the cell level there are a number of different senescence pathways, most of which are autolytic, that is, the genetic and biochemical events originate within the senescing cell itself. Nucleus, vacuole, plastids and mitochondria interact during cell senescence. Up to the point where organelle integrity is lost, some kinds of senescence may be halted, extended or even reversed by various treatments, but beyond this threshold there is a rapid decline in viability leading to death. Developmental cell senescence and death occur during differentiation of xylem, floral tissues, embryos and seeds. Leaves, fruits and some flowers lose chlorophyll during senescence as chloroplasts differentiate into pigmented plastids.

The products of chlorophyll breakdown are deposited in the cell vacuole. Proteins and nucleic acids are hydrolysed and the nitrogen and phosphorus liberated are exported from the leaf to sink tissues. Fruit ripening shares a number of regulatory and biochemical features with leaf and flower senescence. Senescence contributes to root turnover, an important factor in global carbon balance. Plants and their parts often must attain maturity before they are able to respond to signals that induce senescence. Floral induction and seed formation stimulate senescence. In monocarpic species the entire plant undergoes reproductive death. Polycarpic plants flower repeatedly during their lifetimes, and show no clear relationship between senescence and longevity. Senescence is a strategic and tactical response to seasonal and unpredictable stresses, including changing day length, flooding, drought, excessive light, darkness, nutrient limitation and disease.

3.3 Plant Death

Plant death is a condition or a state and is the culmination of and separate from, the process of dying. Application of the term “cell death” to the physiology of senescence, though widespread, seems inappropriate. By definition, changes that occur in dead cells are post-mortem and non-biological. Biologists studying terminal events in development need to distinguish between the regulated activity of viable biological structures and the pathological outcomes of organic collapse. Total organ death does not mean that the plant is dead. Death of cells, tissues and organs are normal physiological processes of plant development. As tissues and organs die, so are new ones formed though automatic replacement.

4.0 CONCLUSION

Flower bud formation requires a series of changes in the differentiation pattern of apical axillary buds. Flower bud development is a process with high level of complexity characterized by distinct physiological phases. All these changes and reactions during flower bud initiation, senescence and death are adaptive strategies for survival under unfavourable weather conditions in different seasons of the year.

5.0 SUMMARY

Cell, tissue and organ differentiation is the change in structure and function that results in cell, tissue and organ specialisation. The capacity to reverse the process of differentiation is a characteristic of the plastic nature of plant development. Factors affecting induction and differentiation can be broadly divided into two: environmental and internal factors. Senescence and development interact at different levels. Senescence is a terminal stage of plant development. It often, but not invariably, ends in the death of cells, tissues, organs or the whole plant. As tissues and organs die, so are new ones formed though automatic replacement.

6.0 TUTOR MARKED ASSIGNMENT

1. List the factors that affect induction and differentiation.
2. Explain the importance of plant nutrition as a factor that affects induction and differentiation.
3. Differentiate between plant senescence and death.

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UNIT 2 MECHANISMS IN PLANT GROWTH AND DEVELOPMENT

CONTENTS

1.0 INTRODUCTION

Plant growth is a process that is highly relevant in a range of contexts. The ability of an individual plant to grow and achieve a certain size in a given environment is one of the prerequisites to reproduce successfully and achieve the desired yield. Plant growth is of fundamental importance as it forms the basis of all agricultural productivity. It is therefore not surprising that the processes underlying plant growth are of immense importance to researchers. These include the biophysical and biochemical limitations on photosynthesis, that respiration should not be wasteful or should be made less ‘wasteful’ in order to have more photosynthates available for growth. Other researchers would want to work on the efficient uptake or use of nutrients including water or study the molecular mechanisms that determine cell division. The ultimate goal is often to change or affect these processes in a way that will positively shape the growth and productivity of plants.

2.0 OBJECTIVES

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

- discuss plant growth environment and the challenges within the environment
- identify the effects of high light intensities rates of photosynthesis leading to higher rate of biomass production per unit leaf area

- explain the quantitative estimates of total plant mass, above-ground mass and/or yield.

3.0 MAIN CONTENT

3.1 Plant Environment and Light Intensity

Understanding plant growth becomes even more challenging because of the strong effect of the environment, which may modulate the various components of the growth processes in different, sometimes contrasting, ways. For example, plants grown at high light intensities generally have higher rates of photosynthesis and thereby a higher rate of biomass production per unit leaf area than low-light grown plants. However, plants grown at high light at the same time have a reduced amount of leaf area per unit plant mass. At light levels higher than $25\,\text{mol}\,\text{m}^{-2}\,\text{day}^{-1}$, this may lead to a situation where, for some species, the growth rate is not stimulated anymore although the rate of photosynthesis per unit leaf area is still increasing. Physiological interactions may become even more complex when two or more environmental factors interact.

3.2 Quantitative Estimates of Total Plant Mass

Plant growth models as a simplification of complex systems have tremendous value as a way to structure and integrate available knowledge, test hypotheses and come up with quantitative estimates of total plant mass, above-ground mass and/or yield. Plant growth models come in a wide variety, ranging from simple formulae that mathematically capture plant size over time with just two or three parameters, up to highly complicated simulation models that evaluate global change effects on the performance of vegetation worldwide. They apply an array of conceptual approaches and incorporate a range of more-or-less detailed physiological processes, mostly centred around the carbon economy of the plant, as this provides the backbone for all growth.

3.2.1 Empirical Models

The simplest models of plant mass or productivity are empirical models, also denoted as ‘statistical’ models. Empirical models are frequently used in such different fields as agriculture, horticulture and forestry to describe and/or forecast the productivity in monocultures of economically interesting plant species. In terms of mechanism, they can be considered as a ‘null-model’, as they do not contain any physiological processes at all, rather, they can be seen as dose–response curves (DRCs) which relate biomass or yield observations in a given geographic location or climatic zone to one climatic or edaphic variable of interest. They can also be extended to include several independent factors. Simple or multiple regression techniques then provide an equation that can be used as a predictor for biomass.

Empirical models are extremely simple yet effective in their ability to predict the productivity of natural and crop stands with one notable exception: they perform badly if they are to predict yield outside the boundaries where data have been collected. One example where extrapolation may lead to erroneous estimates is the case of temperature. Generally, crops like rice and maize are relatively cold-sensitive and grow and produce better at warmer temperatures. However, this may not be extrapolated to too high night temperatures, as quite some species become sterile under those conditions, with reduced yield.

3.3 Photosynthesis – Respiration Model

The next level of complexity is formed by models that explicitly simulate photosynthesis and respiration. Employing the dependencies of photosynthesis for light, CO_2 and temperature, as well as the amount of leaf area present for a given plant or canopy, such models calculate the total carbon fixation of a plant or vegetation over a given time step. Subsequently sugars required for maintenance of respiration are subtracted from the total amount of produced photosynthates, and the remaining sugars are then distributed with some rule over the various vegetative and generative compartments of the plant. In a final step, these sugars are converted to biomass, after which the whole calculation repeats again for the next reaction.

This process or mechanism is dependent upon:

a. The amount of N in the leaves available for the photosynthetic machinery.
b. The extent to which a plant canopy is approached as one big leaf or as different leaf layers.
c. Water or nutrient availability.
d. Temperature constraints.

3.4 Importance of Growth Mechanism Simulations in Plants

The mechanistic simulation models of plant growth have considerable uses in the study of plants. These include:

- To predict the growth rate or productivity of a crop in a variety of climatic conditions.

- They also form an indispensable help in management decision making.
- To predict growth outside the strict boundaries where conditions for plant performance have been tested experimentally. Although an exact tolerance limit is generally not stated, crop modellers often seem to accept differences between observed and predicted growth of 10–15% as being reasonably good. Different wheat models, developed by research groups based on different continents, are generally performing very well at the geographic location they were developed for.

3.5 Mechanistic Top-Down Models

An alternative way to analyse growth is a top-down approach. Starting with the total biomass of the plant, one can dig down and factorize the underlying parameters and processes into increasingly more detailed components. This approach is often applied to analyse experimental data in a systematic framework based on carbon-economy principles. Aim of such an analysis is to examine which of the underlying processes vary between treatments, genotypes or species and which ones remain relatively constant.

3.5.1 Relative Growth Rate (RGR)

The most basic expression of growth is the so-called ‘Absolute Growth Rate’ (AGR), which is the change in size of the plant per unit of time. If AGR is constant, plant mass will increase linearly over time. This variable does not incorporate the changes in size of young plants, as they will often increase biomass in a way that is approximately proportional to the biomass of the plant already present. The principle of proportional growth is engrained in the concept of ‘Relative Growth Rate’ If RGR would be strictly constant, then plant mass will follow an exponential trajectory over time:

3.5.2 Factorising RGR in Underlying Components

Following not only the progression in plant mass, but also in leaf area allows RGR to be factorised into two underlying components, one representing the total amount of leaf area per unit plant mass (Leaf Area Ratio; LAR), the other the increase in biomass per unit leaf area [Unit Leaf Rate (ULR); an alternative term is Net Assimilation Rate (NAR). The power of this simple factorisation cannot be overestimated because ULR is often strongly correlated with photosynthesis. Hence, without doing more than weighing plants and measuring leaf area, already a fairly good indication can be obtained whether observed differences in RGR are due to the structural component (LAR) or to the gas exchange, as characterized by the ULR. This then is achieved without any measurements of photosynthesis or respiration, with all their problems of scaling up from leaf to whole plant and from the short term (with measurements mostly carried out over minutes or, at best, hours) to the full day or growth season.

LAR can be factorised further into two components, the fraction of the total biomass allocated to leaves (Leaf Mass Fraction; LMF) and the amount of leaf area that is realized per unit biomass invested in leaves, which is termed Specific Leaf Area (SLA). RGR, ULR, LAR, SLA and LMF are the classical parameters used in growth analysis.

4.0 CONCLUSION

Although final biomass or yield would be the indicator for how successful a plant integrates the various processes and organs, the main result of such a model would be an improved understanding of the intricate network of physiological and morphological traits and how that is responding when the environment changes.

5.0 SUMMARY

In this unit, we discussed a range of plant growth models with varying physiological detail. This included empirical models, mechanistic bottom-up models, which often focus only on the carbon-supply part of growth; and more-or-less mechanistic top-down models factorising RGR into increasingly smaller subcomponents. On the whole, RGR, ULR, LAR, SLA and LMF are the classical parameters used in growth analysis.

6.0 TUTOR-MARKED ASSIGNMENT

1. List the components of factorised RGR.
2. Define the following plant growth parameter, RGR, ULR, LAR, and LMF.
3. Mention the factors that photosynthesis-respiration model depends upon.

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UNIT 3 THE SIGMOID GROWTH CURVE

CONTENTS

1.0 INTRODUCTION

This is a pattern of growth of an organism in a new environment where by the population density of that organism increases slowly initially, in a positive acceleration phase, then increases rapidly approaching an exponential growth rate then declines in a negative form. A growth curve is an empirical model of the evolution of a quantity over time. Growth curves are widely used in natural sciences for quantities such as population size or biomass for population growth analysis, individual body height or biomass. Values for the measured property can be plotted on a graph as a function of time.

2.0 OBJECTIVES

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

- discuss the sigmoid curve
- explain the phases of the sigmoid curve
- draw the sigmoid curve
- highlight the importance of sigmoid curve in natural sciences.

3.0 MAIN CONTENT

3.1 Phases of the Sigmoid Growth Curve

Any population growing exponentially starts off slowly, goes through a rapid growth phase, and then levels off once the carrying capacity of the area is reached. Plotting a graph of such a population yields an S-shaped curve. This curve can be divided into three phases:

- Exponential
- Transitional
- Plateau

3.1.1 Exponential Growth Phase

- Initially, population growth will be slow (lag period) as there are few reproductive individuals that are likely widely dispersed.
- As numbers accumulate, there is a rapid increase in population size as natality greatly exceeds mortality
- Mortality is low because there are abundant resources and minimal environmental resistance.
- Population growth is fastest during the exponential growth phase because (birth rate + immigration) exceeds (death rates + emigration).

3.1.2 Transitional Phase

- As the population continues to grow, resources eventually become limited, which leads to competition for survival.
- Natality rates start to fall and mortality rates begin to rise, leading to a slowing of population growth.
- Population growth slows down during the transitional phase because disease, predation and competition set limits to population increase. Disease spreads faster as populations get larger and therefore reduces the number of individuals who can reproduce. Predators can hunt more successfully as the prey population increases, which in turn increases the population of predators (negative feedback). Resources become scarce when a population is large, which in turn increases competition.

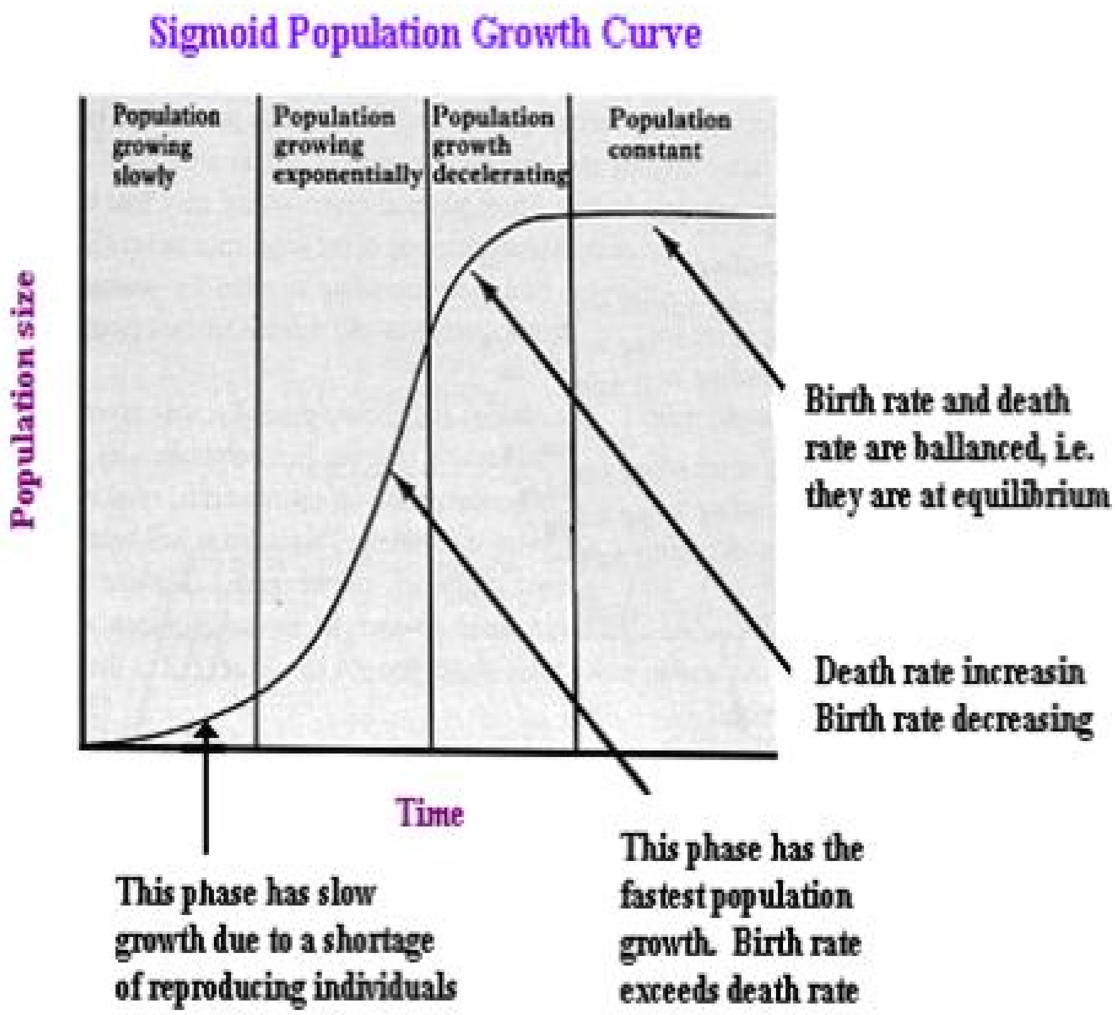
3.1.3 Plateau Phase

- Eventually the increasing mortality rate equals the natality rate and population growth becomes static.
- The population has reached the carrying capacity (**κ**) of the environment, with limiting factors keeping the population stable.
- The population size at this point will not be constant, but will oscillate around the carrying capacity to remain even.
- Population growth is zero at the plateau phase because it has reached its carrying_capacity, which is the maximum population size that an environment can support. At carrying capacity,

populations tend to produce more offspring than can be supported by the environment. This leads to extreme competition for resources such as food, shelter, nesting space and so on.

3.2 The Sigmoid Curve

S-shaped growth curve (sigmoid growth curve) is pattern of growth in which, in a new environment, the population density of an organism increases slowly initially, in a positive acceleration phase; then increases rapidly approaching an exponential growth rate as in J-shaped curve but then declines in a negative acceleration phase until at zero growth rate the population stabilises. This slowing of the rate of growth reflects increasing environmental resistance which becomes proportionately more important at higher population densities. This type of population growth is termed ‘density dependent’ since growth rate depends on the numbers present in the population. The point of stabilisation, or zero growth rate, is termed the ‘saturation value’ or ‘carrying capacity’ of the environment for that organism. The peak point represents the point at which the upward curve begins to level, produced when changing population numbers are plotted over time.



3.3 Importance of the Sigmoid Curve

The sigmoid curve is extensively used in the study of population dynamics of fast growing organisms like yeast. Its importance lies in the fact you can:

- Describe growth in size across time.
- Model human size as a function of age
- Indicate a time of maximum growth and the asymptotic location of the maximum growth rate.

4.0 CONCLUSION

Growth curves are widely used in biology for quantities such as population size or biomass for population growth analysis, individual body height or biomass. The sigmoid curve is extensively used in the study of population dynamics of fast growing organisms like yeast.

Values for the measured property can be plotted on a graph as a function of time.

5.0 SUMMARY

Any population growing exponentially starts off slowly, goes through a rapid growth phase, and then levels off once the carrying capacity of the area is reached. Plotting a graph of such a population yields an S-shaped curve.

6.0 TUTOR-MARKED ASSIGNMENT

1. List the phases of the sigmoid curve.
2. Draw a typical sigmoid curve.
3. What is the usefulness of the sigmoid curve?

7.0 REFERENCES/FURTHER READING

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UNIT 4 FACTORS AFFECTING PLANT GROWTH AND DEVELOPMENT

CONTENTS

1.0 INTRODUCTION

All the developmental processes occurring in plants involve growth. The growth of plants involves various changes such as the addition of new cells through cell division, an increase in its size and weight**,** and an irreversible increase in the volume. Therefore, we can define the term growth as a permanent and irreversible change in the size of a cell, organ or whole organism usually accompanied by an increase in its dry weight. This growth is dependent upon a number of factors, some of which are external while others are internal.

2.0 OBJECTIVES

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

- differentiate between internal and external factors affecting plant growth and development
- identify external factors affecting plant growth and development
- discuss internal factors affecting plant growth and development.

3.0 MAIN CONTENT

Factors that influence the growth and development of plants can be broadly divided into two, namely internal factors and external factors.

Internal factors consist of things that are inherent in the plant like crop type and variety. A crop or plant is known by the class it belongs and those characters that distinguished one plant from another are purely hereditary. Also the presence of enzymes and hormones affect plant growth and development. External factors are those factors that are environmental in nature to the plant. The plant cannot influence what happens around it but can adapt to those changes in the environment. These external factors are light intensity, water adequacy, temperature, and minerals. Both internal and external factors control growth and development of plants through their influence in the internal activities of plants like the processes of photosynthesis, respiration, protein, chlorophyll synthesis, osmotic pressure, and mitosis.

3.1 External Factors

The plant growth is influenced by a variety of external factors. These include light, temperature, water, nutrients**.**

3.1.1 Light

There are two major effects of light on plants; one is related with photosynthesis and the other with growth and morphogenesis. The effect of light on photosynthesis, growth, development, and differentiation in plants is called photomorphogenesis**.** All these processes are light dependent.

For example, if a plant is allowed to grow in complete darkness, it shows marked etiolation (i.e. phenomenon exhibited by green plants when grown in darkness). The seedlings grown in dark are pale, elongated with primary leaves unexpanded and yellow. On the other hand, the seedlings grown in light are sturdy, green with shorter internodes, expanded leaves, and upright apex**.** These effects are in response to light. Besides this, most of the processes in plants are controlled by light like reproduction, seed germination, growth of seedling**,** and differentiation in various tissues and organs.

3.1.2 Temperature

Temperature is a primary factor affecting the rate of plant growth and development. Plant growth is the result of cellular metabolism and processes. Since the metabolic activities of plants are directly affected by the variation in temperature, their growth rate is also influenced.

The rate of growth of plant tissues increases with the increase in temperature up to optimum levels**,** after which it declines as the temperature becomes extreme. The temperatures for optimal growth vary with the type of plant. Some annual flowers and vegetables are extremely sensitive to cold whereas some plants require a cold treatment in order to stimulate flowering in later stages.

Germination of seeds in plants is also affected by extreme temperature conditions. Some seeds of winter season crops germinate at 5ºC to 25ºC while seeds of summer crops germinate at 10ºC to 35ºC

3.1.3 Water

Water is necessary for virtually every function of plant growth. It is used in photosynthesis and other metabolic processes and then ultimately lost by transpiration**.**

Excessive transpiration or water deficiency in the soil causes water stress in the plants. The plant growth is considerably retarded during water stress**,** but sometimes excessive water also stops the growth of the plant.

Shortage of water damages plant cells, resulting in decreased growth, wilting**,** and leaf scorch, and eventually leaf drop and root damage while too much water reduces the amount of oxygen in the soil, resulting in root loss or injury. It can also make the plant more susceptible **to** many fungal diseases**.**

3.1.4 Nutrients

Plants require nutrients in the form of inorganic ions for normal growth and development. Almost every metabolic process in plants requires inorganic nutrition. Thus, the growth of plants greatly depends upon the supply of these essential elements**.** In the absence of these elements, the plant growth gets retarded.

They obtain inorganic nutrients from the air, water, and soil. For example, carbon and oxygen are obtained from carbon dioxide and hydrogen from water. They also absorb a wide variety of mineral elements from the soil. For example, nitrogen, phosphorous, potassium, calcium, magnesium, iron, zinc, boron etc.

3.2 Internal Factors

These internal factors are mainly genetic and hormonal in nature.

3.2.1 Hormonal Factors

In addition to temperature, water, and inorganic nutrition, the growth and differentiation of plants also depend on some plant hormones. These plant hormones are also known as plant growth regulators. They regulate the distribution and fate of nutrients in different organs of the plant body.

Plant growth regulators are broadly divided into two groups based on their functions in a living plant body. One group is involved in growth promoting activities, such as cell division, cell enlargement, pattern formation, tropic growth, flowering, fruiting, and seed formation. The other group is involved in various growth inhibiting activities such as dormancy and abscission. They also play an important role in plant responses to wounds and stresses of biotic and abiotic origin. Thus, these hormonal factors play a major role in the growth and differentiation of plants.

3.2.2 Genetic Factors

The seed of mango germinates to produce a mango plant; it never grows into a palm tree. Similarly, a tomato seed gives rise to a tomato plant. All the information about the form and shape of the plant body and the specific pattern of growth and differentiation in plants are stored as genetic information in the genes located inside the cell of a seed. As the development processes begin the genetic information is passed from genes to RNA to proteins within the cells. Some very specific genes are responsible for the synthesis of specific enzymes (proteins) which then catalyze specific biochemical processes that are necessary for growth and differentiation in plant cells.

4.0 CONCLUSION

The growth of a plant is dependent on various factors which may be internal or external. This is because these factors are directly or indirectly involved in various morphological, physiological and developmental processes in plants that are necessary for the overall growth and development of plants.

5.0 SUMMARY

Factors that influence the growth and development of plants can be broadly divided into two: internal and external factors. The external factors are light, water, temperature, and minerals. These factors, either internal or external, control growth and development of plants through their influences in the internal activities of plants like the processes of photosynthesis, respiration, protein, chlorophyll synthesis, osmotic pressure, and mitosis, flower and seed formation, dormancy and seed germination.

6.0 TUTOR-MARKED ASSIGNMENT

1. List the external factors that affect the growth and development of plants.
2. Mention the internal that can influence plant growth.

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MODULE 3 PHOTOSYNTHESIS, YIELD LIMITING FACTORS AND GROWTH REGULATORS

UNIT 1 PHOTOSYNTHESIS, PLANT GROWTH AND PARTITIONING OF ASSIMILATE

CONTENTS

1.0 INTRODUCTION

Photosynthesis is one of the principle biochemical processes underpinning plant growth and development. Because of its basic nature, it is intimately involved with reproductive growth and determining crop yields. Photosynthesis of a crop canopy can be broken down into three components; leaf area development, photosynthetic rate per leaf area, and partitioning of assimilates between vegetative and reproductive growth, or source-to-sink relationships. The leaf surface area intercepts the solar radiation and allows for the photosynthetic conversion of that radiant energy into chemical energy. This production of chemical energy and the subsequent utilisation of that chemical energy used to fix CO_2 into photosynthetic carbon assimilates constitutes the source side of yield development. The fruiting buds, flowers, and fruit development constitute the reproductive sink side of the yield equation, although other vegetative growing points can operate as secondary sinks.

2.0 OBJECTIVES

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

- define photosynthesis
- discuss the factors that affect photosynthesis
- identify what are c3 and c4 plants
- explain the principles involved in assimilates transfer to plant organs.

3.0 MAIN CONTENT

All life on earth depends on plants. Plants are autotrophic, meaning they can convert simple molecules like CO_2 from the atmosphere and minerals from the soil into the complex carbohydrates, proteins, and fats, forming the basis of living organisms. The most important set of chemical reactions in plants harness the energy of sunlight in the process of photosynthesis which generates sugar, oxygen, and a molecule called ATP. ATP is energy in its simplest form and powers the chemical reactions that support life in both plant and animal cells.

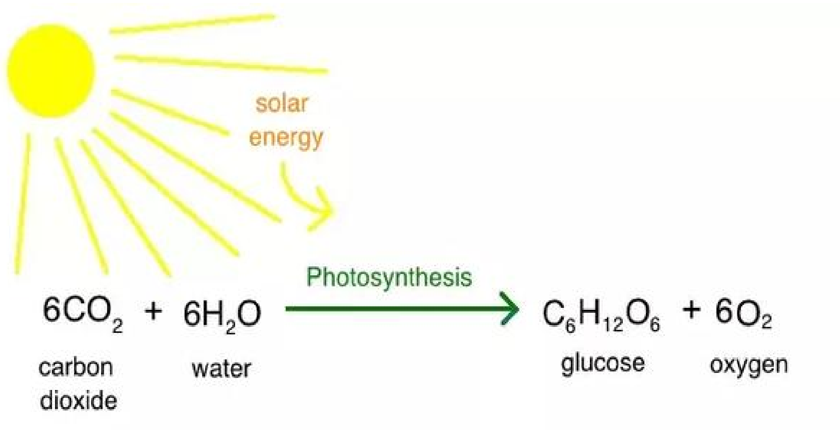
3.1 The Basics of Photosynthesis

Photosynthesis literally means "to put together with light." All of the reactions of photosynthesis happen inside chloroplasts. Chloroplasts are small organelles that are green because they contain chlorophyll. Mesophyll cells in the leaves and stem contain many chloroplasts, each having a highly ordered array of membranes arranged in stacks. These stacks are called thylakoid membranes and are solar panels with a large surface area that organize chlorophyll and pigments called carotenoids that can collectively absorb and utilize light energy.

Photosynthesis has two distinct parts:

1. **Light reactions**: The light absorption part of photosynthesis is referred to as the light reactions. It relies on energy from the sun, so it occurs only during the day in the thylakoid membrane of the chloroplasts. In the light reaction, water is split and oxygen released, but more importantly, it provides the chemical energy to fix CO_2 into carbohydrate.
2. **The carbon reactions**: Carbon or dark reactions occur in the matrix of the chloroplast called the stroma and uses protein types called enzymes. The most important enzyme in this process is called rubisco. Rubisco is the most abundant protein in plants and therefore, the major consumer of nitrogen. This is why when plants are deficient in nitrogen, they are not productive and turn

yellow because they stop photosynthesizing. The dark reaction creates three carbon sugar products that leave the chloroplast for use in respiration and sucrose (common table sugar) synthesis. The sucrose is converted to starch or shipped out to other parts of the plant for storage or growth through the phloem.



3.1.2 Factors Affecting Photosynthesis

The following points highlight the 14 main factors affecting photosynthesis. They are: 1. Temperature 2. Carbon Dioxide Concentrations 3. Light 4. Intensity 5. Quality 6. Duration 7. Oxygen 8. Water 9. Mineral Elements 10. Air Pollutants 11. Chemical Compounds 12. Chlorophyll Contents 13. Protoplasmic Factor 14. Accumulation of Carbohydrates.

1. **Temperature:** When CO_2, light and other factors are not limiting, the rate of photosynthesis increases with a rise in temperature, over a range from 6°C to about 37°C. Above this temperature, there is an abrupt fall in the rate and the tissue dies at 43°C. High temperatures cause the inactivation of enzymes and therefore affect the enzymatically controlled 'dark' reactions of photosynthesis.

   The optimum temperature for the maximum falls between 20-30°C. Above 25-30°C the maximum rate is not maintained as the time factor begins to operate and the optimum temperature is reduced from 37°C to 30°C. Given other factors are limiting, the rate of photosynthesis follows Vant Hoffs rule between 6°C-30°C to 35°C i.e., it doubles with each increase of 10°C. The reason being that all the reactions of the Calvin cycle are temperature dependent and the rate of diffusion of CO_2 to the chloroplasts is accelerated by high temperature.

2. **Carbon Dioxide Concentrations:** Nearly 0.032% by volume of carbon dioxide is present in the atmosphere and at this low level it acts as a limiting factor. Under laboratory conditions when light and temperature are not limiting factors, increase in CO_2 concentration in the atmosphere from 0.03% to 0.3-1% raises rate of photosynthesis.

With the further increase in the concentration of CO_2 progressively the rate of carbon assimilation increases slightly and then it becomes independent of CO_2 concentration.

Thereafter, it remains constant over a wide range of CO_2 concentrations. Plants vary in their ability to utilise high concentrations of CO_2. In tomatoes, high concentration of CO_2, above the physiological range, exerts harmful influence causing leaf senescence. During the early period of the earth, the concentration of CO_2 in the atmosphere was as high as 20%.

3. **Light:** The photosynthetically active region of the spectrum of light is at wavelengths from 400-700 nm. Green light (550 nm) plays an important role in photosynthesis. Light supplies energy for the process. Light varies in intensity, quality and duration. A brief account on these three aspects is given as follows:
4. **Intensity:** When CO_2 and temperature are not limiting and light intensities are low, the rate of photosynthesis increases with an increase in its intensity. At a point saturation may be reached, when further increase in light intensity fails to induce increase in photosynthesis. Optimum or saturation intensities may vary with different plant species e.g., C_4 and C_3. C_3 plants become saturated at levels considerably lower than full sunlight but C_4 plants are usually not saturated at full sunlight. When the intensity of light falling on a photosynthesizing organ is increased beyond a certain point, the cells of that organ become vulnerable to chlorophyll catalyzed photo-oxidations. Consequently, these organs begin to consume O_2 instead of CO_2 and CO_2 is released. Photo-oxidation is maximal when O_2 is present or carotenoids are absent or CO_2 concentration is low.
5. **Quality:** The action spectrum for photosynthesis in leaves shows two major peaks, one in the red and the other one in the blue. In these regions, chlorophylls absorb maximal light. Most effective wavelengths differ with different plants. It is of interest to note that plants show high photosynthesis in the blue and red light while red algae do so in green light and brown algae in blue light. The blue-green algae have action spectrum peak in yellow or orange light.

6. **Duration:** In general, a plant will accomplish more photosynthesis when exposed to long periods of light. It has also been found that uninterrupted and continuous photosynthesis for relatively long periods of time, may be sustained without any visible damage to the plant. We would also do well to bear in mind that if we remove the source of light, the rate of CO_2 fixation falls to zero immediately. Clearly, no species has evolved and/or has developed a storage battery in its leaves whereby the immediate products of the photochemical reactions can be retained in significant amounts to be utilised for the fixation of CO_2 later on.

7. **Oxygen:** Oxygen has been shown to inhibit photosynthesis in C_3 plants while C_4 plants show little effect. It is suggested that C_4 plants have photorespiration and high O_2 stimulates it. The rate of photosynthesis increases by 30-50% when the concentration of oxygen in air is reduced from 20% to 0.5% and CO_2, light and temperature are not the limiting factors. Oxygen is inhibitory to photosynthesis because it would favour a more rapid respiratory rate utilizing common intermediates, thus reducing photosynthesis. Secondly, oxygen may compete with CO_2 and hydrogen becomes reduced in place of CO_2. Thirdly, O_2 destroys the excited (triplet) state of chlorophyll and thus inhibits photosynthesis.

It may be stated that direct effect of O_2 on photosynthesis remains to be understood.

8. **Water:** Water is an essential raw material in carbon assimilation. Less than 1% of the water absorbed by a plant is used in photosynthesis. The decrease in water contents of the soil from field capacity to the permanent wilting point results in the decreased photosynthesis. The inhibitory effect is primarily attributed to increased dehydration of protoplasm and also stomatal closure. The removal of water from the protoplasm also affects its colloidal state, impairs enzymatic efficiency, inhibits vital processes like respiration, photosynthesis etc. Dehydration may even damage the micromolecular structure of the chloroplasts.

It is also assumed that primary factor of dehydration in retarding photosynthesis is due to stomatal closure which reduces CO_2 absorption. Water deficiency may cause drying of the cell walls of mesophyll cells, reducing their permeability to CO_2. Water deficiency may accumulate sugars and thus increase respiration and decrease photosynthesis.

9. **Mineral Elements:** As discussed earlier, several minerals are essential for plant growth. These include Mg, Fe, Cu, CI, Mn, P and are closely associated with reactions of photosynthesis.
10. **Air Pollutants:** Gaseous and metallic pollutants decrease photosynthetic activity. These include ozone, SO_2, oxidants, hydrogen fluorides, etc.
11. **Chemical Compounds:** Compounds like HCN, H_2S, etc. when present even in small quantities, depress the rate of photosynthesis by inhibiting enzymes. In addition, chloroform, ether etc., also stop photosynthesis and the effect is reversible at low concentrations. However, at high concentrations the cells die.
12. **Chlorophyll Contents:** The rate of photosynthesis in two varieties of barley having normal green leaves and yellow leaves was studied. CO_2, light and temperature were not limiting factors. The rate of assimilation per unit area of leaf surface in the two varieties was the same even though the green-leaved variety contained ten times more chlorophyll than the yellow one. Clearly, the chlorophyll in the green leaves is surplus. Leaves having high chlorophyll content do not photosynthesize rapidly since they lack the enzymes or co-enzymes to use the products of the light reactions to reduce available CO_2.
13. **Protoplasmic Factor:** Besides chlorophyll certain protoplasmic factors also influence the rate of photosynthesis. They affect the dark reactions. It has been shown that these factors are absent in the young stage and develop as the seedling becomes old.

    That these protoplasmic factors appear to be enzymatic is indicated by the fact that the capacity for photosynthesis is lost at temperatures above 30°C or at strong light intensities in many plants even though cells are green and living.
14. **Accumulation of Carbohydrates:** Accumulation of photosynthate in the plant cells, if not translocated, slows down and finally stops the process. The accumulated products increase the rate of respiration. Sugar is also converted into starch and the accumulation of starch in chloroplasts reduces their effective surfaces and the process slows down.

3.2 Photosynthetic Variations of the Carbon Reactions (C3 & C4 plants)

Plants are classified based on how they complete photosynthesis. The dark reactions described above are found in more than 95 percent of the plants on Earth. They are called C3 plants because the first organic molecule that CO_2 is incorporated into is a three-carbon molecule. Two variations of the carbon reactions have evolved in angiosperm plants as ways to get around the problem of photorespiration. They are C4 photosynthesis. Plants with C4 photosynthesis include corn, buffalograss, and many weedy grasses including crabgrass. It is called C4 photosynthesis because the first organic molecule that CO_2 is incorporated into is a four-carbon malate molecule. These C4 plants minimize photo-respiration and water loss through a specialized cellular architecture in the leaves: light reactions occur in one cell type and the carbon reactions occur in cells called bundle sheath cells not in direct contact with the air. Plants with C4 photo-synthesis are able to achieve high rates of photosynthesis with their stomata only slightly open which minimizes water loss. They often look better than C3 plants during hot dry conditions because they are able to protect the plant from high water loss by closing their stomata. Plants with crassulacean acid metabolism (CAM) photosynthesis, such as cacti, all succulents, and purslane, minimize photorespiration and water loss by keeping their stomata completely closed during the day and so no water is lost. This also means they cannot take in CO_2 during the day. To get around this, CAM plants take in CO_2 through the stomata at night and store it as a molecule called malate. Then during the day, with the sun shining and the stomata closed, rubisco coverts the malate to useful carbohydrate. Although this enables CAM plants to grow in extreme heat and be extremely water efficient, they have low photosynthetic productivity — they grow slowly.

3.3 Plant Growth and Partitioning of Assimilate

All the developmental processes occurring in plants involve growth. The growth of plants involves various changes such as the addition of new cells through cell division, an increase in its size and weight**,** and an irreversible increase in the volume. Therefore, we can define the term growth as a permanent and irreversible change in the size of a cell, organ or whole organism usually accompanied by an increase in its dry weight.

Partitioning of assimilated carbon among sink organs is a critical factor that controls the rate and pattern of plant growth. During the sequence of development, different plant parts exert varying demands on the available nutrient and assimilate resources of the whole plant system. Classical growth analysis has provided a background of quantitative information on the distribution of dry matter in different organs throughout development.

Photosynthate partitioning is the deferential distribution of photosynthates to plant tissues. A photosynthate is the resulting product of photosynthesis. These products are generally sugars. These sugars that are created from photosynthesis are broken down to create energy for use by the plant. Sugar and other compounds move via the phloem to tissues that have an energy demand. These areas of demand are called sinks. While areas with an excess of sugars and a low energy demand are called sources. Many times sinks are the actively growing tissues of the plant while the sources are where sugars are produced by photosynthesis—the leaves of plants. Sugars are actively loaded into the phloem and moved by a positive pressure flow created by solute concentrations and turgor pressure between xylem and phloem vessel elements (specialized plant cells). This movement of sugars is referred to as translocation. When sugars arrive at the sink they are unloaded for storage or broken down and or metabolized. The partitioning of these sugars depends on multiple factors such as the vascular connections that exist, the location of the sink to source, the developmental stage, and the strength of that sink. Vascular connections exist between sources and sinks and those that are the most direct have been shown to receive more photosynthates than those that must travel through extensive connections. This also goes for proximity those closer to the source are easier to translocate sugars to. Developmental stage plays a large role in partitioning, organs that are young such as meristerm and new leaves have a higher demand, as well as those that are entering reproductive maturity—creating fruits, flowers, and seeds. Many of these developing organs have a higher sink strength. Those with higher sink strengths receive more photosynthates than lower strength sinks. Sinks compete to receive these compounds and combination of factors playing in determining how much and how fast sinks receives photosynthates to grow and complete physiological activities.

4.0 CONCLUSION

Partitioning of assimilates between vegetative and reproductive growth, or source-to-sink relationships is dependent of demand. Assimilates are made possible through the simple but complex process in plants called photosynthesis. Virtually in life, both animal and plant depend on photosynthesis.

5.0 SUMMARY

Photosynthesis is one of the principle biochemical processes supporting plant growth and development. This is the most important set of chemical reactions in plants where the energy of sunlight is harnessed to generate sugar, oxygen, and a molecule called ATP. Some plants are classified as either C3 or C4 based on the number of carbon molecules involved in the process. These sugars that are created from photosynthesis are broken down to create energy for use by the plant. Sugar and other compounds move via the phloem to tissues that have an energy demand. These areas of demand are called sinks. Sinks compete to receive these compounds and combination of factors playing in determining how much and how fast sinks receives photosynthates to grow and complete physiological activities.

6.0 TUTOR-MARKED ASSIGNMENT

1. Give the balanced formula of photosynthesis.
2. List all factors that affect photosynthesis.
3. Differentiate between sink and source.

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UNIT 2 YIELD LIMITING FACTORS AND YIELD COMPONENTS

CONTENTS

1.0 INTRODUCTION

Plant productivity is decreasing due to detrimental effects of various biotic and abiotic yield reduction factors that are majorly environmental in nature. Therefore, minimising these losses is a major area of concern to ensure food and fiber security under the ever changing climate. Environmental abiotic stresses, such as drought, extreme temperature, cold, heavy metals, or high salinity, severely impair plant growth and productivity. In many regions of world, crop losses due to increasing water shortage will further aggravate the impacts of climate change; the most noticeable is the reduction in yields and yield component of plants.

2.0 OBJECTIVES

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

- discuss plant morphology and characteristics of plants
- explain yield limiting factors in plants
- identify growth and yield components of some plants.

3.0 MAIN CONTENT

To properly understand yield and yield components of plants, you have to study and know the morphological characteristics of plants. Plant morphology examines the pattern of development, the process by which structures originate and mature as a plant grows. While animals produce all the body parts they will ever have from early in their life, plants constantly produce new tissues and structures throughout their life.

3.1 Plant Morphology and Characteristics

Plant morphology or phytomorphology is the study of the physical form and external structures of plants. Plant morphology is useful in the visual identification of plants. It represents a study of the development, form, and structure of plants, and by implication, an attempt to interpret these on the basis of similarity in plants and origin. When structures in different species are believed to exist and develop as a result of common, inherited genetic pathways, those structures are termed to be homogenous. For example, the leaves of mango, orange and guava all look very different, but share certain basic structures and arrangement of parts.

Secondly, plant morphology observes both the vegetative (somatic) structures of plants, as well as the reproductive structures. The vegetative structures of vascular plants include the study of the shoot system, composed of stems and leaves as well as the root system. The reproductive structures are more varied, and are usually specific to a particular group of plants, such as flowers and seeds. At the largest scale is the study of plant growth habit, the overall architecture of a plant. A plant morphologist examines the pattern of development, the process by which structures originate and mature as the plant grows. The way in which new structures develop and mature might be affected in the plant's life when they begin to be influenced by the environment to which the structures are exposed. A morphologist studies this process, the causes, and its final result on the yield and yield components of the plant.

3.2 Yield Components of Plants

One of the metrics used to determine the efficiency of food production is crop yield. Crop yield (also known as "agricultural output") refers to both the measure of the yield of a crop per unit area of land and the grain resulting yield usually expressed as ton per hectare.

As plants grow after germination and within the competitive biotic and abiotic environment, structures and components of the plant emerge and grow. These vegetative structures include the stems, leaves, shoot system, the root system. Later in the life of the plant, reproductive organs emerge or develop. The performance of these structures and organs including the canopy size and form, branches and vines all will sum up into yields or products of choice. Depending on the crop, and the output of interest, yield components of some selected crops will include the followings.

3.2.1 Rice Yield Components

1) Average leaf length (cm)
2) Average leaf width (mm)
3) Average number of leaf per plant
4) Germination percentage (%)
5) Total number of tillers/m^2
6) Number of days to heading
7) Number of days to maturity
8) Plant height (cm)
9) Weight of 1000 seed (gm)
10) Grain yield(t/ha)
11) Total tillers/ m^2
12) Number of effective tillers/ m^2
13) Panicle length (cm)
14) Total grain per panicle

3.2.2 Yield Components of Maize

Growth components of maize

1) Plant height (cm) at 4, 8, 12 WAP
2) Number of leaves/plant
3) Length of leaf (cm)
4) Width of leaf (cm)
5) Leaf area index

Yield components of maize

1) Dry cob weight (t/ha)
2) Number of cobs per plant
3) Number of seed per cob
4) Dry grain weight (t/ha)
5) Dry Stover weight at harvest (t/ha)
6) weight of 100 seeds (gm)

3.2.3 Yield Components of Bambara Groundnut

a) Growth components of Bambara groundnut

1) Number of days to 50% flowering of bambara groundnut
2) Number of days to maturity of bambara groundnut
3) Number of leaves per plant of bambara groundnut
4) Canopy width (cm) of bambara groundnut
5) Plant height (cm) of bambara groundnut

6) Length of tap root (cm) at 50% flowering of bambara groundnut
7) Number of lateral roots at 50% flowering of bambara groundnut
8) Length of longest lateral root at 50% flowering of bambara groundnut

(b) Yield components of Bambara groundnut

1. Number of pods per plant
2. Number of seeds per pod
3. 100 seed weight(g)
4. Dry pod weight (t/ha)
5. Seed yield (t/ha) of bambara groundnut
6. Shelling percentage (%)
7. Total plant biomass (t/ha)
8. Shoot dry matter at harvest (t/ha)
9. Dry root weight at harvest (t/ha)
10. Number of nodules per plant
11. Dry weight of nodules per hectare (kg/ha)

3.2.4 Yield Components of Cowpea

- Number of branches/stand
- Number of pods/stand
- Length of pod (cm)
- Number of seeds/pod
- 100 seed weight (g)
- Dry grain weight (t/ha)
- Shelling percentage (%)
- Harvest index
- Dry root weight at harvest (t/ha)
- Total plant biomass (t/ha)
- Dry pod weight (t/ha)
- Shoot dry matter (t/ha)

3.2.5 Yield Components of Sunflower

- plant height (cm)
- stem diameter (cm)
- head diameter (cm)
- 1000 seed weigh (gm)
- dry matter (t/ha)
- harvest index
- seed yield per plant (gm)
- seed yield (t/ha)
- leaf number
- 1000 seed weight. (gm)

3.3 Yield Limiting Factors

Plants require a balance of six critical factors in order to optimise growth— temperature, humidity, carbon dioxide, water, nutrients, and light. When growing in a controlled environment, growers can control these conditions to maximize their plants' growth potential.

There are limits to a plant's ability to utilize each parameter at any given time. Overexposure to any one factor can be detrimental to plant health and growth rate. For example, fertilisation allows the plant access to extra resources to increase growth rates but too many nutrients can be toxic, resulting in burned plant roots. Water is necessary, but if a plant is over-watered, the oxygenation of the root zone is reduced thereby killing the plant. Some of these yield limiting factors are environmentally based and are as summarized below.

Rainfall and Water

Rainfall is the most common form of precipitation. It is the falling of water in droplets on the surface of the Earth from clouds. The amount and regularity of rainfall vary with location and climate types and affect the dominance of certain types of vegetation as well as crop growth and yield.

Light

Light is a climatic factor that is essential in the production of chlorophyll and in photosynthesis the process by which plants manufacture food in the form of sugar (carbohydrate) and subsequently into other organic compounds. Three properties of this climatic factor that affect plant growth and development are light quality, light intensity and day length (photoperiod). Light quality refers to the specific wavelengths of light; light intensity is the degree of brightness that a plant receives; and day length is the duration of the day with respect to the night period. Aside photosynthesis, other plant processes that are enhanced or inhibited by this climatic factor include stomatal movement, phototropism, photomorphogenesis, translocation, mineral absorption, and abscission.

Temperature

The degree of hotness or coldness of a substance is called temperature. It is commonly expressed in degree Celsius or centigrade (C) and degree Fahrenheit (F). This climatic factor influences all plant growth processes such as photosynthesis, respiration, transpiration, breaking of seed dormancy, seed germination, protein synthesis, and translocation. At high temperatures the translocation of photosynthate is faster so that plants tend to mature earlier. In general, plants survive within a temperature range of 0 to 50 C. The favourable or optimal day and night temperature range for plant growth and maximum yields varies among crop species.

Enzyme activity and the rate of most chemical reactions generally increase with rise in temperature. Up to a certain point, there is doubling of enzymatic reaction with every 10 C temperature increase. But at excessively high temperatures, denaturation of enzymes and other proteins occur. Excessively low temperatures can also cause limiting effects on plant growth and development. For example, water absorption is inhibited when the soil temperature is low because water is more viscuous at low temperatures and less mobile, and the protoplasm is less permeable.

Air

The air is a mixture of gases in the atmosphere. The oxygen and carbon dioxide in the air are of particular importance to the physiology of plants. Oxygen is essential in respiration for the production of energy that is utilized in various growth and development processes. Carbon dioxide is a raw material in photosynthesis.

Relative Humidity

Relative humidity (RH) is the amount of water vapour in the air, expressed as the proportion (in percent) of the maximum amount of water vapor it can hold at certain temperature. For example, an air having a relative humidity of 60% at 27^{o} C temperature means that every kilogram of the air contains 60% of the maximum amount of water that it can hold at that temperature.

The relative humidity affects the opening and closing of the stomata which regulates loss of water from the plant through transpiration as well as photosynthesis.

Wind as Climatic Factor

Air movement or wind is due to the existence of pressure gradient on a global or local scale caused by differences in heating. This climatic factor serves as a vector of pollen from one flower to another thus aiding in the process of pollination. It is therefore essential in the development of fruit and seed from wind-pollinated flowers as in many grasses.

Nutrients

There are optimum levels of nutrient availability that should be met in the soil and plant for maximum crop production. Understanding and managing plant nutrients for crop production is of paramount importance.

Soil constraints

Soil constraints can be any physical or chemical restriction to the normal root proliferation into the subsoil. Constraints can be naturally occurring, or as a result of management. Soil constraints can often be minimised with the use of correct nutrition or the addition of soil ameliorants.

Physiological Factors

The main physiological factors responsible for yield fluctuations are the sensitivity of plants to environmental stress. The magnitude of crop photosynthesis is primarily determined by the size and longevity of the foliage and, to a lesser extent, by the efficiency of carbon fixation. Water shortage and air temperature strongly affect leaf production, expansion and death. Flower and pod abortion result from a temporary shortage of assimilates produced by intense intra-plant competition between vegetative parts, especially the stem apex, and reproductive organs at the beginning of flowering. Most of these physiological processes are influenced by the environment.

Plant Disease and Insects

Pests and diseases can severely impact plants and contribute to low yields. Crops and plants should be inspected regularly for pests as well as disease and deficiencies. A combination of biological, chemical and cultural control measures to control pests is considered the most effective and sustainable approach to addressing pest problems.

Weeds

Weeds can result in competition with plants or crops species for nutrients and soil moisture. Management strategies in weed control is the integrated approach with the use of herbicides which offers the best approach to reduce the impact of weeds.

4.0 CONCLUSION

Plant structure, growth pattern, organs constitute measureable components of plants. It is important to remember that while there are many factors that limit plant growth and development, it is equally of note that some of these factors can be managed and manipulated. The key issue is to identify the most limiting factors and target them with cost-effective strategies in other to optimise yields.

5.0 SUMMARY

Plant morphology is useful in the visual identification of plants. As plants grow, structures and organs emerge either aerially or subterranean. These will constitute the components that will eventually

contribute to final yields of plants. These yields are limited by a number of factors, some of which could be manipulated for optimal yields.

6.0 TUTOR MARKED ASSIGNMENT

1. List the growth components of the following crops: maize, sunflower, cowpea, rice.
2. Mention yield components of Bambara groundnuts and cowpea.
3. List yield limiting factors of plants.
4. Explain RH of 45% at 25^o C.

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UNIT 3 GROWTH REGULATORS: AUXINS, GIBBERELLINS, CYTOKININS ETC.

CONTENTS

1.0 INTRODUCTION

You may have often wondered why in a germinating seedling, roots grow in downward direction whereas shoots grow upwards. Why some flowers bloom during the day, but close at night, as if to sleep. Why one rotten apple in a basket leads to rotting of others or what causes leaf fall? How are the processes of cell division and cell elongation controlled? These are some of the questions, amongst many others, which do not have any simple answers, for most of these phenomena are controlled by complicated interactions among three levels of controls-genetic, hormonal and environmental.

The various genes in a species are turned on at precise times to control cell activity and various characteristics of organisms. One class of potent chemicals that coordinate growth and development in plants and animals are hormones. They trigger cellular reactions in target cells and also determine the genes that are to be expressed at a particular stage of development. Environmental factors such as light and temperature also affect and control growth and development. These will be dealt with in this unit.

2.0 OBJECTIVES

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

- identify the classes of plant growth hormones

- explain the various types of plant growth hormones
- discuss the effects and application of plant growth hormones.

3.0 MAIN CONTENT

We all know that plants need light, water, oxygen and nutrition to grow and develop. All these qualify as extrinsic factors. While extrinsic factors are important, plant growth also depend on intrinsic factors too. They can be intracellular genes or intercellular chemicals. These chemicals are called **plant growth regulators**. Plant growth regulators are small, simple chemicals produced naturally by plants to regulate their growth and development.

Plant growth regulators can be of a diverse chemical composition such as gases (ethylene), terpenes (gibberellic acid) or carotenoid derivates (abscisic acid). They are also referred to as plant growth substances, phytohormones or plant hormones.

3.1 Classification of Plant Growth Hormones

Based on their action, they are broadly classified as follows:

- Plant Growth Promoters: They promote cell division, cell enlargement, flowering, fruiting and seed formation. Examples are auxins, gibberellins and cytokinins.
- Plant Growth Inhibitors: These chemicals inhibit growth and promote dormancy and abscission in plants. An example is an abscisic acid.

Note: Ethylene can be a promoter or an inhibitor, but is largely a plant growth inhibitor.

3.2 Types of Plant Growth Hormones, Their Effects and Applications

3.2.1 Auxins

Auxins were the first growth hormone to be discovered. They were discovered due to the observations of Charles Darwin and his son, Francis Darwin. The Darwins observed that the coleoptile (protective sheath) in canary grass grows and bends towards the source of light. This phenomenon is 'phototropism'. In addition, their experiments showed that the coleoptile tip was the site responsible for the bending. Finally, this led to the isolation of the first auxin by F. W. Went from the coleoptile tip of oat seedlings. First isolated from human urine, auxin is a term applied to natural and synthetic compounds that have growth

regulating properties. Plants produce natural auxins such as Indole-3-acetic acid (IAA) and Indole butyric acid (IBA). Natural auxins are found in growing stems and roots from where they migrate to their site of action. Naphthalene acetic acid (NAA) and 2, 4-dichlorophenoxyacetic (2, 4-D) are examples of synthetic auxins.
Effects.

- Promote flowering in plants like pineapple.
- Help to initiate rooting in stem cuttings.
- Prevent dropping of fruits and leaves too early.
- Promote natural detachment (abscission) of older leaves and fruits.
- Control xylem differentiation and help in cell division.

Applications.
- Used for plant propagation.
- To induce parthenocarpy i.e. the production of fruit without prior fertilization.
- 2, 4-D is widely used as an herbicide to kill dicotyledonous weeds.
- Used by gardeners to keep lawns weed-free.

Note: The growing apical bud in higher plants inhibits the growth of the lateral buds. This phenomenon is **Apical Dominance**. Removal of the apical bud allows the lateral buds to grow. This technique is commonly used in tea plantations and hedge-making.

3.2.2 Gibberellins

It is the component responsible for the 'bakane' disease of rice seedlings. The disease is caused by the fungal pathogen *Gibberella fujikuroi.* E. Kurosawa treated uninfected rice seedlings with sterile filtrates of the fungus and reported the appearance of disease symptoms. Finally, the active substance causing the disease was identified as gibberellic acid.

There exist more than 100 gibberellins obtained from a variety of organisms from fungi to higher plants. They are all acidic and are denoted as follows – GA_1, GA_2, GA_3 etc. GA_3 (Gibberellic acid) is the most noteworthy since it was the first to be discovered and is the most studied.

Effects

- Increase the axis length in plants such as grape stalks.
- Delay senescence (i.e. ageing) in fruits. As a result, their market period is extended.
- Help fruits like apples to elongate and improve their shape.

Applications

- The brewing industry uses GA_3 to speed the malting process.
- Spraying gibberellins increase sugarcane yield by lengthening the stem.
- Used to hasten the maturity period in young conifers and promote early seed production.
- Help to promote bolting (i.e. sudden growth of a plant just before flowering) in cabbages and beet.

3.2.3 Cytokinins

F. Skoog and his co-workers observed a mass of cells called 'callus' in tobacco plants. These cells proliferated only when the nutrient medium contained auxins along with yeast extract or extracts of vascular tissue. Skoog and Miller later identified the active substance responsible for proliferation and called it kinetin.

Cytokinins were discovered as kinetin. Kinetin does not occur naturally but scientists later discovered several natural (example – zeatin) and synthetic cytokinins. Natural cytokinins exist in root apices and developing shoot buds – areas where rapid cell division takes place.

Effects

- Help in the formation of new leaves and chloroplast.
- Promote lateral shoot growth and adventitious shoot formation.
- Help overcome apical dominance.
- Promote nutrient mobilisation which in turn helps delay leaf senescence.

3.2.4 Abscisic Acid

Three independent researchers reported the purification and characterisation of three different inhibitors – Inhibitor B, Abscission II and Dormin. Later, it was found that all three inhibitors were chemically identical and were, therefore, together were given the name abscisic acid. Abscisic acid mostly acts as an antagonist to Gibberellic acid.

Effects

- Regulate abscission and dormancy.
- Inhibit plant growth, metabolism and seed germination.

- Stimulates closure of stomata in the epidermis.
- It increases the tolerance of plants to different kinds of stress and is, therefore, called ‘stress hormone’.
- Important for seed development and maturation.
- It induces dormancy in seeds and helps them withstand desiccation and other unfavourable growth factors.

3.2.5 Ethylene

A group of cousins showed that a gaseous substance released from ripe oranges hastens the ripening of unripe oranges. Consequently, they found that the substance was ethylene – a simple gaseous plant growth regulator. Ripening fruits and tissues undergoing senescence produce ethylene in large amounts.

Effects

- Affects horizontal growth of seedlings and swelling of the axis in dicot seedlings.
- Promotes abscission and senescence, especially of leaves and flowers.
- Enhances respiration rate during ripening of fruits. This phenomenon is ‘respiratory climactic’.
- Increases root growth and root hair formation, therefore helping plants to increase their absorption surface area.

Application

Ethylene regulates many physiological processes and is, therefore, widely used in agriculture. The most commonly used source of ethylene is Ethephon. Plants can easily absorb and transport an aqueous solution of ethephon and release ethylene slowly.

- Used to break seed and bud dormancy and initiate germination in peanut seeds.
- To promote sprouting of potato tubers.
- Used to boost rapid petiole elongation in deep water rice plants.
- To initiate flowering and synchronising fruit-set in pineapples.
- To induce flowering in mango.
- Ethephon hastens fruit ripening in apples and tomatoes and increases yield by promoting female flowering in cucumbers. It also accelerates abscission in cherry, walnut and cotton.

4.0 CONCLUSION

Plant Growth Regulators can be of a diverse chemical composition such as gases, terpenes, or carotenoid derivates. They are small but simple chemicals produced naturally by plants to regulate their growth and development. Plant growth regulators are indispensable in our study of plant growth and development.

5.0 SUMMARY

In summary, one or the other plant growth regulator influences every phase of growth or development in plants. These roles could be individualistic or synergistic; promoting or inhibiting. Additionally, more than one regulator can act on any given life event in a plant. Along with genes and extrinsic factors, plant growth regulators play critical roles in plant growth and development. Factors like temperature and light affect plant growth events (vernalisation) via plant growth regulators.

6.0 TUTOR MARKED ASSIGNMENT

1) Match the plant growth regulator and the scientist associated with it.

Plant Growth Regulator	**Scientist**
1. Gibberellins	a. Independent researchers
2. Auxins	b. E. Kurosawa
3. Abscisic acid	c. F. Skoog
4. Cytokinins	d. F. W. Went

2) List two applications for each of the followings plant growth regulator: Gibberellins; Auxins; Abscisic acid and Cytokinins.

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MODULE 4 PLANT GROWTH MEASUREMENTS, GROWTH ANALYSIS AND ROLES OF PLANT ORGANS

UNIT 1 PLANT GROWTH AND MEASUREMENTS

CONTENTS

1.0 INTRODUCTION

Growth in a plant is the outcome of cell division, enlargement of the new cells and their differentiation into different types of tissues. These processes of growth are accompanied by either a permanent change in size (usually an increase in length or volume) and or an increase in the dry weight of the growing parts. In plants, growth is confined only to meristems. The extreme apices of root and shoot, for instance are occupied by primary meristems while in their older parts, secondary meristems (i.e., cambia) give rise to additional vascular tissues and the protective layers of cork cells. The activity of each meristem influences the activity of the other meristems especially those near to it, giving rise to what is called as growth correlations. For instance, while the main apical shoot meristem is active it retards the activity of more recently initiated lateral bud meristems, a phenomenon usually referred to as ‘apical dominance’.

2.0 OBJECTIVES

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

- discuss growth processes in plants
- explain approaches/techniques of growth measurements
- examine how to sample and measure the various parts of plants.

3.0 MAIN CONTENT

Growth can be determinate—when an organ or part or whole organism reaches a certain size and then stops growing—or indeterminate—when cells continue to divide indefinitely. Plants in general have indeterminate growth.

Differentiation is the process in which generalised cells specialise into morphologically and physiologically different cells. Since all the cells produced by division in the meristems have the same genetic make- up, differentiation is a function of which particular genes are either expressed or suppressed. The kind of cell that ultimately develops also is a result of its location: Root cells don't form in developing flowers, for example, nor do petals form on roots.

3.1 Techniques/Approaches to Measuring Plant Growth

To capture enough data on the overall wellbeing of your plants, we recommend that you record at least one final weight measure, one measure of root, and all measurements that pertain to the type of plant you are using.

3.1.1 Weighing Plants: Fresh vs. Dry Weight

- **Measuring Fresh Weight**: While you can technically measure the fresh weight of plants without harming them, the simple act of removing a plant from its growing "medium" can cause trauma and affect the ongoing growth rate and thus your experiment. Measuring the fresh weight of plants is tricky and should probably be saved as a final measure of growth at the end of the experiment. Here is the process for measuring fresh weight:
    1. Remove plants from soil and wash off any loose soil.
    2. Blot plants gently with soft paper towel to remove any free surface moisture.
    3. Weigh immediately (plants have a high composition of water, so waiting to weigh them may lead to some drying and therefore produce inaccurate data).

- **Measuring dry weight**: Since plants have a high composition of water and the level of water in a plant will depend on the amount of water in its environment (which is very difficult to control), using dry weight as a measure of plant growth tends to be more reliable. You can only capture this data once as a final measure at the conclusion of your experiment.
    1. Remove the plants from the soil and wash off any loose soil.
    2. Blot the plants removing any free surface moisture.
    3. Dry the plants in an oven set to low heat (100° F) overnight.
    4. Let the plants cool in a dry environment (a Ziploc bag will keep moisture out) - in a humid environment the plant tissue will take up water. Once the plants have cooled, weigh them on a scale.
    5. Plants contain mostly water, so make sure you have a scale that goes down to milligrams since a dry plant will not weight very much.

3.1.2 Root Mass

Root mass is recommended as a final measurement as the plant must be removed from its growing medium in order to capture accurate data. There are quite a few different methods for measuring root mass depending on the type and structure of the roots.

- Grid intersect technique:
    1. Remove the plant from the soil.
    2. If you are working with thin or light roots, you may want to dye the roots using an acidic stain.
    3. Lay the roots on a grid pattern and count the number of times the roots intersect the grid.
- Trace the roots on paper, measure each of the tracings, and calculate root length from the tracings.
- Count the number of roots.
- Measure the diameter of the root. This is especially useful for root vegetables such as beets, carrots, potatoes, etc. that have a large root.

3.1.3 Root Shoot Ratio

Roots allow a plant to absorb water and nutrients from the surrounding soil, and a healthy root system is key to a healthy plant. The root:shoot ratio is one measure to help you assess the overall health of your plants. Your control group of plants will provide you with a "normal" root:shoot ratio for each of your plant types, any changes from this normal level (either up or down) would be an indication of a change in the overall health of your plant. It is important to combine the data from the root:shoot ratio with data from observations to get an accurate understanding of what is happening with your plants. For example, an increase in root:shoot ratio could be an indication of a healthier plant, provided the increase came from greater root size and not from a decrease in shoot weight. To measure the root:shoot ratio:

i. Remove the plants from soil and wash off any loose soil.
ii. Blot the plants removing any free surface moisture.
iii. Dry the plants in an oven set to low heat (100° F) overnight.
iv. Let the plants cool in a dry environment (a Ziploc bag will keep moisture out) - in a humid environment the tissue will take up water. Once the plants have cooled weigh them on a scale.
v. Separate the root from the top (cut at soil line).
vi. Separately weigh and record the root and top for each plant. (Dry weight for roots/dry weight for top of plant = root/shoot ratio)
vii. The root/shoot ratio can be calculated for each treatment.
viii. Plants contain mostly water, so make sure you have a scale that goes down to milligrams since a dry plant will not weight very much.

3.1.4 Measurement by Observation

There are many different features of a plant that can be measured through observations to determine the extent of plant growth/health. The following table describes some of the measures that you can make and also recommends how frequently you should make these observations during the course of your experiment.

	Measurement	Procedure	Frequency of Measurement
When starting with seeds	First Cotyledon	Record the number of days from planting to the emergence of the first cotyledon ("seed leave(s)" that are the first to emerge from the ground).	Once

	Percentage of seeds that germinate	Calculate the percentage of seeds that germinated under each of the variables in your experiment.	Once
When starting with young plants	Plant height	Measure the height of the main plant from the border of the container to the top of the main plant stem. Note: you do not want to measure from the top of the soil, as the soil may condense with watering over time.	Every 2-3 days
	Number of leaves (indicates a plant's physiological age)	Counting Leaves: Count and record the number of leaves on each plant. Count every visible leaf on the plant, including the tips of new leaves just beginning to emerge. You may want to place the plant over some graph paper to avoid counting errors.	Every 2-3 days
	Surface area of leaves	Method 1: Trace the leaves on graph paper and count the squares covered to give you an estimate of the surface area for each leaf. Repeat this for each leaf on a plant and for each plant in your experiment. Method 2: Trace out each leaf on paper. Make sure to use the same type of paper every time AND make sure that the paper is not wet. Cut out the leaf tracings	Every 2-3 days

		and weigh them. Weigh the cutouts and divide the total weight by the number of leaves to give you the average leaf area for each plant. Repeat this for each of the plants in your experiment. Method 3: Digital image analysis: Using a digital camera capture an image of a plant. Using special software, analyse the surface area of the leaves.	
	Plant color	Record any observations on changes or differences in plant color.	Every 2-3 days
When you are using flowering plants these two measurements serve as an additional indication of plant wellbeing	1st Flowering	Record the number of days since initial planting to the first flower.	Once
	Number of Flowers	Record the number of flowers on each of the plants. Buds should be included in your flower count.	Every 2-3 days

4.0 CONCLUSION

As plants grow and develop they need to be monitored through regular measurements of growth parameters. This will assist in knowing the contributions of the various parameters to the final yield of the plant. Measurement of growth parameters also assist in the management of plants through reviews of management practices that will improve on their performances.

5.0 SUMMARY

Growth can be determinate or indeterminate. As cells produce by divisions in the meristems, differentiation into various tissues and organs takes place as controlled by the genetic makeup of the plant. These tissues and organs become measureable parameters of plant growth leading to low or increased yields.

6.0 TUTOR MARKED ASSIGNMENT

1. What is the frequency of taking these measurements: leaf area; plant height; colour; first t flowering; number of flowers.
2. Give stepwise approach to taking weight of roots.
3. Mention observable characters of plants.

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UNIT 2 GROWTH ANALYSIS: RELATIVE GROWTH RATE, CROP GROWTH RATE, NET ASSIMILATION RATE, LEAF AREA INDEX

CONTENTS

1.0 INTRODUCTION

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. It uses simple primary data in the form of weights, areas, volumes and contents of plant components to investigate processes within and involving the whole plant These calculations can otherwise be tedious especially in a case where statistics is involved.

We take the simplest possible approach, calculating the most fundamental of the growth parameters according to purely `classical' methods across one harvest-interval (meaning the period of time between two successive harvests). This contrasts with the 'functional' or 'dynamic' approach, involving the use of many harvests and fitted curves, which can be either parametric or form-free, and also contrasts with the 'combined' approach involving curves fitted to classically derived values . Our focus in this unit is to calculate the most fundamental of the growth parameters according to purely `classical' methods across one harvest-intervals.

2.0 OBJECTIVES

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

- discuss the basis of calculating the growth analysis
- explain the formulae for calculating the basic growth indexes.

3.0 MAIN CONTENT

The functional leaves, dry matter production and leaf area index are the main growth factors which may directly reflect on grain yield. Growth analysis parameters like crop growth rate (CGR) are product of LAI. Relative growth rate (RGR) measures the increase in dry matter with a given amount of assimilatory material at a given point of time and net assimilation rate (NAR) is the net gain in total dry matter per unit leaf area per unit time.

3.1 Traditional Plant Analysis

In traditional plant growth analysis and yield component analysis, both use simple plant characteristics to generate more complex indices relating to plant growth or productivity. In the traditional approach, plant growth is the outcome of net rates of production which contribute material as plants persist in time and some of the biomass accumulated may be deposited in constituents of special interest.

3.2 Symbols Used

The under listed symbols are used when calculating both simple and complex plant growth analysis.

A	Land area (plot size sampled)
B_N	Number of branches per plant
F_N	Number of flowers per plant
L_A	Leaf area per plant
L_W	Leaf dry wt per plant
N	Number of plants
P_N	Number of pods per plant
S_N	Number of seeds per plant
S_W	Seed dry wt per plant
t	Time
T	Total stem length per plant
V	Any primary value, see Table 2
W	Total dry wt per plant
W_S	Shoot dry wt per plant
W_Y	Dry wt per plant which constitutes 'yield'

Source: P. A. Tolliffe (1982)

3.3 Formulae for some Traditional plant analysis

I. Traditional plant growth analysis

Growth rate and components of growth rate

Absolute growth rate	$\mathbf{AGR} = (dW/dt)$
Crop growth rate	$\mathbf{C} = (N/A)(dW/dt)$
Relative growth rate	$\mathbf{R} = (1/W)(dW/dt)$
Unit leaf rate	$\mathbf{E} = (1/L_A)(dW/dt)$
Leaf area index	$\mathbf{L} = N(L_A/A)$
Leaf area ratio	$\mathbf{F} = L_A/W$
Specific leaf area	$\mathbf{SLA} = L_A/L_W$
Leaf weight ratio	$\mathbf{LWR} = L_W/W$

Persistence of growth

Biomass duration	$\mathbf{Z_W} = N\int_{t_1}^{t_2} W\,dt$
Leaf area duration	$\mathbf{Z_L} = N\int_{t_1}^{t_2} L_A\,dt$

Presence and partitioning of dry matter

Planting density	$\mathbf{D} = N/A$
Biomass density	$\mathbf{B_D} = (N \times W)/A$
Harvest index	$\mathbf{H} = W_Y/W$

Source: P. A. Tolliffe (1982)

3.4 Relative Growth Rate (RGR)

Relative Growth Rate (RGR) is the central parameter in plant growth analysis. Relative growth rate measures the increase in dry matter with a given amount of assimilatory material at a given point of time.

$$\text{Relative growth rate} = \frac{\text{InW2} - \text{InW1}}{\text{t2} - \text{t1}}$$

Where, In = Natural log, W1= Dry weight of plant/m^{2}recorded at time t1, W2= Dry weight of plant/m^{2}recorded at time t2, t1and t2 were the interval of time, respectively and is expressed as g/g/day.

3.5 Net Assimilation Rate (NAR)

Net Assimilation Rate (NAR) is increase in dry wt. of plant per unit leaf area per unit time. NAR is calculated from the following equation:

$$\text{Net assimilation rate} = \frac{(\text{W2} - \text{W1})(\text{Log L2} - \text{Log L1})}{(\text{t2} - \text{t1})(\text{L1} - \text{L2})}$$

Where L1 and L2 are total leaf are at time t1 and t2 respectively. W1 and W2 are total dry wt. at time t1 and t2 respectively.

3.6 Leaf Area Index (LAI)

Leaf area index (LAI) expresses the leaf area over the surface area occupied by the plant. The LAI of plants treated with N had an ascending behavior over the time (Fig. 6A) and at some point would reach a maximum value, at which the plants will have the maximum capacity to intercept solar energy. The ascending behavior of LAI can be attributed to a high rate of leaf formation and foliar expansion, especially in treatments of 100% NH 4 + and 50%NH 4.

$$\text{Leaf area index} = \frac{\text{Total leaf area}}{\text{Unit land area}}$$

3.7 Crop Growth Rate (CGR)

Crop growth rate is a measure of the increase in size, mass or number of crops over a period of time. The increase can be plotted as a logarithmic or exponential curve in many cases. The crop growth rate calculation is dependent on the values of NAR (Net Assimilation Rate) and LAI (Leaf Area Index) of the crop. From the values of NAR and LAI, you can calculate the value for CGR as follows

CGR = NAR x LAI
The crop growth rate is the efficiency of the complete crop over a specific soil area.

3.8 Leaf Area Ratio (LAR)

Leaf Area Ratio represents the efficiency of a particular leaf area over time usually at the end of the life of the crop
LAR over the life of the crop = final leaf area / final plant dry weight

3.9 Net Assimilation Ratio (NAR)

NAR = RGR / LAR

This value represents the efficiency of production of the crop over time usually at the end of the cropping season.

4.0 CONCLUSION

Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. They are useful tools in assessing the overall performance of our crops over time.

5.0 SUMMARY

In crops that are actively photosensitizing, dry matter production and leaf area index are the main growth factors which may directly reflect on grain yield. Growth analysis parameters like crop growth rate (CGR), Relative growth rate (RGR), and net assimilation rate (NAR) are indexes of productivity and efficiency of resources used in production at a given point in time.

6.0 TUTOR MARKED ASSIGNMENT

Give the formula for the following growth analysis

a) CGR
b) RGR
c) NAR
d) LAI
e) LAR

What is the importance of Leaf Area Index in crop production?

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UNIT 3 ROLES OF PLANT ORGANS: LEAF, STEM, ROOTS, FLOWERS, FRUITS, SEEDS

CONTENTS

1.0 INTRODUCTION

All living organisms consist of cells. These cells form tissues at tissues constitute the organs. The various parts of plants are linked together and synchronically function to produce its output which is considered as final yield. Plant organs include the roots, stems, leaves, and reproductive structures (flowers, fruits and seeds). Each organ performs a specialized task in the life of the plant. Roots, leaves, and stems are all vegetative structures. Flowers, seeds, and fruits make up reproductive structures. The roots support the plant and supply it with water and nutrients. Stems connect the roots and leaves. Leaves capture energy from sunlight and use it to manufacture carbohydrates for the plant.

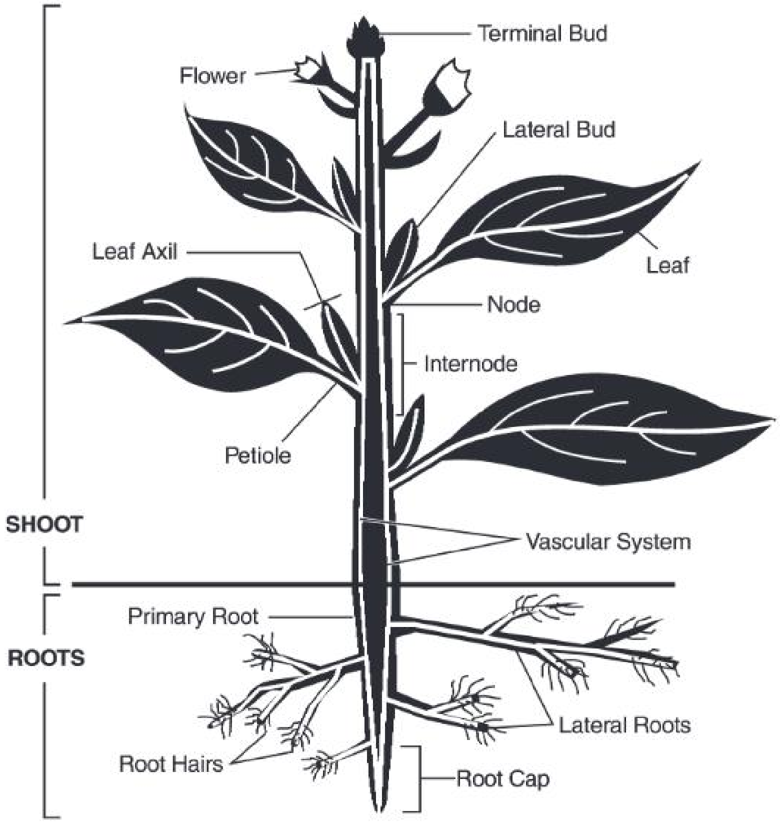
2.0 OBJECTIVES

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

- discuss the various organs of the plant
- explain the functions of the organs of the plant.

3.0 MAIN CONTENT

Plants have specialized organs that help them survive and reproduce in a great diversity of habitats. As earlier mentioned, all living organisms consist of cells. It is the cells that make the tissues which later become organs like roots, stems, leaves, flowers, fruits and seeds.



Principal Parts of a Vascular Plant

3.1 The Plant Root

The root is the first plant structure to emerge from a seed during germination. Roots are mostly found below the soil surface. They represent about 50% of a plant's weight. The first root to emerge from a seed is the primary root, or radicle. There are two basic types of root systems in plants: taproot systems and fibrous root systems.

- Taproot systems feature a single, thick primary root, called the **taproot**, with smaller secondary roots growing out from the sides. The taproot may penetrate as many as 60 meters (almost 200 feet) below the ground surface. It can plumb very deep water sources and store a lot of food to help the plant survive drought and other environmental extremes. The taproot also anchors the plant very securely in the ground.
- Fibrous root systems have many small branching roots, called fibrous roots, but no large primary root. The huge number of threadlike roots increases the surface area for absorption of water and minerals, but fibrous roots anchor the plant less securely.

Although most plant roots do not spread more than one to two meters into the ground, the taproots of many trees grow deeply into the soil and can often reach water far below the soil surface.

The primary functions of roots are to absorb water and nutrients from the soil and to support the plant in an upright position. Roots also distribute the food energy produced in the leaves to the rapidly growing areas found at the root tips. Some plants also use their roots as specialized food storage reserves.

3.2 The Plant Stem

Plant stems connect the roots with the leaves. Plant stems are important because they transport water and nutrients from the roots to the leaves. They also transport food energy from the leaves to the roots. Stems function as supportive structures. They hold a plant's leaves up toward the sun so they can capture energy from sunlight. Tall, strong stems give a plant a competitive advantage by holding the leaves above those of other plants, increasing their exposure to sunlight. Young, green stems help leaves collect sunlight for photosynthesis. Stems also support flowers and reproductive structures that allow for the perpetuation of the plant species.

3.3 The Plant Leaf

Leaves are the keys not only to plant life but to all terrestrial life. The primary function of leaves is to capture sunlight for manufacturing food reserves. This process is called photosynthesis. Photosynthesis occurs within specialized cells found in leaves or modified stems such as cladophylls. During photosynthesis, water and carbon dioxide chemically combine in the presence of sunlight to make plant sugars, oxygen, and water. Many of the external structures of leaves are designed to help the plant photosynthesise so it can manufacture sugar food reserves. In addition to capturing sunlight for photosynthesis, leaves are also important in the process of gas exchange.

Photosynthesis requires carbon dioxide and produces oxygen. To maintain a supply of carbon dioxide, the plant opens tiny pores called stomata located on the undersides of leaves. The opened stomata allow carbon dioxide to enter a leaf. Oxygen produced by photosynthesis also escapes through the stomata. At the same time, tiny droplets of water vapor escape from the humid environment inside the leaf into the dry air around the plant. This process of water evaporation from the surface of the plant is called transpiration. Plant leaves therefore aid the process of transpiration.

3.4 The Plant Flower

Flowers are the reproductive structures of angiosperms (flowering plants). Reproductive structures play an important part in the life cycle of plants because they promote sexual reproduction and produce seeds and fruits that aid the dispersal of the plant species. Flowers, like any other part of the plant, vary in structure, size, and composition. Some flowers resemble stems, whereas others resemble leaves. Flowers develop from buds, as do shoots. Therefore, they are considered to be specialised branches of a plant.

3.5 The Plant Fruits

A fruit is a ripened ovary. Fruits are the fleshy substances that usually surround seeds. Fruit is an organ that contains seeds, protecting these as they develop and often aiding in their dispersal e.g. coconut nuts float in water and are thus transported to distant places Fruits ripen as the seeds mature within. Fruits help to distribute seeds rather than protect them. When man and animals eat fruits, they are channels for the dispersal of the seeds.

3.6 The Plant Seed

In flowering plants seeds are the structures containing the embryo plant for the next generation. Each seed consists of an embryo, food source, and protective outer coat. Seeds are surrounded by a seed coat and contain the embryo axis and the cotyledons. They contain either one cotyledon (monocotyledonous plants) or two (dicotyledonous plants). Cotyledons contain stored food. It can lie dormant for some time before germinating when environmental conditions are right.

4.0 CONCLUSION

All living organisms consist of cells. These cells form tissues. Tissues form organs. Plant organs include their roots, stems, leaves, and reproductive structures. The various parts are linked together and synchronically function to produce its output which is considered as final yield.

5.0 SUMMARY

Plants have specialised organs that help them survive and reproduce in a great diversity of habitats. As earlier mentioned, all living organisms consist of cells. It is the cells that make the tissues which later become organs like roots, stems, leaves, flowers, fruits and seeds. These organs have specialised roles to play in the life of the plant.

6.0 TUTOR-MARKED ASSIGNMENT

1. Mention main plant organs that you know.
2. What are the roles of the following plants organs?
   (i) flower (ii) seed (iii) roots
3. Do you consider leaf as an organ of a plant? Mention the most important role of a leaf as a plant organ.

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