

COMPARATIVE ANATOMY OF MAJOR PLANT ORGANS

THE ROOT

The primary functions of the root system are :the attachment of the plant to the soil, the absorption of water and mineral ions from the soil and the transport of materials to and from the shoot system. A secondary, though very common function is storage.

ROOT ANATOMY

The root apex (external features)

The tip of a growing root is always protected by a root cap. This is a conical cap of tissue which protects the apical meristem which lies within. It is easiest to see on aerial roots (e.g. Red Mangroves, epiphytes) and roots of seedlings grown on moist filter paper (e.g. cabbage, cauliflower etc.). The apical meristem lies within the root cap and cannot be seen in the intact root. The bare part of the root is the region of elongation in which cells derived from the apical meristem are increasing in length by vacuolation. Above this region the root is usually covered with root hairs for a short distance. Root hairs usually have a short life and wither away on the older parts of the roots. Above the region of root hairs, lateral roots emerge from within the tissues.

The apical meristem

Within the root cap are the small, thin walled and densely packed cells of promeristem which are actively dividing. The most actively dividing cells are grouped around a quiescent centre in which few cell divisions occur. Cells derived from the promeristem form derived meristems which, together with the promeristem, make up the apical meristem of the root. The outermost layer forms the protoderm, which is one cell thick. Within the protoderm is the ground meristem which is several cells thick. Provascular meristem (procambium) forms the central core. Cells in the three layers differ from each other in shape and in the direction in which they divide. The cells which finally differentiate from them are determined by their planes of division and subsequent vacuolation.

Differentiation of primary tissues

Vacuolation of cells begins before cell division has ceased but is most active after divisions have ceased. This is when the greatest elongation of tissues takes place. Cells from the protoderm from the epidermis (piliferous layer) of the root. Differentiations of epidermal cells involve only elongation and the formation of root hairs from some of them. The ground meristem produces only the parenchyma of the cortex of the root. During the maturation of most of the cortical parenchyma cells, some of the intercellular material softens so that they become rounded and intercellular spaces appear. The layer of cells closest to the epidermis (hypodermis) usually remains more compact and also does the innermost layer of the cortex (endodermis). The endodermis is of special significance in roots. Its cells develop a distinctive thickening of the radial and transverse walls, the casparian strip or band. This thickening involves the impregnation of the middle lamella and primary walls with suberin (a deposit- thin varnishlike layer which helps to seal moisture inside tissue) and sometimes becomes overlaid with cellulose which becomes lignified. The strip is also closely associated closely with the protoplast of each cell. In some plants (e.g. epiphytic orchids) the cells of the hypodermis also develop casparian strips, after which they are known as the exodermis.

It is in the stele, derived from the procambium that the greatest variety of differentiation occurs. The layer immediately inside the endodermis remains more or less unchanged except for lengthening of the cells during vacuolation. This is the pericycle. The pericycle is usually formed from a single layer of closely packed parenchyma cells but is may be more than one cell thick. The first cells of the vascular system to differentiate are patches of protophloem. Protophloem cells are difficult to recognize with certainty because they are simply narrow, elongated cells without clearly distinguishable features. Sieve tube elements and companion cells (small, slender, living cells) appear only later. The first cells to become lignified are the vessel elements of the protoxylem, formed in groups alternating with the patches of protophloem, immediately inside the pericycle.

Differentiation of both xylem and phloem proceeds towards the centre of the root. The last vessel elements to become lignified after that part of the root has stopped elongating are the largest vessel elements of the metaxylem. There is always a layer of parenchyma left between adjacent groups of primary xylem and primary phloem. There is no cambium at this stage, even in dicots. Dicots usually have the vascular tissues gathered closely at the centre of the root with the xylem either united by a central mass of metaxylem, or with a small medulla. Monocots usually have thicker roots with more protoxylem groups and larger medulla or pith at the centre. It is in small dicot roots that differentiation of metaxylem extends to the centre of the root, so that the xylem is star-shaped when seen in Transverse Section(TS). Thickened dicot roots and all monocot roots have a central medulla and alternating, but unconnected groups of primary xylem and phloem.

Older roots

Monocots

In monocots, no cambium is formed and the primary structure remains more or less unchanged throughout the life of the root. Changes are restricted to the outer layers of the cortex and the endodermis. Root hairs disintegrate after they have ceased to carry out their absorbing function. The endodermal cells opposite the absorbing protophloem become covered with a secondary lamella of suberin. These changes in the endodermis are characteristics of monocot roots but also found in dicot roots. Monocot roots do not branch much. The needs of the growing plant are met by the addition of more adventitious roots to the fibrous root system.

Dicots

A dicot root with primary structure has no cambium but a cambium usually forms at an early stage from the parenchyma cells which lie between xylem and phloem and in the pericycle outside the protoxylem.

THE STEM

The primary functions of the stem are to support the leaves in the best position for photosynthesis and to transport materials to and from the leaves.

THE STEM ANATOMY

The primary structure of the stem develops from cells derived from the apical meristem. The apical meristem consists of a promeristem, from which all other cells are derived and three derived meristems (protoderm, ground meristem and provascular strands (procambial strands). The protoderm gives rise to the epidermis of the stem, the ground meristem gives rise to the ground tissues (medullar or pith, cortex) and provascular (procambial) strands gives rise to the vascular bundles.

In dicots, vascular bundles are usually arranged to form a cylinder, with cortex outside, medulla inside and medullary rays between adjacent bundles. In monocots, vascular bundles are usually scattered throughout the ground tissue.

In dicots, a layer of meristematic tissue, the fascicular cambium remains between xylem and phloem and soon divides to give rise to secondary xylem and phloem. There is no cambium in monocots. They can only undergo primary growth - growth in length of shoots (and roots).

THE LEAF

The primary function of the leaf is to carry on photosynthesis which occurs in the mesophyll layer. The other functions includes:

1. it is the main organ for getting rid of excess moisture (i.e. transpiration)
2. it is the main organ for respiration.

LEAF ANATOMY

Parts of the leaf

The leaf base is often slightly swollen. If it is very swollen, it is called pulvinus. A pulvinus is capable of growth movements which turn the leaf so that it is held at right angles to incident light.

The petiole is essentially stem-like in structure. Some petioles are radially symmetrical like a stem. Most are dorsiventral in structure.

The leaf blade consists of midrib which is dorsiventral in structure.

The basic structure of the lamina of the leaf is very constant. There is always an upper (adaxial) and lower (abaxial) epidermis, one or both of which contain stomata. Chlorenchyma forms mesophyll between the adaxial and abaxial epidermis. Vascular bundles, each enclosed in a parenchymatous bundle sheath, lie at about the centre of the mesophyll.

Leaves which are held in a horizontal position have dorsiventral symmetry. Leaves which stand upright, or hang downwards, have isobilateral symmetry. A leaf with isobilateral symmetry has a 'upper' and 'lower' sides and has similar internal structure next to each epidermis. Dorsiventral leaf structure is typical of dicots but is found also in some monocots (e.g. yam). In such leaves, the adaxial epidermis has thicker cuticle and few stomata than the abaxial epidermis. There may be no stomata in the adaxial epidermis. The stomata is formed by the partial separation of two adjoining specialized epidermal cells. Immediately beneath the adaxial epidermis, are one or several layers of palisade mesophyll. The cells of palisade mesophyll are elongated at right angles to the epidermis. Although, these cells appear closely packed, they show abundant air spaces between the cells and contain chloroplasts. Beneath this, is a loose spongy mesophyll composed of chloroplast. The cells are rounded or irregularly shaped and air spaces are very conspicuous. The largest air spaces exist next to where there are stomata in the abaxial epidermis. These are substomatal chambers. The vascular bundles of small veins are located at the junction of palisade and spongy mesophyll. Each vein contains xylem and phloem, surrounded by a layer of parenchyma cells which form a bundle sheath.

Isobilateral leaves are typical of monocots but occur in some dicots (*Eucalyptus* spp). There is no difference in cuticle thickness or stomatal distribution between the adaxial and abaxial epidermis. There is usually little differentiation of the mesophyll in the palisade and spongy layers. In some leaves (e.g.

maize), the mesophyll is all more or less of the spongy type. In others (e.g. Eucalyptus spp), it is all palisade mesophyll.

DIFFERENCES BETWEEN MONOCOTS AND DICOTS

	Monocots	Dicots
1.	Have one cotyledon	Two cotyledons
2.	Floral parts are in three or multiples of threes	Floral parts are in fours or fives or multiples of fours or fives
3.	Layers (except in yam) are parallel-veined	These are net veined
4.	Have fibrous root system	Typically develop a tap-root system
5.	In monocots e.g. maize, the root usually has a wide, well defined pith area surrounded by a band of conducting tissue containing alternating bundles of xylem and phloem cells	In the root of dicots, there is no pith, xylem and phloem are separated by parenchymateous tissue i.e. center section filled with xylem while phloem occurs outside
6.	Vascular bundles in stems of monocots are scattered through the stem so that there is no pith or very little cortex	Vascular bundles in stems of dicots are well arranged with an extensive pith and a wide cortex
7.	In stems of monocots, there is the absence of cambium between xylem and phloem	Presence of cambium between xylem and phloem

Crop Physiology

Living organisms are built up of molecules and while alive, they are centres of intense and complex chemical activity. Their growth, development, movements and reproductive activities are the outcome of these highly complex and chemical changes. The study of the functioning of living organisms is usually referred to as their physiology and hence the study of the functioning of crop is known as crop physiology.

A TYPICAL PLANT CELL

The early microscopists recognised that living material was built up from, or divided into minute compartment or cells. The cells is the basic unit of living matter. Typical vascular plants consists of hundreds of billions of cells. An average apple leaf is made up of approximately 50 million cells. Many different kinds of cells make up the body of plants. All the various specialized cells, are however, derived from cell division and subsequent enlargement and differentiation from groups of meristematic cells situated at the apices of roots, leaf and stems. Such cells have thin cell walls rich in hemicelluloses and pectin. Within the cell wall, the living material (protoplast) consists of cytoplasm and a large nucleus, the latter occupying two-third to three-quarter of the protoplast volume.

Minute vacuoles (rich in fatty and protein material) are enclosed by a membrane (the homoplast) which has semi-permeable properties, elasticity and an essential content of lipids.

The lining layer of cytoplasm has a granular appearance due to presence of various inclusions or cellular particles. Some of these: the mitochondria, are spherical or cylindrical bodies, the other is the proplastids. These are the bodies from which develop, during differentiation, the various forms of plastids, most important are the chloroplasts (in photosynthetic parenchyma) and starch-forming amyloplasts (of storage parenchyma). Mitochondria and plastids are centres for metabolic activity and can increase by division

and are constant features of the cytoplasmic complex. Cells in tissues are firmly cemented together by the middle lamella. Each protoplasm is separated from its neighbouring protoplasts by the two intervening cell walls and the middle lamella between them.

A Plant Cell

STRUCTURE AND FUNCTION OF CELLS

Plant cells are bounded by a membrane. They are also surrounded by a more or less rigid wall. The cell is made up of the cell wall and the protoplast, the living portion of the cell. The protoplast is composed of cytoplasm and minute subcellular bodies, called organelles, that carry on specific functions. Each type of cell and each component have a special structure, chemical composition and function.

CELL WALL: Give protection, support and shape to each cell and form the structural framework of the plant as a whole. The cell wall is non living. Thickness and other physical properties of cell walls vary greatly with age, type and function of the cell. It is composed of three distinct layers: the primary cell wall which is formed during early stages of growth is composed of layers of cellulose, hemicellulose and pectin. This layer is thin and water-permeable and elastic. The secondary cell wall, usually present in mature cells, is laid against the inner surface of the primary cell wall after the cell has achieved its maximum expansion. Lignification occurs in this region and the process makes the cell wall rigid and unstretchable. They provide mechanical support for the plant. The middle lamella, the outermost layer of a mature cell wall, consists of pectin and cements together primary cell walls of adjacent cells.

PROTOPLAST: Is the living portion of a cell inside the cell wall. It is surrounded by the plasma membrane or plasmalemma, a selectively permeable, flexible membrane composed of lipids and proteins. These membranes regulate the movement of water as well as organic and inorganic materials into and out of the protoplast.

CYTOPLASM: Is a viscous matrix enclosed by the plasma membrane. It contains water, proteins, carbohydrates, lipids and inorganic salts. Suspended in it are the organelles, which carry on all functions necessary to sustain life.

ENDOPLASMIC RECTICULUM: Is a long, membrane network which extends throughout large portions of the cytoplasm. Its function is inter and intracellular transport of cellular products, as a surface for protein synthesis, in separating enzymes and enzyme reactants, in moving cell components during cell division, and in physical support. It often appears to be connected to the nuclear membrane and the plasma membrane in meristematic cell. In differentiated cells, the ER may be less prominent and may be represented only by discontinuous vesicles.

RIBOSOMES: In the cytoplasm and often associated with the endoplasmic reticulum are extremely small dense globular particles called ribosomes. They contain ribonucleic acid (RNA) and proteins and are involved in the synthesis of proteins, including enzymes. Polyribosomes are aggregations of many ribosomes, either on the endoplasmic reticulum or floating free in the cytoplasm, where they also function in protein synthesis.

PLASTIDS: Their function range from photosynthesis to the storage of starches and fats. They are classified by colour. Chloroplasts (green) chromoplast (yellow, red or orange) and leucoplast (colourless). The chloroplast are the dominant plastic in the leaves and other green parts of a plant. In a typical green cell of a leaf, there are 20 to 100 chloroplasts. Chloroplast contain chlorophyll and carotenoid pigments but the yellow and orange carotenoids are masked by chlorophyll and do not become evident until the chlorophyll deteriorates. Chloroplasts also contain the enzyme and intermediate substances required for conversion of radiant energy into chemical energy by photosynthesis. Each chloroplast may have a large number of disk-shaped grana lamellae, highly folded or convoluted layers of the inner membrane of the chloroplast. The grana membranes contain chlorophyll molecules which capture high energy from the sun. Yellow and orange flowers, fruits and seeds lack chlorophyll when mature, owing their colour instead to chromoplasts. These variously shaped plastids synthesize and retain

yellow (carotene), red (xanthophylls) and orange (carotenoid) pigments rather than chlorophyll. Leucoplasts are nonpigmented organelles of different shapes which are usually elastic and serve in the synthesis and storage of starch, oils and proteins from smaller molecules. They are located in the colourless leaf cells of variegated leaves, stems, roots and other storage organs, as well as underlying tissues of the plant not exposed to light.

MITOCHONDRIA: Are smaller than most plastids, are pickle shaped. Each mitochondrion contains a semigel stroma of proteins (enzymes) within a two-layered membrane. The mitochondria serve as the cell's power-house and are the major sites for respiration. They are distributed in the matrix of the cytoplasm and are often in contact with the ER or nuclear envelope. The number of mitochondria in a cell is variable but living plant tissues contain 500-800/cell. They contain DNA (deoxyribonucleic acid) and ribosomes and can effect protein synthesis.

DICTYOSOMES: The dictyosomes or golgi bodies, serve as collection centres for complex carbohydrates, they are believed to be involved in cell-wall synthesis and the packaging of cellular products for excretion from the cell. They are characteristics of meristamatic cells, and appear to increase in number during cell differentiation. They develop numerous vesicles thought to serve as a source of plasma membrane components. The vesicles may be involved in the transport of polysaccharide material to developing cell walls.

MICROTUBULES: Are proteinaceous structures located in the cytoplasmic matrix of non dividing cells and in the spindle fibers of cells undergoing cell division. They are involved in the growth of cellulose fibers in the cell wall. During cell division, microtubules attach to the chromosomes and appear to draw them to the opposite poles.

LYSOSOMES: These organelles are bounded by a single membrane and contain enzymes capable of digesting various cellular components such as proteins and lipids. Their exact functions are unclear, but they are believed to be important in the development of those cells which are hollow at maturity. They may also be a defensive mechanism against invasion by pathogens.

VACUOLES: Young meristematic cells have many minute vacuoles within the cytoplasm. As cells grow and mature, these vacuoles fuse into a large central vacuole, which increases in size until it may occupy 80 or 90% of the intracellular volume. The vacuole is filled with cell sap, an aqueous solution of inorganic salts and organic solutes. It is the storage compartment for materials which are no longer needed and may be detrimental to metabolic processes in the cytoplasm. These materials are stored as insoluble crystals in the cell sap. The vacuole is surrounded by a semi permeable membrane known as the tonoplast which regulates the pH of the cytoplasm and controls chemical composition. The vacuole may contain pigments such as the anthocyanins, which are responsible for some colours of flowers, fruits and autumn leaves.

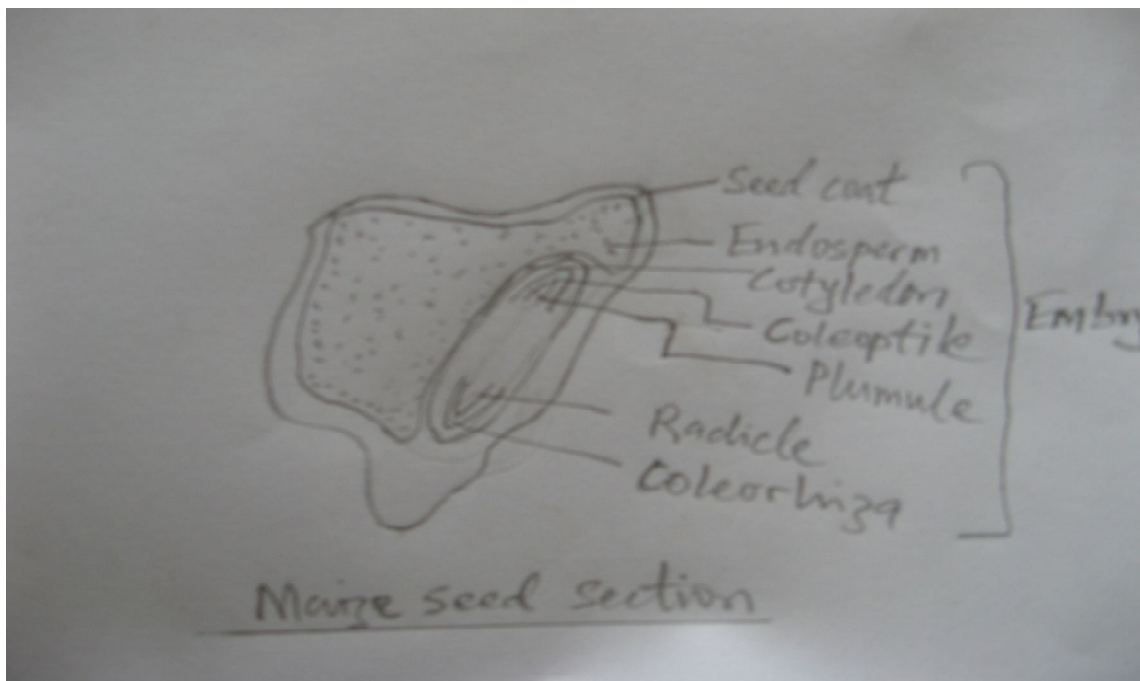
NUCLEUS: The nucleus of a mature plant cell is the largest organelle in the cell except for the vacuole. It is usually spherical or disk-shaped, 10 to 20 micrometers (μm) in diameter and surrounded by a double membrane called the nuclear envelope. In young cells, the nucleus is centrally located, but as the vacuole expands to fill most of the cell, the nucleus is pushed into a corner. The nucleus contains a gel-like nucleoplasm, comparable to the cytoplasm of a cell. It contains one or more spherical bodies called nucleoli and is composed of DNA, RNA and proteins, collectively referred to as chromatin. When cell division begins, the chromatin condenses to form microscopically visible bodies called chromosomes. The DNA of the chromosomes contains genetic information and controls the synthesis of specific enzymes on the ribosomes. These enzymes control the metabolic activities of the cell and determine the overall characteristics of the organism. The maintenance of active metabolism in the cytoplasm is dependent upon the presence of the nucleus.

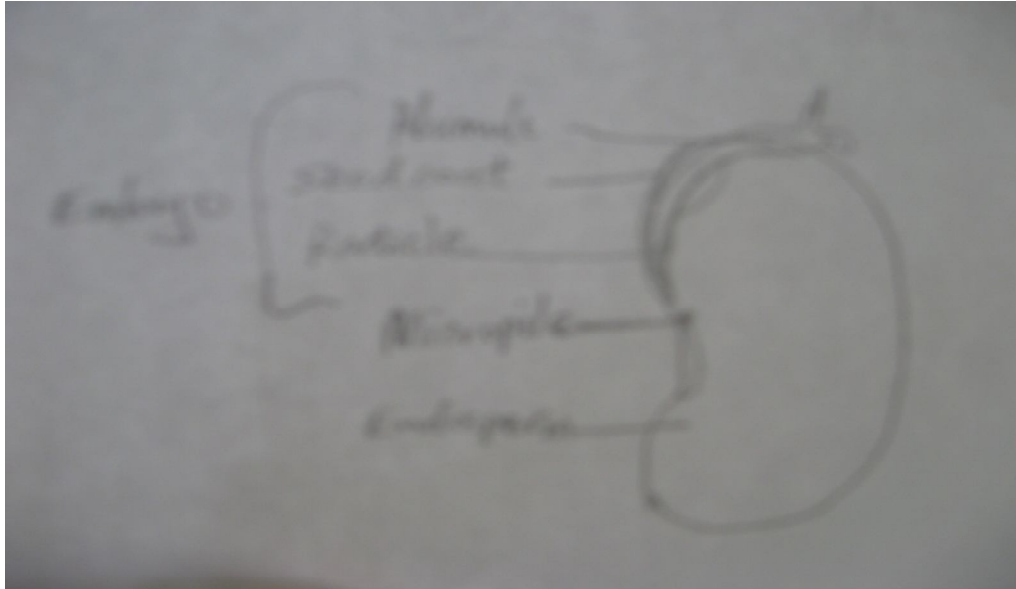
Cells and Tissue

Not only is the cell the basic unit of life, it is also the fundamental morphological unit of the plant body. Cells are in turn organized into groups, whose structure or function, or both are distinct from others. These groups of cells are called tissues.

A plant begins as a fertilized egg or zygote, in the ovary of a flower. The zygote undergoes cell division, and differentiation. The process of growth and morpho-physiological specialization of cells produced by the meristems - giving rise to an embryo

A monocot seed section diagram





A DICOT SEED SECTION DIAGRAM

As the embryo develops into a young seedling and then an adult plant, the embryonic character persists in regions of continued cell division called **meristems** continue to contribute new cells to the plant body as older cells begin to differentiate and mature. Unlike animals where the size and form of the adult is determined in the early stages of embryo formation, meristems give plants their unique character of indeterminate or continuous growth.

The two principal meristems are the “apical meristems located at the apex of the shoot and root. The apical meristems are responsible for adding to the length of the shoot and root axis, called primary growth and the cells and tissues derived from these meristems form the primary plant body. Many plants undergo an increase in girth or thickening of the stems and roots by adding new vascular tissues to the primary body. This lateral growth is called secondary growth and is produced by a lateral meristem called the vascular cambium.

Simple tissue are made up of (one type of cells) Parenchyma, Collenchyma and Sclerenchyma while complex tissues are made up of (several different types cells) xylem, phloem and epidermis.

Parenchyma

Parenchyma cells are found throughout the plant body in the cortical regions of stems and roots and in the mesophyll of leaves and are scattered throughout the vascular tissues. Parenchyma cells serve primarily in photosynthesis (in which case they may be called chlorenchyma), storage and wound healing.

Collenchyma and Sclerenchyma (Supporting tissues)

Collenchyma cells may be considered parenchyma cells that are specialized for support – young tissues. They are commonly found in the cortex of stems and petioles or along the veins in leaves and are characterized by thickened primary walls. Sclerenchyma cells on the other hand, are scattered throughout the plant in both primary and secondary tissues. There are two types of Sclerenchymas sclerids and fibers are generally very long and slender. Both sclerids and fibers have thick secondary walls that are heavily lignified. For instance, linen thread consists primarily of sclerenchyma fibers from stems of flax plant (*Linum spp*).

Complex tissues

Epidermis: The epidermis is a superficial tissue that forms a continuous layer over the surface of the primary plant body. Cells of the epidermis are usually regular in shape, they are appressed very tightly together and their outer walls are covered with a waxy cuticle. In leaves the integrity of the epidermis is interrupted with pores, which allow for exchange of carbon-dioxide, water and oxygen between the leaf and the ambient air. The pores are surrounded by specialized epidermal cells called. The principal function of the epidermis is to provide mechanical protection and to restrict water loss.

Vascular tissue

The vascular tissues are concerned primarily with the distribution of nutrient, water and products of photosynthesis. There are two types of vascular tissues: Xylem and Phloem.

Xylem is a structurally and functionally complex tissue concerned primarily with water conduction, storage and support. The cells most characteristics of xylem are the principal water conducting elements; tracheids and vessel elements. Xylem tissues also contain parenchyma cells, which function primarily as storage, and mechanical cells (sclerids and fibers) which provide support.

Phloem: This tissue also is both structurally and functionally complex. Phloem is concerned primary with the distribution of organic molecules between “source” that is photosynthetic or storage tissues, and “sinks” or regions of active growth and metabolism.

The principal conducting elements are sieve cells on sieve tubes phloem also contain parenchyma cells. Some of which are specialized companion cells or transfer cells as well as sclerids and fibers. Vascular tissues are of two origin: primary (Apical meristem) and secondary (Vascular cambium).

Plant Organs

Just as cells are grouped together to form tissues with distinct structures are functions, tissues are also grouped together to form Organs. The following are known as plant organs: Roots, stems, leaves, flowers and fruits. The first 3 organs (roots stems and leaves) are known as the 3 principal vegetative organs.

Topic: Photosynthesis

Basic concepts: Metabolism, Anabolic process, quantum yield, photosystems, Emerson effect, pigments, Hill’s reaction, assimilatory powers, CAM, C₄ plants, photorespiration, phosphorylation.

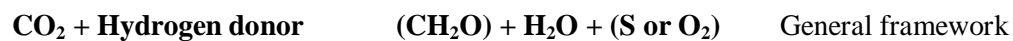
Learning objectives:

1. Understanding relationship between photosynthesis and yield

2. Understanding mechanism of photosynthesis
3. Understanding factors affecting photosynthesis
4. Comparative analysis of C₃, C₄ and CAM
5. Photosynthesis, carbon sequestration and environmental health

Theoretical Background: Living systems are thermodynamically open system; such systems exchange energy and matter with the environment. Conceptually, there are two types of such energy transformation in living systems; anabolic and catabolic process. Anabolic process involves the transformation of energy into biological polymer, while catabolic process is breakdown or degradation of biological polymer and the consequent liberation of energy. Photosynthesis is an anabolic process found predominantly in higher plants, whose mode of nutrition is autotrophic. Autotrophic organism are further divided into phototrophic and chemotrophic organism depending on the energy source. All major crops of agronomic values belong to photoautotrophic organism, since they are capable of transforming radiant energy, in the presence of pigments into biological polymers. Chemotropic organism uses other source of energy and they are predominantly found among the lower plants.

Chemically the process could be represented as follows:

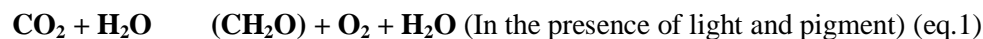


Where:

Hydrogen acceptor = CO₂

Hydrogen donor = H₂O, H₂S (chemolithotroph), organic acid (chemoorganotroph)

In the case of phototrophic organism:



Equations 1 and 2 Energy acquisition process

Equation 3

Carbon assimilation process

Photosynthetic efficiency metrics:

1. Percentage of energy conversion of radiant energy into assimilatory powers (NADPH₂ AND ATP), which is approximately 32 %
2. Quantum yield = O₂/light energy. With increasing wavelength of light there is a reduction in the evolution of O₂, a phenomenon referred to as red drop. ($E = hc/\lambda$). It was later observed that in order to enhance photosynthesis there is a need for two light harvesting systems, Emerson effect.
3. Percentage of carbon assimilation; $NAR = RGR/ LAR$

Tab. 1 Conceptual Framework of Photosynthesis

Parameters for comparison	Photosynthetic stages	
	Light	Dark
Process type	Energetic (Acquisition and conversion of energy)	Metabolic (Assimilation of CO ₂) <ul style="list-style-type: none"> ○ Calvin cycle ○ Hatch+Slack cycle ○ CAM cycle
Organ	Quantasome <ul style="list-style-type: none"> ○ Pigment system (PSI +PSII) ○ Grana 	Stroma (Thylakoid matrix)

Process product	<ul style="list-style-type: none"> ○ ATP ○ NAPH.H₂ ○ Products of photolysis 	<ul style="list-style-type: none"> ○ O₂ ○ (CH₂O)_n
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Tab. 2 COMPARATIVE ANALYSIS OF TYPES OF PHOTOPHOSPHORYLATION

	Types of photophosphorylation	
	Non-cyclic	Anoxysenic photosynthesis (cyclic)
Organism	Green plant	Bacteria
Type of photosynthetic unit	PS I and II	PI
Electronic flow	P _{II} →P _I →CO ₂ unidirectional	Circular
Wave length	680nm – 700nm	700nm
Types of assimilatory power	NADPH ₂ , ATP	ATP
Capacity for photophosphorylation	Low	High

Photosynthetic efficiency	High	Low
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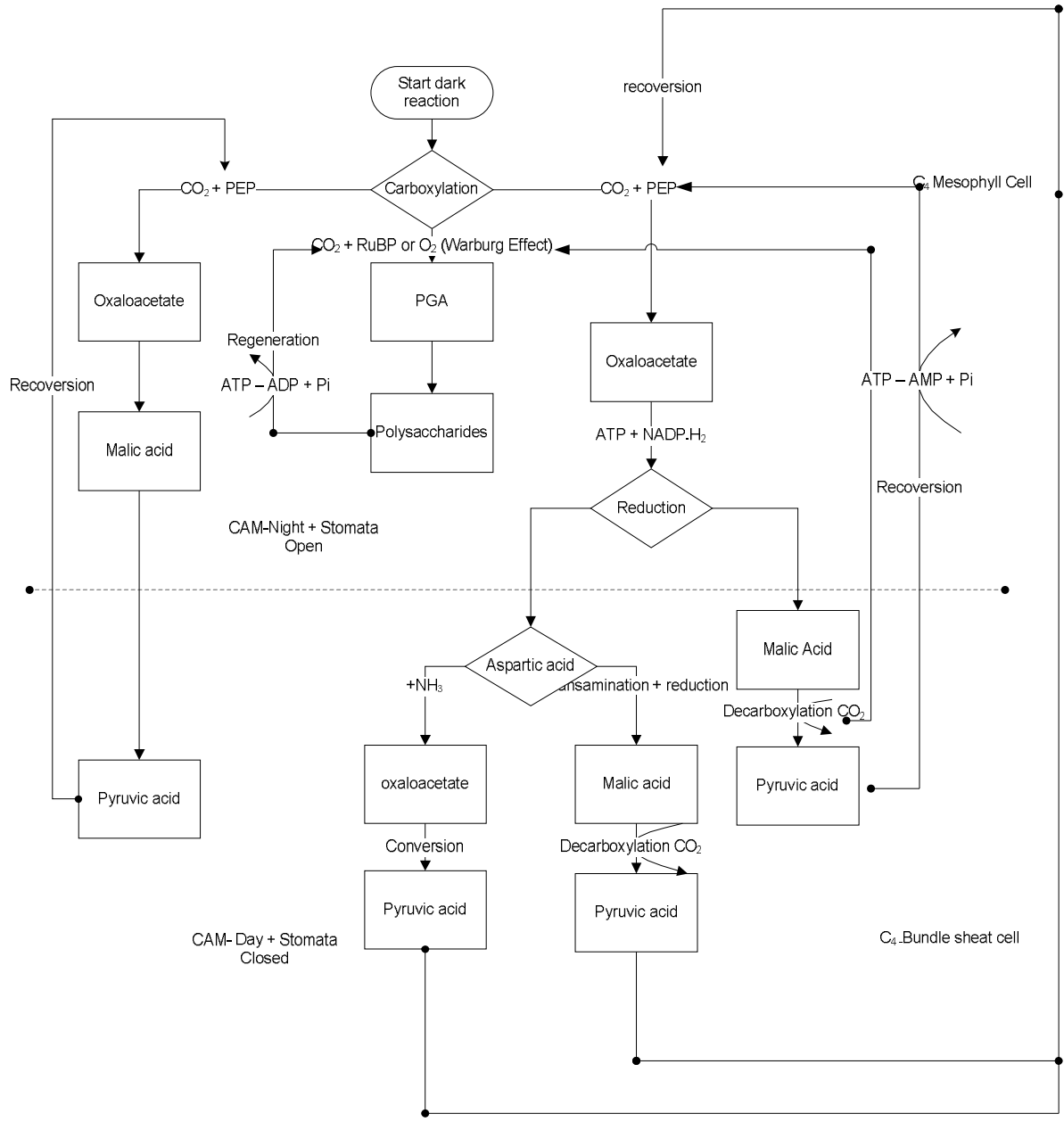
Tab.3 Dimensions of Dark reaction during photosynthesis

Parameters for Comparison	Dark reaction cycle		
Plant type	C₃	C₄	CAM
Nomenclature	Calvin cycle or Pentose phosphate reduction cycle	Hatch + slack cycle	CAM cycle
CO₂ acceptor	Ribulose 1,5 Biphosphate (RuBP)	RuBP Dicarboxylic acid Phosphoenolpyruvic acid (PEP)	PEP RuBP
First stage product	Phosphoglyceric acid (PGA)	Oxaloacetic acid/malic acid (Carboxylic acid)	Malic acid and Malate
Compartmentalization of carboxylation	None	Spatial (Mesophyll +Bundle sheath)	Temporal (Diurnal pattern in mesophyll)
Plant habitat	Hydrophytes Mesophytes	Xerophytes	Halophytes

Morphology of the chloroplast	Monomorphic	Dimorphic	Fleshy leaf, stem and petioles
Bundle sheath	Few or no chlorophyll	Chlorophyllous	-
Morphology of chlorophyllous mesophyll	Not distinguishable 5> mesophyll	Kranz anatomy 4-5 mesophyll	-
Photorespiration	More	lesser	-

Flow chart of Dark reactions of C3, C4 and CAM Plants

Figure 1



Factors affecting photosynthesis are:

1. Light
2. Water
3. Temperature
4. Carbon dioxide concentration

5. Mineral nutrients, most especially, NPK and some micro nutrients

Topic: Translocation and assimilate partitioning in relation to yield determination

Basic concepts: Translocation, transport, assimilate or photosynthates, partitioning, allocation, phloem, xylem, source, sink, sink strength.

Theoretical Background: Product of photosynthesis are transported, allocated and partitioned among various sinks. From the agronomic point of view, it is not only enough to generate adequate photosynthates, but they should be partitioned to organs of great economic returns, this is reflected in the harvest index, indicating the proportion of the economic biomass relative to the general biomass.

Transportation in long distant is referred to as translocation of solute or sap, while short distant movement of molecules and ions is generally accepted as transportation.

A solute **translocation pathway** is the phloem, a living cell compared to the xylem which is dead. The phloem is consisting of:

1. Sieve elements
 - a. Sieve tube element
 - b. Sieve plate pores
2. Sieve cell
3. Companion cell
4. P-protein

Translocation pattern: Source - Sink

The pattern of solute translocation is from the source to sink. The source are organs with assimilate concentrations more than their need; conversely the sink organs are with assimilate concentrations lesser than their needs.

Transported Materials:

1. Inorganic
2. Organic
 - a. Carbohydrates (non-reducing sugars)
 - b. Proteins (Amino acids, amides, P-protein, protein kinase, ubiquitin, chaperones, protease inhibitors)
3. Hormones

Mechanism: The photosynthates produced from the reduction of CO₂ is eventually allocated to various metabolic processes, or partitioned into various organs. The photosynthates could be allocated into the process of RuBP regeneration, storage of transitory starch or synthesis of sucrose for eventual transportation. The decision of whether to store photosynthates as starch or synthesize sucrose depends on the concentration of inorganic phosphorus in cytosol. When it is high sucrose is synthesised and eventually transported, while low concentration of it, leads to storage in the form of starch.

Sucrose is transported to the phloem-companion cell complex through apoplast or symplast path. Loading of sucrose via H⁺/sucrose symport transportation leads to the reduction of water potential, while unloading at sink leads to the increase in water potential. This process in the phloem pathway leads to osmotically **generated pressure gradient**, with the sap moving by **mass pressure** from source to sink. Allocation of photosynthates for storage or differential distribution to various organ is a function of the activities of certain enzymes like *acid invertase*, *starch phosphorylase* and *sucrose synthetase*. Differential distribution (partitioning) of photosynthates among sink organs is dependent on various factors. There are different models proposed to explain assimilate partitioning in crop plant. Please see the matrix below for comparative analysis. We shall be focusing our attention on functional equilibrium model. The basic assumptions of this model are:

1. Assimilate is constant at a given period in time.

2. Partitioning is a proportional process and involves a trade-off at any given period in time
3. Changes in partitioning during ontogeny (developmental stages) reflect changes in plant's priority – phenotypic plasticity
4. Differential distribution is to process that is limiting at that point in time

Functional equilibrium model:

Dry matter allocation = $W_r/W_s \propto A_s/A_r$

Where:

W_r – Weight of root

W_s – Weight of shoot

A_s – Activity of shoot (carbon assimilation)

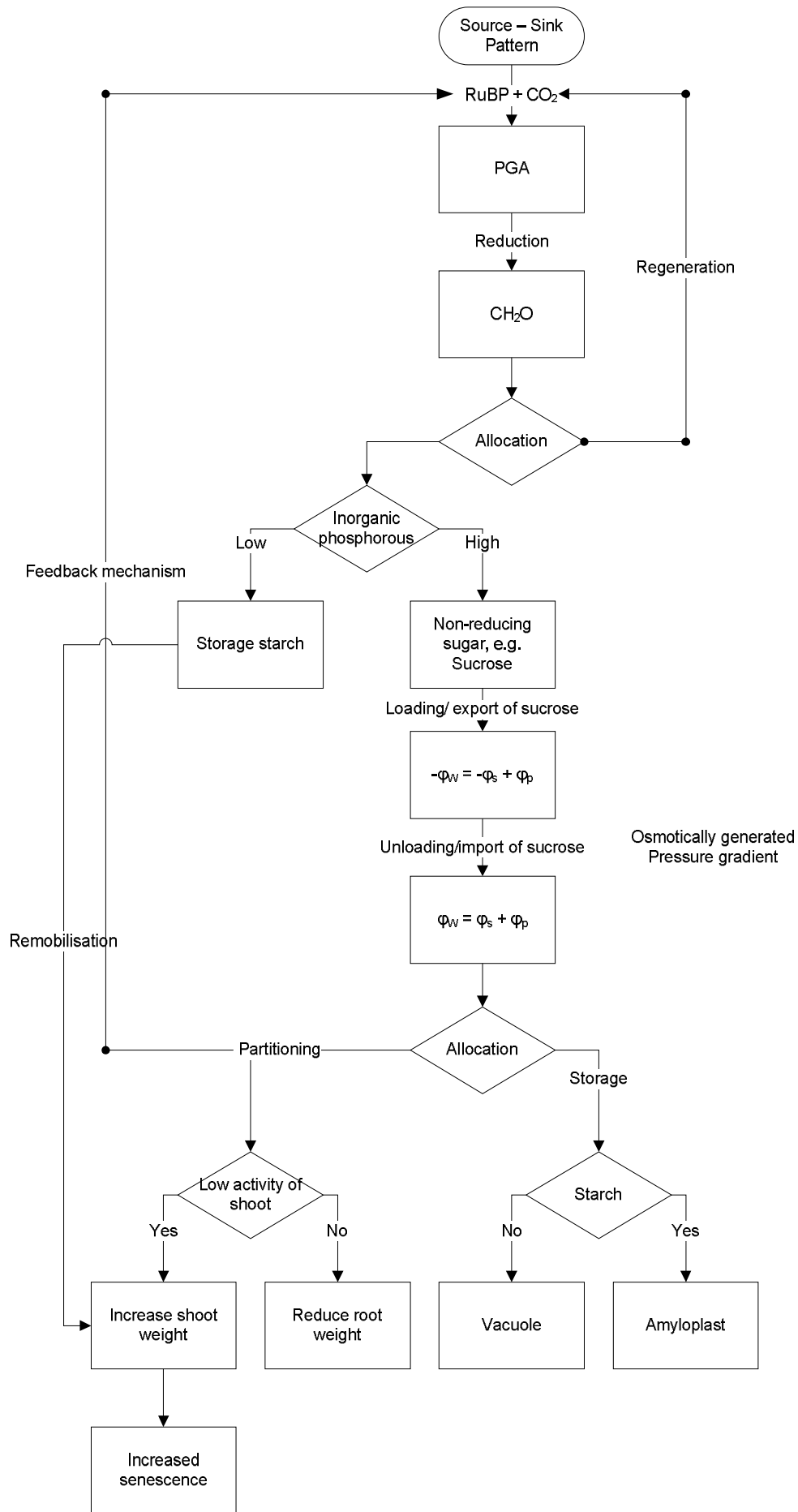
A_r – Activity of root (nutrient and water uptake)

With respect to yield, high yield is recorded when there is a there is functional balance of physiological activities, contrary to which assimilates could be partitioned to other sinks indicating priority process, which may not be of economic value to the farmer.

COMPARATIVE ANALYSIS OF MODEL S OF ASSIMILATE PARTITIONING

Models name	Assumptions	Model	Deficiency of the model

Descriptive Allometry	Predetermined RGR among organs	Allometric pattern = $f\{\text{genotype} \times \text{environment} \times \text{dev}\}$	Fluctuation in dry matter allocation could not be explained by the model
Functional Equilibrium (Teleonomic model)	Existence of functional balance among the plant organs (Shoot and Root)	<ol style="list-style-type: none"> 1. Dry Matter Allocation = $W_r/W_s \propto A_s/A_r$ 2. Or Carbon/Nitrogen 	Not applicable to other organ aside from shoot and root
Canonical Model	Interrelationship of parts	<ol style="list-style-type: none"> 1. Non linear, dynamical process 2. Numerical analysis 	Too quantitative
Sink Strength	Commonality of assimilate pool	<ol style="list-style-type: none"> 1. DMA = $f\{\text{sink strength} - (\text{source strength} + \text{transport resistance})\}$ 2. $f_i = s_i/\Sigma S$ 	Sink strength is conceptual, not measurable
Transport Resistance		DMA = $f\{\text{pressure gradient} \times \text{differences in labile carbon}\}$	Complexity in computing resistance transport parameters



The above Conceptual Model according to Sakariyawo 2009