COURSE CODE: **PCP 101**

COURSE TITLE: **Introductory Plant Physiology**

NUMBER OF UNITS: **2 Units**

COURSE DURATION: **2 Hours per week**

COURSE DETAILS:

Course Coordinator: **Dr. M. O. Atayese;** B.Sc. M.Sc., PhD
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COURSE CONTENT:

Nature of living organisms; Plant nutrition, elements and their functions; Uptake of nutrients; Sources of metabolites; Chemosynthesis and photosynthesis; Cycles of raw materials (nitrogen cycles); Respiration; Method of elimination of waste material of production in plants; Plant hormones; homeostasis, osmoregulation in plants; Reproduction (sexual and asexual); Growth and development, patterns of growth, factors affecting growth, flowering and fruit growth; Enzymes (properties/characteristics, composition, types, mechanism of action, estimates of rates, inhibitors).

COURSE REQUIREMENTS:

This is a compulsory course for all students majoring in the field of Agriculture or Agricultural related disciplines in the University. In view of this students are expected to participate in all the course activities and have minimum of 75% attendance to be able to write the final examination

READING LIST:

1. 1. P. O. Adetiloye, K. A. Okeleye and G. O. Olatunde. 2006. Principles and Practices of Crop Production. Printed by Ideas and Innovations Publication LTD. Pp 54-87

2. Federal Fertilizer Department, Federal ministry of Agriculture and Rural Development (2002). Fertilizer Use and Management Practices for Crop in Nigeria E,A. Aduayi, V.O Chude, S.O Olayiwola (Eds) printed by S. B. Garko International Ltd. Pp.

3. J.R Okalebo K.W. Gathua and P.L Woomer (1993) Laboratory method of soil and plant analysis: A working Manual. Tropical Soil Biology and Fertility Programme, 1993. SBN 9966-9892-1-8. Soil Science Society of East Africa Technical Publication No.1. Printed by Marvel EPZ (Kenya) LTD, Nairobi, Kenya. Pp. 88.

4. S. K. Verma and Mohit Verma 2007. Plant Physiology, Biochemistry and Biotechnology. Printed by S. Chanel and Company Ltd, New Delhi.

LECTURE NOTES

NATURE OF LIVING ORGANISM

What are living organisms?

These are organisms characterized by performance of certain life processes. Non living things may be able to perform one or more to these process, for instance, a machine can move, it is only living organism that can perform all of the activities.

Example of living things are: microorganism e.g bacteria, Algae, fungi, lower green plants, non flowering (gymnosperms), flowering plants (Angiosperms) and animals.

Majority of agricultural plants otherwise known as crops are generally found with the non flowering and flowering plants.

Performance of these basic activities by the plant has been of immense benefits to man. For instance, Plants' efforts at feeding through the process of photosynthesis bring about accumulation of starch in maize, cassava, rice, yam, e.t.c. and lipids in groundnut, palm kernel seed e.t.c. As a result of the primary role of plant in food manufacturing, they are referred to as **PRIMARY PRODUCERS**.

We shall restrict our exploit in this class to plant in general and in particular those of agricultural importance. The processes in questions are: Movement, Respiration, Nutrition, Irritability, Growth, Excretion, Reproduction Intractability and Aging.

Movement (locomotion)

Movement in plant involves some parts of its body.

Movement in plant is quite different from that of animals. While animals move the whole body from one place to another (locomotion), plant move some parts of its body. Movement of materials over long and short distances also contribute to movements in plants.

Respiration: This is the process whereby food taken in is oxidised and energy is released for other life processes.

Nutrition: This is intake of simple raw materials by plant and their synthesis into food. Food is used by living things to construct and maintain life.

Irritability: This is also referred to as sensitivity and responsiveness. It is the process of responding to changes in the surrounding or environment.

Growth: The process in which an increase in size of an organism is referred to as growth. This is brought about by the combined efforts of all other processes such as feeding, respiration e.t.c.

Excretion: This is the removal of waste products from chemical reactions which have occurred in organisms.

Reproduction: Every living thing has the capacity to reproduce its type to ensure continuity, avoid extinction.

Intractaction: Every living thing has capacity to interact with its type or other living things. Plants intract with lower as well as higher animals and other plants. They also intract with micro organisms all in effort to sustain the ecosystem. This is a very important concept in ecology.
Aging: All living develops from one stage to the other as time pass on them. This leads to aging from juvenile through maturity and senescence.
The summary is therefore **MR NIGERIA**

Plant nutrition, Elements and their function

Plant nutrition is the study of the chemical elements that are necessary for plant growth. There are several principles that apply to plant nutrition. Some elements are directly involved in plant metabolism (Arnon and Stout, 1939). Metabolism is the life sustaining chemical activity, i.e. The series of processes by which food is converted into the energy and products needed to sustain life. However, this principle does not account for the so-called beneficial elements, whose presence, while not required, has clear positive effects on plant growth.
Plant nutrition is a difficult subject to understand completely, partially because of the variation between different plants and even between different species or individuals of a given clone. Elements present at low levels may cause deficiency symptoms, and toxicity is possible at levels that are too high. Further, deficiency of one element may present as symptoms of toxicity from another element, and vice-versa. Carbon and oxygen are absorbed from the air, while other nutrients are absorbed from the soil. Green plants obtain their carbohydrate supply from the carbon dioxide in the air by the process of photosynthesis

A nutrient that is able to limit plant growth according to Liebig's law of the minimum, is considered an essential plant nutrient if the plant can not complete its full life cycle without it. There are 16 essential plant nutrients.

Macronutrients:

- N = Nitrogen
- P = Phosphorus
- K = Potassium
- Ca = Calcium
- Mg = Magnesium
- S = Sulfur
- Si = Silicon

Micronutrients (trace levels) These are elements that are vital to plant growth but are only required in minute amounts, very much like vitamins in human diets. They are known as micro-nutrients because of the tiny amounts found in normal soils. For the average home vegetable grower micro nutrients are an academic rather than a practical subject. Identifying micro nutrient deficiencies is difficult even for experts and usually requires laboratory analysis. With iron deficiency, even laboratory analysis is difficult. Luckily for us, most of these deficiencies are very rare and rotation, use of compost and manures will cure them. These elements include:

- Cl = Chlorine
- Fe = Iron
- B = Boron
- Mn = Manganese
- Na = Sodium

- Zn = Zinc
- Cu = Copper
- Ni= Nickel
- Mo = Molybdenum

These nutrients are further divided into the mobile and immobile nutrients. A plant will always supply more nutrients to its younger leaves than its older ones, so when nutrients are mobile, the lack of nutrients is first visible on older leaves. When a nutrient is less mobile, the younger leaves suffer because the nutrient does not move up to them but stays lower in the older leaves. Nitrogen, phosphorus, and potassium are mobile nutrients, while the others have varying degrees of mobility.

Plants uptake essential elements from the soil through their roots and from the air (mainly consisting of nitrogen and oxygen) through their leaves. Nutrient uptake in the soil is achieved by cation exchange, wherein root hairs pump hydrogen ions (H^+) into the soil through proton pumps. These hydrogen ions displace cations attached to negatively charged soil particles so that the cations are available for uptake by the root. In the leaves, stomata open to take in carbon dioxide and expel oxygen. The carbon dioxide molecules are used as the carbon source in photosynthesis.

Though nitrogen is plentiful in the Earth's atmosphere, relatively few plants engage in nitrogen fixation (conversion of atmospheric nitrogen to a biologically useful form). Most plants therefore require nitrogen compounds to be present in the soil in which they grow.

Functions of nutrients

Each of these nutrients is used in a different place for a different essential function.

Carbon

Carbon forms the backbone of many plants biomolecules, including starches and cellulose. Carbon is fixed through photosynthesis from the carbon dioxide in the air and is a part of the carbohydrates that store energy in the plant.

Hydrogen

Hydrogen also is necessary for building sugars and building the plant. It is obtained almost entirely from water.

Oxygen

Oxygen is necessary for cellular respiration. Cellular respiration is the process of generating energy-rich adenosine triphosphate (ATP) via the consumption of sugars made in photosynthesis. Oxygen gas is produced as a by-product from this reaction.

Phosphorus

Phosphorus is important in plant bioenergetics. As a component of ATP, phosphorus is needed for the conversion of light energy to chemical energy (ATP) during photosynthesis. Phosphorus can also be used to modify the activity of various enzymes by phosphorylation, and can be used for cell signalling. Since ATP can be used for the biosynthesis of many plant biomolecules, phosphorus is important for plant growth and flower/seed formation.

Potassium

Potassium regulates the opening and closing of the stoma by a potassium ion pump. Since stomata are important in water regulation, potassium reduces water loss from the leaves and increases drought tolerance. Potassium deficiency may cause necrosis or interveinal chlorosis.

Nitrogen

Nitrogen is an essential component of all proteins. Nitrogen deficiency most often results in stunted growth.

Sulphur

Sulphur is a structural component of some amino acids and vitamins, and is essential in the manufacturing of chloroplasts.

Silicon

Silicon is deposited in cell walls and contributes to its mechanical properties including rigidity and elasticity

Calcium

Calcium regulates transport of other nutrients into the plant and is also involved in the activation of certain plant enzymes. Calcium deficiency results in stunting.

Magnesium

Magnesium is an important part of chlorophyll, a critical plant pigment important in photosynthesis. It is important in the production of ATP through its role as an enzyme cofactor. Magnesium deficiency can result in interveinal chlorosis.

Iron

Iron is necessary for photosynthesis and is present as an enzyme cofactor in plants. Iron deficiency can result in interveinal chlorosis and necrosis.

Boron (B)

Boron is necessary for calcium to perform its functions in the plant but too much boron is also harmful to the plant. Excess use of magnesium sulphate will also cause a boron imbalance. The symptoms of boron deficiency are poor development of the growing tip of the plant. It is more likely in soils with pH above 6.5.

Confirming boron deficiency is a job for laboratory analysis. Adding borax to the soil will correct the deficiency but borax is also a herbicide. For garden growers who are unlikely to want to pay for professional testing and recommendations the best advice is to avoid over use of magnesium sulphate, rotate and use plenty of home made compost.

Copper (Cu)

Copper deficiency is rare but can occur on sandy, peaty and chalky soils with their high pH levels. It is required for root formation. Once again it requires professional analysis to confirm and to determine a proper course of action to rectify. Usually the single use of a copper sulphate based fungicide (Bordeaux mixture) will re-stock the soil for as long as you are likely to grow on it.Excess copper is very toxic to plants and to people. In plants it causes reduced growth, yellowing of the foliage, and stunted root development

Iron (Fe)

Iron deficiency causes yellowing of the leaves and a general lack of vigour. It is fortunately rare but unfortunately hard to both diagnose or determine by laboratory analysis. Generally not something the home grower needs to concern himself with but should you suspect you have it then use sulphate of iron fertilizer

Manganese (Mn)

Manganese deficiency is often caused by over liming and is most often found on peaty and sandy soils with a high pH. Symptoms are similar to iron deficiency and can be confirmed by laboratory analysis of the leaf. Susceptible crops include peas and beets.

Adding sulphur to the soil, which will increase the acidity (decreasing pH) will solve the problem.

The following micro-nutrients are rarely lacking and analysis and remedy are professional jobs. Normal additions of composts and manures will resolve deficiency problems. Excess in the soil will probably be due to industrial contamination.

Molybdenum (Mo)

Molybdenum is only required in minute amounts. Molybdenum is a cofactor to enzymes important in building amino acids. Excess of it is as harmful as molybdenum deficiency.

Zinc (Zn)

Zinc deficiency is more likely in soils with high pH than low. Crops most sensitive are tomatoes, onions and beans.

Boron

Boron is important in sugar transport, cell division, and synthesizing certain enzymes. Boron deficiency causes necrosis in young leaves and stunting of plants.

Copper

Copper is important for photosynthesis. Symptoms for copper deficiency include chlorosis. Involved in many enzyme processes. Necessary for proper photosythesis. Involved in the manufacture of lignin (cell walls). Involved in grain production.

Manganese

Manganese is necessary for building the chloroplasts. Manganese deficiency may result in coloration abnormalities, such as discolored spots on the foliage.

Sodium

Sodium is involved in the regeneration of phosphoenolpyruvate in CAM and C4 plants. It can also substitute for potassium in some circumstances.

Zinc

Zinc is required in a large number of enzymes and plays an essential role in DNA transcription. A typical symptom of zinc deficiency is the stunted growth of leaves, commonly known as "little leaf" and is caused by the oxidative degradation of the growth hormone auxin.

Nickel

In higher plants, Nickel is essential for activation of urease, an enzyme involved with nitrogen metabolism that is required to process urea. Without Nickel, toxic levels of urea accumulate, leading to the formation of necrotic lesions. In lower plants, Nickel activates several enzymes involved in a variety of processes, and can substitute for Zinc and Iron as a cofactor in some enzymes.[*citation needed*]

Chlorine

Chlorine is necessary for osmosis and ionic balance; it also plays a role in photosynthesis.

Cobalt has proven to be beneficial to at least some plants, but is essential in others, such as legumes where it is required for nitrogen fixation. Vanadium may be required by some plants, but at very low concentrations. It may also be substituting for molybdenum. Selenium and sodium may also be beneficial. Sodium can replace potassium's regulation of stomatal opening and closing.

Uptake of nutrients (Absorption and conduction)

Green plants absorb H_2o and inorganic salts from the soil through the unicellular hairs and the main roots. Absorption of H_2o by the root and root hair is a passive absorption i.e. energy is required and the normal process of diffusion of osmosis is implicated here. However, absorption of dissolved ions can either be passive or active.

II. Nutrient uptake

A. *Root hairs* of epidermal cells

1. Increase surface area for absorption.
2. Contain membrane proteins, which selectively facilitate ion passage

B. Mechanisms of nutrient uptake

1. *Passive uptake* occurs when an electrochemical gradient favours ion movement, and diffusion occurs through nutrient specific channels in the cell membrane.
2. Active transport of ions can occur against an electrochemical gradient if proton

pumps and specific co-transporters are present within the root-hair cell membrane.

C. Nutrient transfer via mychorrhizal fungi

1. *Mycorrhizae*: *Mutualistic* associations with plant roots.
2. Fungus absorbs nitrogen and phosphorus from soil and provides them to plant.
3. Plant provides sugar to the fungus.

IV. Nitrogen Fixation

Bacteria and pea-family plants form species-specific mutualistic associations.

II. Soil

A. Texture and composition of soil depend on parent rock.

1. Texture affects oxygen availability and root penetration.
2. Composition affects nutrient availability.

B. Nutrient availability

1. Nutrients are in the form of positively or negatively charged ions
2. Positively charged ions tend to bind to organic matter as well as clay.
3. Negatively charged phosphates also bind to organic matter.
4. Soils without organic matter and clay lose nutrients fast.

Sources of metabolites

Metabolites are the intermediates and products of metabolism. The term *metabolite* is usually restricted to small molecules. A **primary metabolite** is directly involved in normal growth, development, and reproduction. A secondary metabolite is not directly involved in those processes, but usually has an important ecological function. Examples include antibiotics and pigments.

The metabolome forms a large network of metabolic reactions, where outputs from one enzymatic chemical reaction are inputs to other chemical reactions.

Metabolites from chemical compounds, whether inherent or pharmaceutical, are formed as part of the natural biochemical process of degrading and eliminating the compounds. The rate of degradation of a compound is an important determinant of the duration and intensity of its action. Profiling metabolites of pharmaceutical compounds, drug metabolism, is an important part of drug discovery, leading to an understanding of any undesirable side effects.

Secondary metabolite

This is natural chemical product of plants not normally involved in primary metabolic processes such as photosynthesis and cell respiration. Also known as secondary plant product.

Secondary metabolites are organic compounds that are not directly involved in the normal growth, development, or reproduction of organisms. Unlike primary metabolites, absence of secondary metabolities does not result in immediate death, but rather in long-term impairment of the organism's survivability, fecundity, or aesthetics, or perhaps in no significant change at all. Secondary metabolites are often restricted to a narrow set of species within a phylogenetic group.

CHEMOSYNTHESIS

This is the transformation of one form of chemical energy into another. Colourless autothrophic bacterial are able to synthesize carbohydrate without light as the source of energy. These bacteria are aerobic and the energy required in the metabolic process is derived from oxidation of certain inorganic compounds present in their environment.

The energy released in the oxidation process is used to convert CO_2 to carbohydrates and other organic compounds such as protein, fats, etc.

Bacterial do not use water as in the normal photosynthesis hence, there no release of oxygen. Examples of these bacteria are sulphur bacteria, iron bacteria and nitrifying bacteria. Sulphur bacterial synthesize organic compound from CO_2 using energy derived from oxidation of hydrogen sulphide (H_2S), sulphur is deposited on the bacteria cell.

Iron bacteria obtain energy from the oxidation of ferrous hydroxide to ferric dioxide.

PHOTOSYNTHESIS

This is the manufacturing of simple carbohydrates such as sugar in the green leaves by the chlorophyll in the presence of sunlight (as a source of energy) from CO_2 and water absorbed from the soil and oxygen is librated. By this process, a large amount of energy is formed by the green cell into chemical energy and stored in the organic substances formed. Glucose or fructose appears to be the first carbohydrate formed in photosynthesis.

$6CO_2 + 12H_20$------------$C_6H_{12}O_6 + 6H_2O + 6O_2$

There are two phases in photosynthesis. The **LIGHT** phase and the **DARK** phase.

The light phase involves a series of chemical reactions of which light is indispensable and therefore called light reaction.

This involves adsorption of light by chlorophyll, splitting of water molecules with the production of reducing agent (NADP).

The dark phase which does not light is a series of chemical reaction of CO_2 (fixation of carbon dioxide) by reducing agent produced during the light phase to organic compound.

Important steps in light phase

Chlorophyll pigments absorb light energy from sunlight and become activated.

The **e**nergy stored in the chlorophyll goes to break up water molecule (Proteolysis/photolysis of water) to give energized electron and oxygen. The energy of the electron is used to synthesis ATP.

The energized electrons are accepted by electron acceptor and are eventually used to reduce NADP to NADPH, a reducing agent needed in the dark phase

One or more ATP molecules may be formed. The products of the light phase are therefore **ATP** and **NADPH** which are needed in the dark phase.

Important steps in dark phase

All reduction steps from CO_2 to sugar are dark reactions.

A 5-cabon compound, ribulose-phosphate is activated by ATP to form Ribulose di- phosphate (RUDP) also a 5 carbon compound.

The RUDP combines with CO_2 to form an unstable 6 carbon complex.

The complex split into two parts, one of which is a stable 3 carbon compound called phosphoglyceric acid.

Many of the remaining portions of the splitting complex is used to re-form ribulose phosphate which fed into the chain of reaction to continue the process.

There is further activation of phosphoglyceric acid to di-phosphoglyceric acid using ATP.

Diphosphogliceric acid is reduced to diphosphoglyceraldhyde by the reducing agent NADPH

6-cabon hexose sugars e.g. glucose or fructose are formed from many molecules of 3-carbon phosphoglyceraldehyde.

All the steps are catalyzed by many enzymes.

Sugar or starch is not the only end products of photosynthesis. Phosphoglyceraldehyde, lipids, protein could also be formed depending on the requirements of the plant at the time.

All these reactions take place in the chlorophyll located in the chloroplast in the leaf of plant.

C_3 Plants

These are plants in which CO_2 fixation is dependent on the enzyme Ribulose 1, 5- diphosphate carboxylase (RUDP). Majority of plant sp. fall into this category e.g slow-growing perennials, desert sp, trees and shrubs in the tropics and the sub tropics, deciduous wooden plants, horticultural plants, agronomic plants like soybeans and cotton e.t.c.

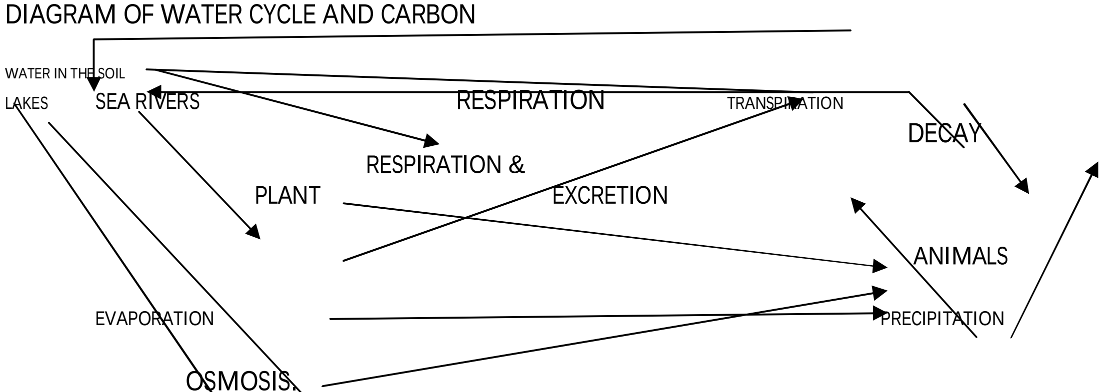
C_4 Plants

These are plants which possesses an additional photosynthetic system. They have high rate of photosynthesis and in turn rapid growth. They ensure high turnover of assimilate, no resistance to the inward diffusion of CO_2. Their CO_2 fixation system is principally due to enzyme phosphophenol pyruvate (PEP) carbohydratase. Examples are tropical grasses, sugarcane, corn, e.t.c.

CYCLES OF RAW MATERIALS IN NATURE

Substances are utilized by plants; animals utilize plants and some of the raw chemical; When they die, their remains are subjected to the decaying action of micro-organisms. The raw materials are put back into circulation. There is thus, for all these raw materials a broad cycle of absorption utilization and ultimate return to the raw material status e.g

DIAGRAM OF WATER CYCLE AND CARBON



Usually, there is a movement of water from the dilute solution outside the cell to the strong solution inside. This movement between solutions separated by membrane is termed osmosis. Plasmolysis is a special type of osmosis that occurs when a stronger solution is outside the membrane than the solution which is contained within the cell. Normal plant cells consist of relatively stronger solution of sugars, salts, pigments, etc and a dilute solution outside the cell.

Transport system in plants

The large number of cells present within a leaf provides a very large surface of contact to the internal atmosphere of the leaf. However, the cells are still perfused with liquid, which is contained in the cell walls since these must be kept moist. If the cell walls are not moistened by liquid derived from the vacuole tissue, the gases of the atmosphere would not be able dissolve and so come into contact with the surface of the protoplasm. Under the conditions of photosynthesis in plant, evaporation of water from the leaf surface is inevitable and this is called transpiration. Water loss through this evaporation or transpiration needs to be replaced by absorption from the soil and movement in the conducting vessels of the xylem. This accounts for how water or sap gets to the top of a tall tree. Because the surface of the root lacks cuticles, it is in direct contact with the moisture in the soil which when free to move, can penetrate through the cortex of the root.

Water and salts enter the root hairs simultaneously and are released to the xylem vessel for uptake via the transpiration stream. The diffusive movement of salt is in the opposite direction from the region of higher to those of lower concentrations. The cells expend energy in causing salts to move against the diffusion gradient. The necessary energy is gotten from the active metabolism of the tissues and the term active absorbs ion and **active transport** are used to describe such movement of salt that is dependent on metabolic activity. The movement of water to the xylem and the subsequent upward movement through the transpiration stream are referred to as **passive uptake.** Hence uptake of nutrient from the soil requires expedition of energy by the root otherwise, there will be the tendency for the nutrient to leach out of the tissue when the concentration is high and this does not occur. The rootxs are therefore capable of accumulating ions in their cells and also selectively take up ions from the soil. For this capability, the root requires energy for respiration, hence the importance of soil aeration to plant roots.

Mechanisms affecting the movement of water in the plant

If a plant is cut a few cm above the soil level, an exudation of water (containing small amount of salts) is often fond to occur from the stump. With this, a small amount of hydrostatic pressure is often set up. This pressure is deemed to be from the root. Closely related to this is the exudation (or gutation) of drops of water from the leaves of intact plants. Gutation appears to be due to the root pressure mechanism which continues to force water up during the night when transpiration is very slow, owing to the closure of the stomata. The plant becomes gorged with water, and the latter is forced out in liquid form from hydathodes. It is thought, however, that root pressure alone is inadequate to account for the upward flow of the transpiration stream especially in shrubs and trees.

Cohesion force

Water molecules have strong attractions towards each other; hence they pull each along a gradient upward the stem.

Adhesion

Water molecules have tendency toward attaching to the their containers (the cell wall in this case) hence they move up along the side of the xylem vessels. This explains the shape the meniscus of water in a cylinder.

Respiration

Basic concepts: Respiration, Redox reaction, glycolysis, glycogenesis, biological polymer, electron transport system, phosphorylation types (photophosphorylation, oxidative phosphorylation, transphosphorylation)

Learning Objectives:

1. Understanding of the basic principle of respiration
2. Understanding of the mechanism of respiration
3. Comparative analysis of aerobic and anaerobic (Fermentation) respiration
4. Factors affecting respiration
5. Importance of respiration in agricultural process

Theoretical background:

Plants are living system, thermodynamically opened to the exchange of energy and matter with the environment. Among the basic characteristics of any living system is the process of transformation of energy or metabolic process. Conceptually, this process could be classified into two catabolic and anabolic processes. Anabolic process is the transformation of energy and matter towards the building of complex biological polymer. An example of such a process is photosynthesis. Catabolic process on the other hand involves breakdown of such biological polymer and the consequent release of energy and other products of metabolism. Respiration is an example of a catabolic process.

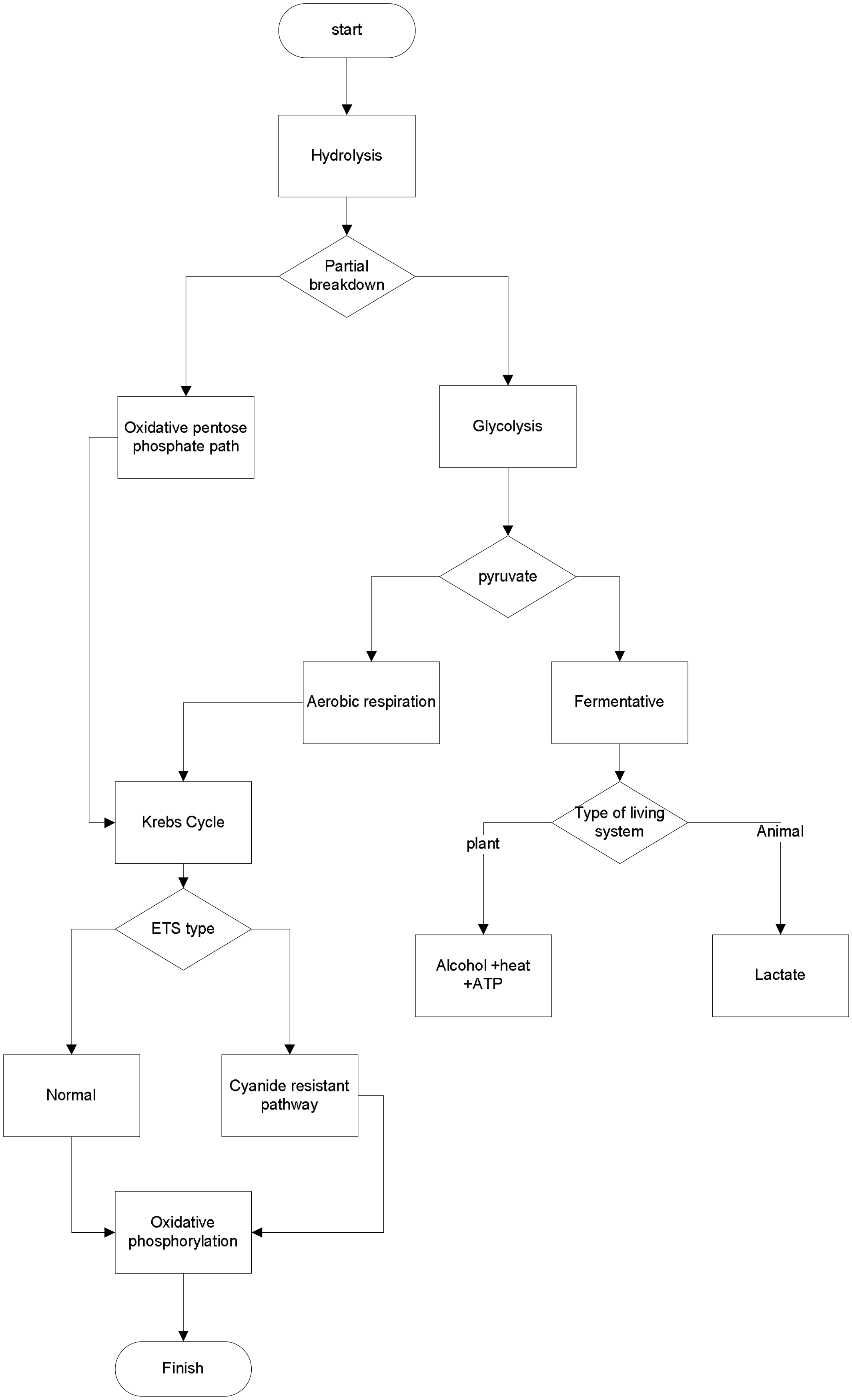
Respiration is a bio- oxidative process; involving loss of electron, proton and the addition of oxygen. Oxidative process is coupled with reduction, hence the process is better characterised as a redox reaction with the formation of energy in the form of ATP, the energy currency of living system. Table 4 provides a conceptual framework of respiration. Respiration in plant is mediated via passive diffusion of gases, with no specialised organ and carrier as obtainable in animals.

Table 1 Dimensions of respiration

Questions dimensions	Responses

What	Biooxidative-reductive process
Why	1. Energy is released which is consumed in various metabolic processes essential for plant and activates cell division 2. It brings about the formation of other necessary compounds participating as important cell constituents 3. It converts insoluble food into soluble form 4. It liberates carbon dioxide and plays a part actively in maintaining the balance of carbon cycle in nature 5. It converts stored energy (potential energy) into usable form (Kinetic energy)
How	**Initial degradation** (hydrolysis)-**Partial degradation** (glycolysis/EMP/oxidative pentose phosphate pathway/Enter-Doudoroff pathway)-**Total degradation** (Krebs cycle and electronic transport system) $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$ glucose, oxygen, carbon dioxide, water
Where	• Cytosol • Mitochondria
When	Throughout the life of the plant

Find below a flow chart depicting the mechanism of respiration in plants (Figure 1)


start
Hydrolysis
Partial breakdown
Oxidative pentose phosphate path
Glycolysis
pyruvate
Aerobic respiration
Fermentative
Krebs Cycle
Type of living system
plant
Animal
ETS type
Alcohol +heat +ATP
Lactate
Normal
Cyanide resistant pathway
Oxidative phosphorylation
Finish

Table

2 Distinction between aerobic and anaerobic respiration

S/N	Aerobic respiration	Anaerobic respiration
1	It is common to all plants	It is a rare occurrence
2	It goes on throughout the life	It occurs for a temporary phase of life
3	Energy is liberated in larger quantity. In total, 38 ATP molecules are formed	Energy is liberated in lesser quantity. Only 2 ATP molecules are formed
4	The process is not toxic to plants	It is toxic to plants
5	Oxygen is utilised during the process	It occurs in the absence of oxygen
6	The carbohydrates are oxidised completely and are broken down into CO_2 and H_2O	The carbohydrates are oxidised incompletely and ethyl alcohol and carbon dioxide are formed
7	The end-products are CO_2 and H_2O	The end-products are ethyl alcohol and carbon dioxide
8	The process takes place partly in cytosol (glycolysis) and partly inside mitochondria (Krebs cycle)	The process occurs only in the cytosol

OSMOREGULATION AND METHODS OF ELIMINATION OF WASTE MATERIALS IN PLANT

Basic concepts: Osmoregulation, transport, transporters, active and passive transport, primary and secondary transport, symport, antiport

Learning objectives:

1. Water balance in plants and strategies for acclimation and adaptation
2. Osmoregulation as a mechanism for maintaining water balance in plant
3. Methods of eliminating waste product in plants

4. Transport mechanism in plant

Theoretical background

Water is very vital towards increased agricultural productivity. Agricultural practise in the topics is greatly hampered by **Abiotic stressors**, namely; drought and heat shock. The presence of these stressors elicit water deficit leading to reduced growth and development in cultivated crop, eventually reducing agricultural productivity. **Salinity** due to inappropriate use of irrigation water or cultivation of crops in soils of high concentration of salt could lead to accumulation of toxic substances in plants. Water balance in plants has to be maintained. Different strategies were devised by plants in combating the adverse effects of osmotic stress towards the maintenance of water.

At the molecular level were observed the following osmoregulatory strategies:

- Synthesis and accumulation of **osmolytes** and **osmoprotectants**
    - Organic nitrogen-containing
    - Organic non-nitrogen containing
- Uptake of compatible ions
- Extrusion, sequestration and compartmentalisation of incompatible ions

The advent of osmotic stress in most crop leads to synthesis and accumulation of osmolytes and osmoprotecting substances.

Among the compatible organic solutes are nitrogen containing:

- Amino acids e.g. proline, glycine betaine
- Amino acids derivates
- Quaternary amino acids

Non-nitrogen containing:

- Sugars
- Cyclic and acyclic polyols; mannitol, sorbitol
- Fructans
- Sulfonium compounds

Accumulation of these substances in the cell *will not lead* to the disruption of normal metabolic activities, hence the name compatible solute. The mechanism of their action is in the reduction of cellular water potential, thus facilitating movement of water into the cell. Apart from that they have been reported to play a vital role in **osmoprotective** functions such as the protection of the protein stability, scavenging **reactive oxygen radical**, adjustment of cellular **redox state** and **membrane stabilisation**.

In other to lower the water potential of plants with the commencement of osmotic stress, inorganic ions like K^+ are passively absorbed by plant down concentration gradient.

Extrusion, sequestration and compartmentalisation facilitate the removal of toxic ions from the cell or compartmentalisation in another organ where like the vacuole, Golgi bodies or endoplasmic reticulum, where their toxic effect could be greatly ameliorated. The process is mediated actively via the actions of certain transporters like;

1. Channels
    a. Selective (Potassium Inward Regulated Channel, KIRC; Potassium Outward Regulated Channel, KORC, Aquaporin)
    b. Non-Selective
2. Carriers; High and low affinity carriers
3. Pumps
    a. Electrogenic (H^+/ ATP-ase, H^+/PP)
    b. Electroneutral

Primary active transport process coupled with the hydrolysis of ATP will lead to the generation of **proton motive force** that will facilitate secondary influx of proton into the cytoplasm or vacuole with other ions transported symportically or antiportically. Apart from regulation of the osmotic status of the cell and water balance, this chemiosmotic regulation could lead to the regulation of nutrient uptake, water balance pH level in the plant and the excretion of toxic waste product of metabolism.
Excretion in plant is the removal from the body toxic waste product of metabolism. Compared to animals, plants do not have as such a specialised organ of excretion. Leaf in most cases act as organ of excretion. Toxic waste product of metabolism like water vapour, carbon dioxide and certain salt are removed from the leaf of the plant.

PLANT HORMONES

Basic concepts: growth, development, phytohormones, physiologically active substances, growth promoters, growth inhibitors, cell division, elongation and differentiation

Learning objectives:

1. Understanding of the concept of growth in plant
2. Understanding the concept phytohormones and their roles in growth of plant
3. Classification of phytohormones
4. Hormonal balance, growth and development in plant

Theoretical background:

Growth could be defined as a process of irreversible, quantitative change in plant. There are various dimensions of these changes; namely weight, form, volume, area and size. Development on the other hand is a qualitative change. The cellular processes underlying growth are:

1. Cell division
2. Cell elongation
3. Cell differentiation

Please find in table 1 a comparative analysis of the cellular basis of growth phase, using certain cytological and kinetic parameters.
Phytohormones are physiologically active substances that affect plant growth and development. They act as chemical messengers or plays signalling role in plant; hence they are functionally integrators and regulators of physiological processes in living organisms. Unlike the animal hormones, plant hormones are fewer in number, they affect most cells in the plant, the response of

plants to them is diverse (pleitropic effect) and they are modulated by environmental, developmental and other hormones through cross-regulation of their actions, that could be antagonistic or synergistic in nature. They are required in small quantity, transported from the site of synthesis to mediate physiological response in other parts of the plant.
Recognised over the years are classical phytohormones; Auxin, Gibberellin, Cytokinin, Abscissic Acid and Ethylene and newer ones; Jasmonic Acid, Salicylic Acid, Brassinosteroid and Strigolactones. Apart from the aforementioned substances there are other substances in plant that play signalling role , though they cannot be classified as hormones, such as polyamines, Reactive Oxygen Species (ROS), Signalling Peptides and Nitric Oxide. Among the classical hormones are growth promoters (Auxin, Gibberellin and Cytokinin) and growth inhibitors (Abscissic Acid and Ethylene).
The mechanism of hormonal action is quite complex and attempts had been made to elucidate its action. After synthesis and accumulation of hormones it is transported to the site of action through the phloem or xylem stream or via diffusion. It it sometimes transported by regulated transport proteins. Perception of environmental perturbation is mediated through binding of hormones to transmembrane or intracellular receptors. Signal transduction or amplification is mediated by the activation of kinase activities through the process of phosphorylation where ATP molecules bind to protein through protein kinase eventually leading to signal amplification. The reverse process of inactivation is through the action of phosphatise. Other elements of signal transduction include the allosteric changes of protein, phophorelay system and regulated protease.
The downstream effect involves:

1. Alternation of gene expression pattern via transcription proteins

2. Non-genomic function

In crop production, most cultivated crops are subjected to actions of various stressors; biotic and abiotic. In the case the crop plant is subjected to both stressors, priority is given to amelioration of the actions of abiotic stressors at the expense of biotic stressors. In all instances of abiotic stressors, there is increased synthesis of ABA, production of induced proteins and other osmoprotective and regulatory substances like Heat Shock Proteins, Proline, Glycine Betaine etc.
Biotic stressors, depending on the nature of the biotic stressors leads to production of salicyclic acid if biotrophic or Jasmonic acid or Ethylene if necrotrophic. The production of these hormones interferes with GA/Auxin induced growth pathways. The non-genomic function leads to the production of antiherbivory function, anti microbial function i.e. defensin protein and the production of plant volatile to suppress the incidence of biotic stressors.
Hormonal actions vary throughout the phenological phases. At juvenile or vegetative phase, growth promoters are more predominant in their actions. Auxin aids cellular division and elongation. Cytokinin controls stomatal aperture and water potential of the leaf, while GA is responsible for the protection of chlorophyll, RNA and degradation of protein. With transition to reproductive phase, though genetically controlled and mediated by environmental factors, hormonal actions equally mediate this process, with growth inhibitors; ABA and Ethylene affecting rate of senescence and maturation, both physiological and harvest. Maturation referred to here is the expression of full reproductive potential, while at physiological maturity; there is a cessation of sexually induced reproductive growth.
See table 3 for a comparative analysis of different phytohormones

Table 3 Hormone types, characteristics and their plant physiological response to their actions

Hormone Type	Source	Transport Direction	Response dimension			
			Biochemical	Physiological		
				Growth	Flower initiation	Flow

Auxin	Apical Bud	Basipetal/Polar	o Nucleic acid activity o Amylase activity o Increase in cell wall permeability o Formation of ATP o Cell wall plasticity o Protoplasmic viscosity	o Shoot/root ratio o Apical dominance o Cell elongation o Cell division o Tropism	✓	✓
Gibberellin	o Young leaves o Root Tips o Embryo	All direction, no polarity	De novo synthesis of the above stated enzymes	o Stem elongation o Apical dominance	✓	✓
Cytokinin	o Root tip o Developing seed o Cambial tissue	Acropetally	o Nucleic acid metabolism o Protein synthesis o Incorporation of RNA	o Cell division o Lateral bud formation		Incre florig activi
Abscissic Acid	o Matured leafs o All plants parts	Acropetally	o Induction of hydrolase o Induction of α amylase activity	o Growth inhibitor o Stomatal physiology		
Ethylene	All parts of plant	Diffusion	o Climacteric raise o Activity of malic and pyruvate decarboxylase o Degreening of citrus o Activity of chlorophyllase	o Growth inhibitor		

Table 4 Comparative analysis of growth phases

Growth phases	Parameters for comparison				
	Cytological parameters				Kinetic parameters
	Cell wall	Protoplasm	Vacuole	Nucleus	Growth rate
Division	Thin/isodiametric	Most dense	Smallest	Largest	Slowly
Elongation	Thicker	Medium	Bigger	Medium	Rapid
Differentiation	Thickest	Least dense	Biggest	Smallest	Steady

Table 5 Dimensions of Physiologically Active Substances

Parameters for comparison	Dimensions of physiologically active substances		
	Phytohormones	Elicitor Molecule	Growth Substances
Nature	Endogenous or naturally occurring	Naturally occurring or synthetic	Naturally occurring or synthetic
Quantity produced	Small	Small	Small

Plant response mode	o Physiological changes o Changes in growth and development o Signalling element	Initiation or improvement of specific compound with hormone-like activities	o Induction of physiological processes o Changes pattern of growth and development
Type of physiologically active substance	o Auxin o Gibberellin o Cytokinin o Abscissic Acid o Ethylene	Brassinosteroids Jasmonic Acid Salicylic Acid Polyamines	

Topic: Homeostasis
Basic concepts: Homeostasis, control, regulation, growth, nasty, tropism, photomorphogenesis, thigmotropism, osmoregulation, autopoiesis
Learning Objectives:

1. Understanding of the concept of homeostasis, regulation and control

2. Life as organisational homeostasis and its biological implications

Theoretical Background:
The concept of homeostasis is pervasive in biological sciences. Conceptually it could be defined as biological stability. The basis for this biological stability could be ascribed to circularity observed in living systems. Present knowledge as proposed by Humberto Maturana indicated that the basis of life is organisational invariance, that is the organisational homeostasis observed in all living things. Though not generally accepted by the mainstream of biologist, it could serve as our working hypothesis in the definition of life as opposed to what is obtainable today, where a list of certain characteristics are given in profiling what could be regarded as life.
According to Humberto Maturana Life is an Autopoietic system that is semantically or operationally closed but thermodynamically opened. It is this closure that confers on the system organisational invariance, i.e organisational homeostasis.
The picture below indicated the basic mechanism underlying an autopoietic system, where the system is self-referential, autonomous without input and output.

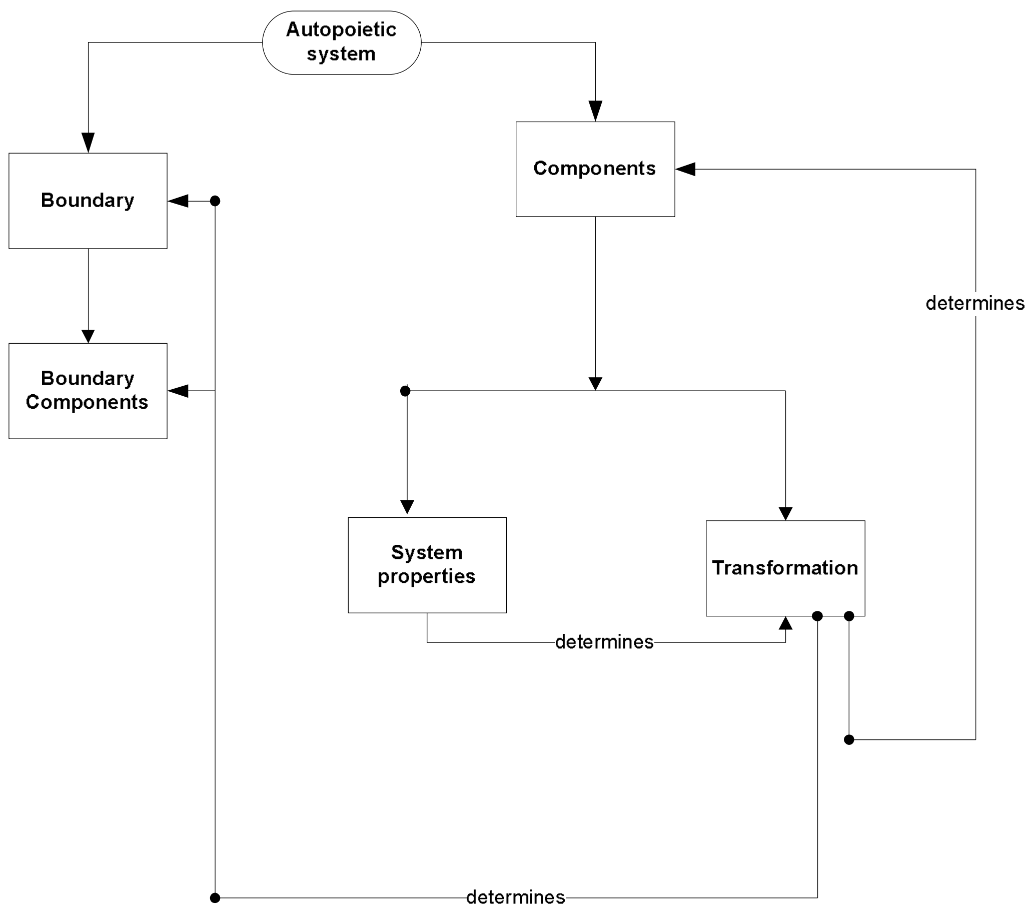


Figure 2

The dimensions of this biological stability are:

1. Physiological

2. Ecological

The basic axiom in any physiological process is that its level of activities is within certain limit for it to operate; all physiological processes operate within certain concentration of solutes, temperature and pH.

The ecological dimension of biological stability presupposes that there is a certain correspondence; functional and structural between the biological system and its environment. This is evident in the cycle of certain elements in nature, such as water, nitrogen, carbon, phosphorus cycles and the formation of different adaptive mechanisms to various ecological conditions. One vivid example is the formation of different ecotypes of plant depending on their adaptability to available water.

1. Mesophytes

2. Hydrophytes
3. Xerophytes
4. Halophytes

Conceptually, biological stability could be considered as a process of coordination and control, while control is a process of regulation. A graphical illustration is provided below depicting homeostasis in a living system.

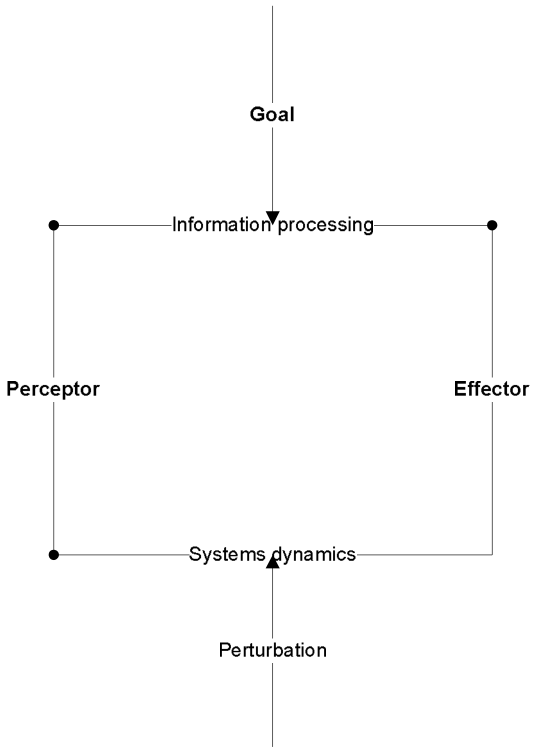


Figure 3

The following elements are depicted in the illustration

1. Perturbation: Any environmental factor, capable of disrupting system's stability. These factors are Abiotic and biotic in nature
2. Sensor: element for detecting difference in status from the system goal. Within the context of a plant, there are different sensors; such as phytochrome, cryptochrome, phototropin and zeaxianthin.
3. Perceptor: plant organs
4. Model: The genetic composition of the plant
5. Goal: homeostasis
6. Information processing: signalling elements and signal transduction
7. Decision making: System survivability and senescence
8. Effector: Plant organ
9. Action: System's response, in plant they could take the following forms; growth, nasty, morphogenesis, tropism and thigmotropism.

Table 6 Comparative plant and animal homeostasis matrix

		Organ/regulatory mechanism	
Scope of balance	Process nomenclature	Animal	Plant
Water	Osmoregulation	Kidney	Active accumulation of osmolyte independent of cellular volume change Uptake of compatible ions Ion extrusion, sequestration and
Nitrate		Kidney and Liver	Nitrogen cycle
Glucose		Pancreas and Liver	Glycolysis and glycogenesis
Temperature	Thermoregulation	Skin	Transpiration

Topic: Growth and Development

Basic concepts: Growth, development, phenology, shoot growth pattern, determinate, indeterminate

Learning expectations:

1. Articulate the concepts of growth and development as it is related to agricultural plants
2. Understand shoot growth pattern
3. Understand factors affecting growth and development in Agricultural plants
4. Understand process involved in reproductive growth and factors affecting it
5. Understand transformative process in fruit growth

Basic theoretical background:

Growth is a process of irreversible increase by cell division and enlargement, including synthesis of new cellular material and organisation of sub cellular organelles. This process also involves conversion of reserve materials into structural materials. There are various dimensions for measuring plant growth:

1. Increase in fresh weight
2. Increase in dry weight
3. Volume
4. Length
5. Height

6. Surface area

Depending on the growth pattern, shoots are classified as:

1. Determinate- flower buds initiate terminally, while shoot elongation stops.

2. Indeterminate- flower buds born laterally, while shoot terminals remain vegetative.

Other classification of the shoot growth pattern is based on the duration of the plant development; shoots are classified annuals, biennials and perennials. Annuals complete their life cycle in one growing season. Biennials require two growing to complete their life cycle, not necessarily two full years. The stem growth is limited during first growing season. Perennials are either herbaceous or woody.
Development is qualitative change in a living system over time. The qualitative aspect of development involves morphological changes and different stages of development over time-phenology. The stages of development are classified as:

1. Vegetative/ Reproductive

2. Exponential, stable and decline, based on the trajectory of dry matter accumulation

3. Functional classification that takes into cognizance the stages of leaf formation, seed/grain set and seed/grain fill

Quantitatively, development is measured as duration; Days-to-harvest-maturity, days-to-flowering, days-to-actual-accrual-of-yield. The inverse to duration of development is the rate of development. The rate of reproductive development is controlled by genetic factors but modulated by environmental influences. The predominant environmental influence is temperature and photoperiod. The rate of reproductive development to these environmental factors at the sub-optimal level is first linear, reaching a plateau at the optimal level, eventually declining at supra-optimal level.
The predominant model proposed concerning development in plant is **phasic theory of development.** The basic assumptions underlying this process are:

a. Development is phasic in nature, i.e. progression from one physiological system state of the meristerm to another

b. Identified are two phases; vegetative and reproductive phases

c. Plant system possesses the capability of development to progress autonomously

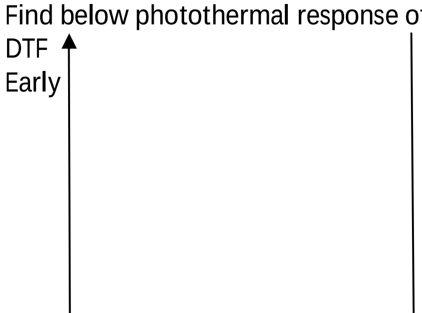
d. The identifies phases of development are irreversible

e. Development process is controlled by various environmental and genetic factors, mainly; temperature and photoperiod (G X PX T)

f. Photoperiod gene and vernalisation genes possesses delaying impact on the process of development

g. Temperature effect is through Q_{10} effect on the activities of the enzymes and ultimately on the biochemical reaction

Developmental process is controlled by genetic factors and modulated by the environment. The predominant environmental factor is temperature and photoperiod.
Find below photothermal response of crops and their effect on days to flowering (DTF)



Late

Base Temperature

Low High

Temperature

At reduced temperature, the delaying effect of photoperiod genes and vernalisation genes is reduced, hence the vernalisation response,; reduction in days to DTF at low temperature, with increasing temperature due to Q_{10} effect, the delaying effects of those genes becomes pronounced, leading to late DTF, beyond the base temperature effects of photoperiod genes becomes predominant. There are distinctive morphological characteristics of the activities of these genes on the phenology of crops, these are listed below. One could infer that for proper development crops possesses vernalisation requirements; duration of days at low temperature to inhibit the activities of vernalisation genes, while the vernalisation response is the reduction in days to flowering due to the thermal effect at low temperature. Vernalisation responsiveness is inversely proportional to the age of the crop, but directly proportional to the duration of exposure to low temperature. Photoperiod responsiveness is directly related to the period of vernalisation and age of the crop.
Temperature effect on the rate of development in crops is expressed quantitatively as the air temperature, in Heat Units (Crop Heat Unit or Growing Degree Days) and as growing points. Quantitatively, the GDD is expressed as:

GDD: $$\frac{(T_{MAX} - T_{MIN})}{2} - T_{BASE}$$

Functionally, there are three different stages of plant development:

1. Juvenility; this stage terminates at the initiation of flowering and fruiting. It may be extensive in certain forest species.

2. Maturation; this stage in most crops coincides with between flowering and the time of crop physiological maturity.

3. Senescence; a physiological aging process in which tissues in an organism deteriorate and finally die. It is considered to be terminal and irreversible, though it can be postponed by removing flower before seeds start to form.

Reproductive growth of crop is considered important because of its agronomic implication. The reproductive structure serves in most cases as organs of economic importance, hence the need to study it and factors affecting its growth and development. Different phases in plant reproductive growth had been identified; namely:

1. Flower induction and initiation

2. Flower differentiation and development

3. Pollination

4. Fertilisation

5. Fruit set and seed formation

6. Growth and maturation of seed and fruit

7. Fruit senescence

The process of transforming vegetative structure into reproductive ones in mediated by various factors; endogenous and exogenous factors. Among the exogenous factors, temperature and photoperiod play a very vital part. Photoperiodism is a phenomenon of plant response to relative length of day to night. Hence plants with respect to their photoperiodic response could be classified as:

1. Short-day plants
2. Long-day plants
3. Day-neutral plants

Some of the agricultural crops require a period of low temperature to initiate flowering. This phenomenon is referred to as vernalisation. It was first observed in winter wheat and many biennials. After flowering, the next process towards complete reproductive growth is pollination; a process of transfer of pollen from anther to stigma. It may be same flower or different flower but same plant; self-pollination or different flowers from different cultivars; cross-pollination. Pollens are transferred by insects, wind or other minor agents like water, snails, slugs etc. There are cases where fruits are formed without pollination and fertilisation; parthenocarpy.

Flowering and fruit growth

Basic concepts: Fruit growth, flowering, climacteric fruits, fruit drop, fruit set

Learning Objectives:

1. Understand transformative process in fruit during maturation
2. Articulate the effect of transformative process on fruit quality profile
3. Articulate factors affecting fruit growth and its agronomic implications
4. Differentiate between climacteric and non-climacteric fruits and implication on fruit shelf life

Basic theoretical Background:

After fruit set, true fruit and associated tissues begin to grow. Food moves from other parts into the fruit tissue, depending on its sink strength and the characteristic quality profile begins to be noticed in the fruit. Physiologically, transformative process experienced during the fruit growth is respiratory in nature. Depending on the type of fruit, some fruits experience a surge in temperature as they ripen; such are referred to as climacteric, e.g. Banana. But not all fruits experience such, the non-climacteric fruits. A rise in temperature with fruit maturation has some economic implication. The shelf life of such fruits is limited. In table 7, the implication of this transformative process on the quality parameters of a fruit is indicated. High temperature, gas composition and relative humidity in the storage atmosphere play a significant role in the rate of this process. High temperature, presence of ethylene and oxygen could be responsible for the increase in the ripening process. At the end of the fruit maturation period, characterised by ripening process, fruits experience senescence- fruit drop, a process mediated by growth inhibitors most especially Abscissic Acid (ABA)

Table 7 Dimensions of transformational processes observed during ripening of fruits

Quality Parameters	**Transformational process**	
	Scope	**Dimension**

Appearance	Pigmentation Green→ yellow or other characteristic colours	• Increase in the activity of chlorophyllase • Sequestration of pigment • Development of carotenoid and anthocyanin in the presence of light and phytochrome • Unmasking of certain pigments
Texture	Softening Hard→ Soft	Hydrolysis of • Cell wall (solubilisation of pectic substances in middle lamellae via methylation of galaturonic acid, reduction in size of polygalacturonide or both • Cell content
Flavour	Development of characteristic • Aroma • Taste Polymers→ monomers Loss of astringency	Production of the secondary metabolites Hydrolytic changes of biopolymers
Condition	Increasing degree of perishability • Climacteric respiratory pattern • Non-climacteric respiratory pattern	• Catabolic process>Anabolic process • Increasing activity of growth inhibitors e.g. C_2H_2 and ABA

ENZYMOLOGY

Enzymes- properties, compositions, Types, Mechanisms of action.

Enzymes are protein compounds that catalyse a specific reaction. Living cells contain thousands of different enzymes that accelerates or decelerates one kind of reaction without itself being changed. In some of these reactions, small organic molecules such as; acids, sugars, nucleotides and lipids are broken down to provide energy for the cell. In other reactions, small molecules are built into complex macromolecules, such as; proteins, DNA, RNA, and polysaccharides, or used to carry signals, or to control cell movement or gene expression. Sometimes the enzyme proteins have non proteins attachment called prosthetic group when bounded by covalent bond, e.g. metals like; Cu, Mg, and

Fe, and co-enzyme or co-factors when bonded by loose hydrogen bond, e.g. Vitamins. The co-enzyme and prosthetic group may become attached to several different protein forming different enzymes. Enzymes exhibit enormous catalytic power, in some cases increasing reaction rates by a factor' of over 1014 (one hundred million). Enzymes dictate the pattern of chemical changes in a cell and without them life as we know it would be impossible.

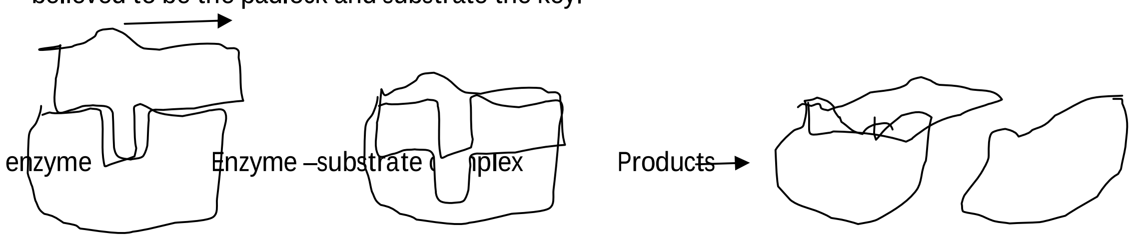
Properties characteristics of Enzymes

a) Small amount of enzymes are needed to convert large amount of substrate into products.
b) Same substrate can be utilized by several enzymes. For instance, isomers, phosphoglucomutase and glucose – 6 – phosphate dehydrogenase act on glucose to produce fructose – 6- phosphate, glucose -1- phosphate and 6-phosphoglucolactone respectively.
c) Enzymes work at narrow range of temperature. Optimum temp is 40^{o}c and could be destroyed at 60^{0}c.
d) They work at specific pH. Most function at around neutral pH (5-7). However, pepsin in stomach works at pH 2-3 and trypsin in duodenum works at pH 8.5.
e) Catalytic actions of enzymes may be specific. Hence an enzyme which catalyse one reaction may not catalyse another. For instance, invertase works on sucrose to produce glucose while zymase act on glucose and give carbondioxide and ethanol.
f) Enzymes are not destroyed by the reactions they catalysed and could be used again.
g) Enzymes could be poisoned by chemical compound like; mercury, chloride, silver chloride and hydrogen cyanide. This inactivate the enzymes, for example HCN blocks the enzymes involve in respiration.

Mechanism of Action (working) of Enzymes.

This can be explained by chemical hypothesis A $\longrightarrow$ B. Chemical energy needed could be in the form of heat (temperature) to activate passive A by bombarding A's molecules to activate it and later turned into B molecules. The energy that A molecule required to react and be converted into molecule B is the activation energy of reaction. Enzymes are believe to catalyse reaction by lowering the activation energy e.g. in

$2H_2O \xleftarrow{catalase} 2H_2O + 2O_2$ the activation energy in the absence of catalase is 18,000cal mol. While in the presence of catalase, it is 6,400 cal mol. Lock and Key Hypotheses: the enzyme is believed to be the padlock and substrate the key.



Classification of Enzymes.

Enzymes are generally of two types, they are : intracellular enzymes and extracellular enzymes. But specifically, enzymes can be classified as follows:

1 According to substrate they act upon, e.g Arginase that act on arginine, tyrosinase act on tyrosine, lipase acts on lipids while proteinase acts on protein and carbohydrases and maltase on carbohydrates and maltose respectively.

2 According to the type of reaction they catalyse. For example: hydrolyses (hydrolytic enzyme), oxidases (oxidation reduction enzymes), phosphorylases (phosphate adding and deleting enzymes).

In both cases above, the suffix-ase is added to the name of the substrate or reaction type.

SPECIFIC ENZYME TYPE

1 Hydrolyses (hydrolytic enzymes)they catalyse the addition of the elements of water to specific bond of substrate. RCO.OR' HOH RCOOH + R'OH

E.G, lipases, carbohydrates, proteases

2 oxidases, (oxidation- reduction enzymes). These catalyse the removal or addition of hydrogen, oxygen or electron from or to substrate, which is thereby oxidised or reduced in the process.

RH +HA R+ AH_2 (removal of H_2)

RO + $_{1\backslash 2}$) O_2 → RO_2 (addition of O_2)

R^{2+} → R^{3+} +e e.g dehydrogenases and oxidases

3 Phosphoric; these catalyse the addition or removal of elements of phosphoric acids, e.g glucose + phosphate Hexokinase glucose – 1- phosphate

4 Carboxylase; these catalyse the removal or addition of CO_2 e.g, ribulose- 1,5 – diphosphate(5C) carboxydismutase Keto acid (6C)

5 Isomers: these catalyse the interconversion of aldose and ketose sugars e.g, Glucose – 6-phosphate Phosphoglucoisomerase fructose -6- phosphate

6 Lyase; these carry out breaking of double bonds e.g, lysozyme (found in tears, nasal mucus and egg) which dissolve certain airbone cocci (bacteria) by breaking the double bond of polysaccharides in their walls.

ESTIMATION OF RATES OF ENZYME ACTIVITIES

1 Use of turnover numbers; this is the number of moles of substrate converted per minute by 1 mole of enzyme. Succine dihydrogenase has turnover number of 1150 while carbonic anhydrase has turnover number 360,000,000.

2 Manometric; gases evolve as a result of enzyme activities are measured manometrically, e.g oxidase, carboxylase.

3 Spectrophotometric: uses the fact different quantities of product have different optical density at the same wavelength. The wavelength used depends on the enzyme type involved. E.g, for amylase, the wavelength is 490nm and for protease it is 700nm.

4 Colouration Method: works on the basis that the substrate and the product have different colour with dye. The disappearance of the colour with time is taken note of e.g. starch + iodine(blue black) Amylase → maltose +iodine + E (iodine colour)

5 Chemical Estimation: this involve titration, chromatography and electrophoresis techniques. For instance, lipase are estimated by breaking lipids into fatty acids

and glycerol using lipases and the liberated fatty acids quantities determined using titration with NaOH and Phenolphtalein as an indicator.

Enzyme Inhibitors

These are compounds that prevent, limit, or stop enzyme activities; they are divided into competitive inhibitors and non competitive inhibitors.

1. Competitive Inhibitors: have similar shape to the substrate and can fit into the active centre of enzymes. They lower enzyme activities e.g, the inhibition by malonic acid of the enzyme succinic dehydrogenase that catalyse the conversion of succnic acid to fumaric acid. Competitive inhibition can be overcome by increasing the concentration of the substrate.
2. Non Competitive Inhibitor: either undergoes chemical reaction with the enzymes and thereby alter the configuration of the enzymes or form bond with enzymes substrate complex to form inactive compound. They normally stop the working of enzymes and effect cannot be overcome by increasing the concentration of the substrate. Examples are effects of poison, heavy metals (Hg, Au, Ag). Cyanide, and carbon.

COMMERCIAL USES OF ENZYME

A papain obtains from plants like pawpaawa leaves- protease is sold as meat tenderizer (Aldolfs). It breakdown protein into peptones and make the meat soft.

B Protein digesting subtilism (from *Bacillus subtillis*) is incorporated into pre-soak laundry agent and detergent for cleaning purposes. It is effective in removing protein- containing stains (chocolate or coffee) from clothes etc.

C Synthetic amylase is used in beer laundry to break down starch substances into maltose.

D synthetic cellulose is used in the textile industry to breakdown clothes into pieces of yarns.