

CHAPTER 29

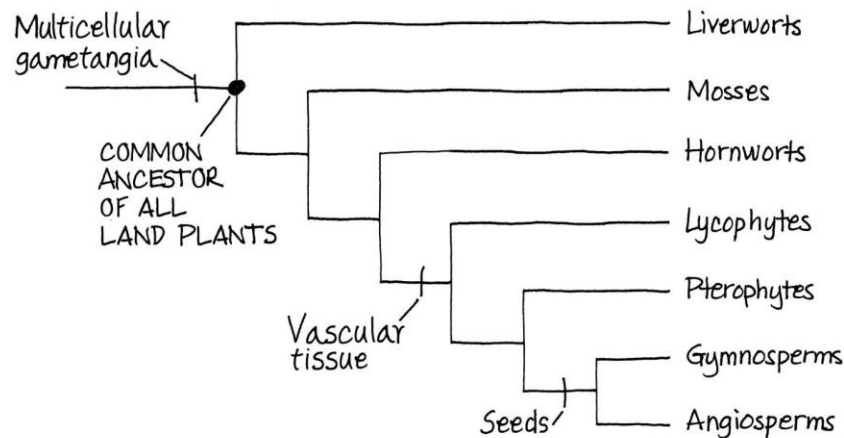
- Land Plants evolved from green algae
 - There is morphological and molecular evidence;
 - Rings of cellulose synthesizing proteins
 - Distinctive rings of protein in plasma membrane to synthesize cellulose in Charophytes and land plants, but not in non-Charophyte algae
 - Structure of flagellated sperm
 - Similar structures of the charophyte sperm found in land plants
 - Formation of phragmoplast
 - In the Chara and Coleochaete genera, among others details of cell division are similar to land plants. In this case a group of microtubules between the daughter nuclei of a dividing cell.
 - Adaptations enabling the move to land
 - Sporopollenin, a durable polymer that prevents exposed zygotes from drying out during periods where the plant is not submerged. In plants this is found in the spore walls
 - Derived traits of land plants
 - Alternation of generations
 - Life cycle includes both multicellular haploid and diploid organisms
 - Gametophyte; a multicellular haploid life state, producing eggs and sperm that fuse together to form a diploid sporophyte
 - Sporophyte; multicellular diploid life state, producing haploid spores by meiosis, thus returning the life cycle to the gametophyte stage
 - Multicellular dependent embryos
 - Multicellular plant embryos develop from zygotes that are retained within the tissues of the female (gametophyte) parent.
 - The embryo is surrounded by specialized placental transfer cells that enhance the transfer of nutrients.
 - This derived trait is known as embryophytes
 - Walled spores produced in sporangia
 - Sporangia; multicellular organs of the Sporophyte that produces spores.
 - Sporocytes; diploid cells/mother cells that are produced in the sporangia that through meiosis generate haploid spores, (coated in sporopollenin)
 - Multicellular gametangia
 - Multicellular organs called gametangia that produce gametes
 - Archegonia (arch-curves-female female pear shaped organ that produces a single non-motile egg retained within the bulbous part of the organ
 - Antheridia (anther-antler-buck-male) male organ that produces sperm and releases it into the environment
 - Apical Meristems
 - Sections at the base of the root and the tip of the shoots that are responsible for plant growth, in both directions, giving it a photosynthesizing advantage
 - Cuticle

- Waxy coating to prevent desiccation during dry spells
 - Stomata
 - Specialized pores allowing gas exchange, serving to support photosynthesis
- Origin and diversification of plants
 - Vascular tissue a distinguished factor
 - Tissue allowing the transport of water and nutrients
 - Bryophytes; Non-vascular plants such like many moss and algae
 - Seedless vascular plants
 - Two main clades;
 - Lycophytes
 - Club mosses and their relatives
 - Monilophytes
 - Ferns and their relatives
 - Seed bearing vascular plants
 - Two main clades
 - Gymnosperms
 - Naked seed plants because their seeds are not enclosed in chambers, conifers are good examples
 - Angiosperms
 - Seeds develop in chambers originating within flowers, consists of all flowering plants (huge clade)
- Mosses and other non-vascular plants have life cycles dominated by gametophytes
 - Bryophytes are represented by three phyla of herbaceous (non-woody) plants
 - Liverworts
 - Mosses
 - Hornworts
 - Bryophyte gametophytes
 - All three of the above phyla have haploid gametophytes as their dominant stage of the life cycle
 - Germinating spores (moss) characteristically produce a mass of green one cell thick filaments called protonema, which produces ‘buds’
 - The ‘buds’ of the protonema have an apical meristem that generates a gamete producing structure called a gametophore
 - Anchored by rhizoids, which are long tubular single cells or filaments of cells, they are not composed of tissues and do not play a primary role in water and mineral absorption, the primary role being filled by the protonema and the gametophores
 - Form multiple gametangia, but the archegonia only produce one egg, while the antheridia produce multiple sperm, which must swim through a film of moisture to reach the eggs produced by the archegonia
 - Bryophyte sporophytes grow out of archegonia
 - Consist of;
 - a foot
 - embedded in the archegonium, absorbing nutrients from the gametophyte
 - Followed by a seta (stem)

- Conducts the material absorbed by the foot to the capsule
 - Then comes the capsule (sporangium)
 - Uses the material to form spores
 - Which discharges the spore through the peristome
 - Upper part of capsule featuring a ring of interlocking tooth like structures
- True for hornwort, liverworts, and mosses, all of which have stomata except the liverworts
- Important as a nitrogen retainer for the soil, and colonizing bare soil, as well as a fuel in some cases
- Ferns and other seedless vascular plants were the first to grow tall
 - Origin and traits of vascular plants
 - Life cycles with dominant sporophytes
 - Sporophytes were the dominant life cycle for plants
 - Transport in xylem and phloem
 - Two types of vascular tissues;
 - Xylem; conducts water and minerals
 - Includes tracheids, tube shaped cells (walls strengthened with lignin) that carry water and minerals up from the roots
 - Phloem; cells arranged in tubes to distribute sugars, amino acids, and other organic products
 - Evolution of roots
 - Evolved in the sporophytes of almost all vascular plants, used to anchor, and absorb water and nutrients. They closely resemble stem tissues of early vascular plants
 - Evolution of leaves
 - Increase surface area and act as the primary photosynthesizing organ
 - From outgrowths of stems
 - Can be classified in two groups
 - Microphylls
 - All lycophytes have these type of leaves
 - Characterised by unbranched vascular tissue
 - Megaphylls
 - Typically larger than microphylls
 - Greater photosynthetic productivity
 - Characterized by branched vascular tissue
 - Sporophylls and spore variations
 - Sporophylls; modified leaves that bear sporangia
 - Sori; Clusters of sporangia, usually on the underside of sporophylls
 - Strobili; Groups of sporophylls forming cone like structures
 - Most seedless vascular plants are Homosporous
 - Homosporous; one type of sporangium that produces one type of spore, which develops into a bisexual gametophyte
 - Heterosporous species produce two kinds of spores;

- Megasporangia on megasporophylls, produce megaspores, which develop into female gametophytes
 - Microsporangia, on microsporophylls produce microspores, which develop into male gametophytes (micro, sperm is small)
- Classification of seedless vascular plants
 - Lycophytes (phylum Lycophyta)
 - Spike moss, quillwort, club moss
 - Spike moss and club moss have vascular tissue and aren't true mosses
 - phylum Pterophyta
 - Ferns, horse tails, whisk ferns
 - Very diverse group
 - Horse tails alive during the carboniferous period
 - Whisk ferns closest to ancestral vascular plants
- Significance of seedless vascular plants
 - Lowered CO₂ levels
 - Grew to great heights creating first forests
 - Decaying plants became coal

Should be able to link and understand this



CHAPTER 30

- Overview
 - First evidence 360 million years ago
 - Seed consists of an embryo and its food supply, along with a protective coat.
 - Huge impact on human society, allowed us to live closer together when we started cultivating seeds, about 8,000 years ago
- Seeds and Pollen Grains are key adaptations for life on land
 - Advantages of reduced gametophytes
 - The tiny gametophytes (microscopic in many seed bearing vascular plants) can develop within the sporangia of the parental sporophyte, sheltering it from environmental stresses, such as desiccation, UV radiation, and nutrient needs.
 - Heterospory: the rule among seed plants

- While many seedless vascular plants are Homosporous, seed plants are Heterosporous
 - They produce two kinds of spores,
 - Megasporangia; producing a single (female) megaspore
 - Microsporangia; producing many (male) microspores
 - Ovules and production of eggs
 - Seed plants are unique in keeping the megasporangium within the parent sporophyte
 - Integument; a layer of sporophyte tissue that envelops and protects the megasporangium.
 - Gymnosperms only have one integument, while angiosperms have two
 - The whole structure is called an ovule (megaspore, megasporangium, and integument(s))
 - Pollen and production of sperm
 - A microspore develops into a pollen grain, which is a male gametophyte enclosed within a pollen wall
 - Pollination; transfer of pollen to the part of a seed plant that contains ovules
 - Eliminates need for water for sperm transport to egg
 - Once a pollen grain germinates, it chews its way to the female gametophyte creating a pollen tube within which it will discharge sperm
 - Useful because it allows the plants to travel long distances before growing
 - Micropyle – top of the integument, where the pollen enters and later, for germination, where the water enters
 - The evolutionary advantage of seeds
 - Spores used to be the only protective life stage, but are single celled, and cannot survive as long as seeds
 - Seeds can last years after being released
 - Have their own supply of food
 - Can be widely dispersed by animals
- Gymnosperms bear ‘naked’ seeds, typically in cones
 - Gymnosperm evolution
 - Progymnosperms; In the late Devonian period-transitional species of seedless vascular plants that were Heterosporous
 - Started about 305 million years ago during the late carboniferous period, when it became drier
 - Conifers – cone bearing gymnosperms, such as spruce, pine, fir, redwoods
 - Four gymnosperms
 - Phylum Cycadophyta
 - Palm like leaves, and huge cones, very little species today because it takes so much energy to produce their massive cones
 - Phylum Ginkophyta
 - Ginkgo Biloba the only surviving species
 - Leaves and fleshy seeds
 - Phylum Gnetophyta
 - Three genera (tropical or desert)
 - Gnetum
 - Ephedra

- Why double fertilization? Perhaps a way for a plant to prevent squandering nutrients on infertile ovules
 - Angiosperm Diversity
 - One clade; (although DNA suggests monocots are a different clade)
 - Eudicots
 - More than 2/3 of all angiosperms, ~170,000 species
 - Two cotyledons
 - Netlike venation
 - Vascular tissue arranged in rings
 - Taproot normally present
 - Pollen grain with three openings
 - Floral organs in multiples of 4 or 5
 - Monocots
 - 1/4 of angiosperms are monocots ~ 70,000 species
 - Single cotyledon
 - Parallel veins
 - Scattered vascular tissue
 - Fibrous root system
 - 1 opening on the pollen grain
 - Floral organs usually in multiples of 3
 - Can have symmetry in one direction (bilateral symmetry) or in all directions (radial symmetry) which each have their own advantages (radial has more species)
 - Basal angiosperms are less derived and include the flowering plants belonging to the oldest lineages
 - 100 species
 - Like Amborella, star anise, water lilies
 - Magnoliids share some traits with basal angiosperms, but developed later, closer to monocots and eudicots than basal angiosperms
 - Animals affect plant speciation, and vice versa

CHAPTER 35

- Overview;
 - Plant growth is linked to its growing environment, and it is highly adaptable.
 - Degree day:
 - The difference between the daily mean temperature and some base temperature.
 - Degree days are summed
 - Phenological events (breaking buds, flowering, fruit ripening) are often triggered when a critical sum is exceeded, i.e. the sum of the degree days hit a certain number.
- 35.1 – Plants have a hierarchical organization consisting of organs, tissues, and cells
 - Intro
 - Tissue;

- Group of cells consisting of one or more cell types, that together perform a specialized function
 - Organ;
 - Several types of tissues that carry out particular functions
- Three basic plant organs: Roots, Stems, and Leaves
 - Root system and shoot system all to be able to get underground water and nutrients, and above ground CO₂ and light, both depend on each other for survival.
 - Roots
 - Organ that anchors plant, absorbs minerals and water and often stores carbohydrates
 - Eudicots and gymnosperms;
 - often have a taproot system, which develops from the embryonic root
 - Taproot gives rise to lateral roots
 - Taproot good for deep soils, where water is deep.
 - Monocots
 - Form adventitious roots; roots emerging from the stem
 - The taproot dies during the embryonic stage
 - Each small root forms its own lateral roots, giving rise to a fibrous root system
 - Good for light rainfall, and soils where water does not penetrate too deeply
 - Root hairs emerge from all roots in increase surface area
 - This tubular extension of a root epidermal cell (not an organ)
 - Many different adaptations of roots, for anchoring, or storing starches
 - Stems
 - Organ that raises and/or separates the leaves, giving them access to sunlight, and raise reproductive structures, facilitating pollination
 - Consists of alternating system of nodes and internodes
 - Node: point at which leaves are attached
 - Internodes; the stem segment between nodes
 - Where the leaf stem meets the main stem, and axillary bud is formed,
 - Axillary bud; structure that can form a lateral shoot (branch).
Young buds grow slowly
 - Apical bud
 - Tip of shoot
 - Composed of developing leaves and a compact series of nodes and internodes
 - Apical dominance
 - The apical bud produces a hormone restricting all other axillary buds, but when the apical bud is destroyed, axillary buds break dormancy, and give rise to a lateral shoot, with its own leaves, axillary buds, and apical bud.
 - Some stems have different functions such as food storage and asexual reproduction

- Rhizomes
 - Horizontal shoot that grows beneath the surface, with vertical shoots later emerging from axillary buds on the rhizome.
- Bulbs
 - Underground shoot consisting of enlarged bases of leaves that store food. (onions)
- Stolons
 - Horizontal shoots that grow along the surface (asexual reproduction, like poison ivy)
- Tubers
 - Enlarged ends of rhizomes or stolons, specialized for storing food (potatoes)
- Leaves
 - Main photosynthetic organ, although stem also photosynthesizes
 - Extensive variation, but generally a flattened blade, and a stalk, and the petiole that is the extension of the stalk that joins the leaf to the stem
 - Difference in venation between monocots and eudicots
 - Monocot = parallel
 - Eudicot = branched
 - Simple leaf
 - Single undivided blade, sometimes deeply lobed
 - Compound leaf
 - Blade consists of multiple leaflets, but no axillary bud at the base of each leaflet
 - Doubly compound leaf
 - Each leaflet is further divided into smaller leaflets
 - Many adaptations
 - Tendrils, spines, storage, reproduction, bracts (pollinator attractant)
- Dermal, vascular, and ground tissues
 - Each forms a tissue system
 - Dermal
 - First line of defense against physical damage and pathogens
 - Epidermis (tightly packed) in herbaceous, cuticle on leaves and stems
 - Periderm on woody plants
 - Trichomes
 - Hair-like growths out of shoot epidermis, reducing water loss, deflecting light, and providing insect defense
 - Vascular
 - Xylem and Phloem
 - Xylem carries water and dissolved minerals
 - Phloem transports sugars
 - Vascular tissue of a root or stem called the stele
 - Stele arrangement varies on species and organ. (monocots and dicot variations)

- Ground tissue system
 - Neither vascular or dermal; everything else
 - Photosynthesis, storage, support
 - If inside vascular tissue, called pith, if outside, cortex
 - Common types of plant cells
 - Parenchyma
 - Thin and flexible primary walls
 - Lack secondary walls
 - Least specialized
 - Perform most metabolic functions –photosynthesis, storage of photosynthates
 - Retain ability to divide and differentiate
 - Collenchyma
 - Generally elongated cells grouped in strands and help support young parts of plant shoot
 - Have thicker and uneven cell walls
 - lack secondary walls
 - Provide flexible support without restraining growth
 - Usually found just below the epidermis
 - Sclerenchyma
 - Rigid due to thick secondary walls strengthened with lignin
 - Lignin is absent in bryophytes
 - Dead at functional maturity
 - Two types:
 - Sclereids short and irregular with thick lignified secondary walls. Found in nutshells and seed coats
 - Fibres long and slender and arranged in threads
 - Water-Conducting Cells of the Xylem
 - Two types; both tubular, elongated and dead at maturity.
 - Tracheids found in the xylem of all vascular plants.
 - Vessel elements almost exclusive to angiosperms
 - Secondary cell walls interrupted by pits. Secondary walls are lignified.
 - Sugar-Conducting Cells of the Phloem
 - Sieve-tube elements alive at functional maturity, though they lack organelles.
 - Each sieve-tube element has a companion cell whose nucleus and ribosomes serve both cells
 - Sieve plates- porous end walls that allow fluid to flow between cells along the sieve tube
- 35.2 Different Meristems generate new cells for primary and secondary growth
 - Plant grows through its life (indeterminate growth)
 - Meristems are perpetually dividing unspecialized tissues that divide when conditions permit
 - A mature plant has embryonic, mature, and developing tissue
 - Determinate growth applies to leaves, flowers, and thorns
 - Meristems are perpetually embryonic

- Apical meristems, located at the end of shoots and roots, provide cells that allow growth in length (primary growth), responsible for almost all of the plant growth in herbaceous species
 - Lateral meristems allow woody species to grow laterally, known as secondary growth.
 - Vascular cambium
 - Adds layers of vascular tissue called secondary xylem and secondary phloem
 - Cork Cambium
 - Replaces the epidermis with thick, tougher periderm
 - Meristems develop into
 - Initials – essentially cells that are still meristem
 - Derivatives – cells that are specialized
- 35.3 Primary growth lengthens roots and shoots
 - Primary growth of roots
 - Root cap
 - Covers the root tip, protecting the delicate apical meristem, and producing a polysaccharide slime that lubricates the soil around the tip of the root.
 - Three overlapping zones of primary growth
 - Cell division at the tip
 - Root apical meristem and its derivatives, producing new cells
 - Elongation zone of the cells follows
 - A few mm behind the tip, pushing the cell division zone into the soil
 - Finally the last zone is the zone of differentiation
 - Cells mature and start specializing in structure and function
 - Eudicot roots produce a star of xylem, and the phloem fills the gaps in the arms of the cross/star
 - Monocot roots the core consists of unspecialized parenchyma cells surrounded by a ring of alternating xylem and phloem tissue
 - The ground tissue, mostly parenchyma cells, is found in the cortex (between the vascular cylinder and the epidermis)
 - In addition to storing carbohydrates, cortical (cortex) cells transport water and salts from the root hairs to the center of the root
 - The cortex, because of its large intercellular spaces, allows for extracellular diffusion of water, minerals, and oxygen from the root hairs, inward
 - Endodermis is the innermost layer of cortex, one cell thick forming the boundary with the vascular cylinder. It is a selective barrier.
 - Lateral roots arise from meristematically active regions of the pericycle (outermost cell layer in the vascular cylinder, just inside the endodermis), which can destructively push through the cortex and epidermis.
 - Only happens if soil nutrient levels are acceptable, as sensed by the root hairs.
 - Primary growth of shoots
 - Shoot apical meristem is a dome shaped mass of dividing cells at the shoot tip.

- Leaf primordia, are what leaves develop from. They are projections shaped like a cow's horn that emerge along the sides of the apical meristem.
 - The shoot elongates due to lengthening of internode cells below the shoot tip
 - Branching occurs from activation of axillary buds
 - Tissue organization of stems
 - Eudicot
 - Vascular tissue of stems consists of vascular bundles arranged in a ring.
 - Xylem next to pith, and the phloem is next to cortex
 - Monocot
 - Vascular bundles are scattered throughout the ground tissue
 - Ground tissue consists mainly of parenchyma cells
 - Collenchyma cells beneath the surface strengthen stems during primary growth.
 - Sclerenchyma cells support the parts of the stems that have stopped elongating.
 - Tissue organization of leaves
 - Epidermis interrupted by pores called stomata (gas exchange)
 - Stomatal complex is a pore flanked by two guard cells which regulate the opening and closing of the pores
 - Mesophyll is the leaf's ground tissue
 - Mainly parenchyma cells that are specialized for photosynthesis
 - Eudicots (2 layers of mesophyll)
 - Palisade in the upper part of the leaf
 - Spongy in the lower part of the leaf
 - Loose arrangement allows gas exchange
 - Veins subdivide repeatedly in the leaves, bringing the xylem and phloem in close contact with the mesophyll.
 - Each vein covered in sheath of normally parenchyma cells
- 35.4 Secondary growth increases the diameter of stems and roots in woody plants
 - Overviews
 - Stems and roots, but rarely leaves, and almost always woody plants
 - Secondary growth tissues produced by
 - Vascular cambium
 - Increases vascular flow and provides structural support
 - Cambium cork
 - Protects from pathogens and water loss.
 - Gymnosperms and eudicots, but not dicots
 - The vascular cambium and secondary vascular tissue
 - In typical stem, a single cell thick cylinder of meristematic cells, located outside pith and primary xylem, but inside primary phloem and cortex, developing from undifferentiated parenchyma cells
 - In typical woody root, forms to the exterior of the primary xylem and interior of the primary phloem and pericycle
 - Elongated initials (initials that are elongated and oriented with their long axis parallel to the axis of the stem) produce

- Tracheids, vessel elements and fibres of xylem,
 - sieve-tube elements, companion cells, and fibres of the phloem
 - axially oriented parenchyma
 - Shorter initials (initials that are elongated and oriented with their long axis perpendicular to the axis of the stem) produce
 - Vascular rays –radial files of parenchyma cells that connect secondary xylem and phloem. These allow transport of substances between xylem and phloem cells.
 - Difference in thickness in secondary xylem walls due to seasonal changes in plant growth requirements produces tree rings
 - Early wood (spring) – thin cell walls to maximize water flow
 - Late wood (fall) – thick walls for support
 - Tree ring - where the two above woods meet
 - Older wood (heartwood – made of secondary xylem) no longer transport, while younger wood (sapwood) still does
 - Secondary phloem sloughs off, and does not accumulate
- Cork Cambium and the production of Periderm
 - Periderm is comprised of cork cambium, which in turn is made of
 - Phelloderm (cork parenchyma) - thin layer of parenchyma cells that forms interior of cork cambium.
 - Cork cells that accumulate exterior of cork cambium, deposit waxy suberin in their walls and then die.
 - Bark
 - All tissues external to the vascular cambium (secondary phloem and periderm)
 - Lenticels
 - Cells in periderm that allow for gas exchange between living stem or root cells and outside air
- 35.5 Growth, morphogenesis, and cell differentiation produce the plant body
 - Overview
 - Development is the when cells form tissues, organs and organisms. It happens as per the genetic information that is inherited
 - Developmental plasticity describes how plants can alter themselves in response to their local environment
 - Steps of development
 - Growth – irreversible increase in size
 - Morphogenesis – process that gives tissue, organ, and organism its shape and determines the positions of cell types
 - Cell differentiation – process by which the cells with the same genes become different from one another
 - Model organisms; revolutionizing the study of plants
 - Arabidopsis thaliana research gave much more insight into plant lives
 - First plant to have genome sequences (27000 genes, 5 chromosomes)
 - Easily transformed by foreign DNA via genetically altered bacteria
 - Provides insight into plant development, aim to discover the blueprints for plant development

- Growth: Cell Division and cell expansion
 - Cell division enhances the potential for growth by increasing the number of cells
 - Plant growth is brought about by cell enlargement
 - The plane and symmetry of cell division
 - Leaf growth results from combination of transverse divisions (for leaf elongation) and longitudinal cell divisions (for leaf broadening)
 - The symmetry of cell division (distribution of cytoplasm between daughter cells which determines cell fate)
 - Asymmetrical cell division signals a key event in development
 - Formation of guard cells involves asymmetrical cell division and a change in the plane of cell division
 - Polarity- condition of having structural or chemical differences at opposite ends of an organism (root end and shoot end) critical to the plant's morphogenesis
 - Asymmetrical cell divisions play a role in establishing polarity
 - First division of plant zygote normally asymmetrical and initiates polarization into the shoot and root
 - The *gnom* mutant of Arabidopsis results from a symmetrical first division
 - Orientation of cell expansion
 - Water uptake accounts for most of cells' expansion, and water is stored in the large central vacuole, (cheap way of filling space in the plant, allowing rapid and economical growth)
 - Greatest expansion is oriented along the plant's main axis
 - Orientation of cellulose microfibrils in the innermost layers of the cell wall cause the cell to expand mainly perpendicular to their main orientation, as they do not stretch
- Morphogenesis and pattern formation
 - Pattern formation - The development of specific structures in specific locations/
 - Two hypothesis for determining the fate of plant cells during formation
 - Lineage-based mechanisms propose cell fate is determined early in development and passed on to progeny (basic pattern is mapped according to the directions in which meristematic cells divide and expand.
 - Position-based mechanisms propose that cell fate determined by final position
 - Hox (homeotic) genes in animals affect number and placement of appendages in embryos (legs, antennae, etc.)
 - In maize, homolog of Hox genes called KNOTTED-1
 - Does not affect the placement of plant organs,
 - Affects development of leaf morphology, including the production of compound leaves
- Gene expression and the control of cell differentiation
 - Cells of a developing organism synthesize different proteins and diverge in structure and function even though all have common genome
 - Cell differentiation depends on the control of gene expression

- Control of gene activation, and positional information is largely from cell to cell communication
 - Arabidopsis root epidermis forms root hairs or hairless cells depending on the number of cortical cells it is touching
- Shifts in development: Phase Changes
 - Plant developmental stages (phases) occur within a single region (apical meristem)
 - Phase changes; morphological changes that arise in the shoot apical meristem.
 - Juvenile to adult phases,
 - Most obvious in the leaf morphology
- Genetic control of flowering
 - A phase change from vegetative to reproductive growth triggered by a combo of environmental cues and internal signals
 - Determinate growth (usually)
 - Involves activation of floral meristem identity genes
 - The order of each primordium's emergence determines its development into a specific type of floral organ (sepal, petal, stamen, carpel)
 - Organ identity genes, dictating the development of the characteristic floral pattern, belonging to the MADS-box family
 - A mutation can cause abnormal floral development, such as petals instead of stamens
 - ABC Hypothesis
 - Three classes of floral organ identity genes
 - A
 - Genes active to the two outer whorls - Sepals and petals
 - B
 - Gene active on the two middle whorls - Petals and stamens
 - C
 - Gene active for the two inner whorls – stamens and carpels

Chapter 36

- Overview
 - Adaptations for resource acquisition despite environment are key to plant survival.
 - Resources have to be transported through various mechanisms, within the plant
- 36.1 – Adaptations for acquiring resources were key steps in the evolution of vascular plants
 - Adaptations above and below ground
 - Natural selection favoured;
 - Taller plants (taller than competition)
 - Plants with broad flat appendages (maximize photosynthesis)
 - Efficient long distance transport (of water, minerals, photosynthesis products)
 - Compromise between enhanced photosynthesis and minimizing water loss
 - Positive Correlation between water availability and leaf size
 - Shoot architecture and light capture
 - Phyllotaxy – arrangement of leaves on a stem, determined by the shoot apical meristem, and is specific to each species

- Most angiosperms have alternate phyllotaxy, with the leaves arranged in an ascending spiral around the stem.
- Golden angle – 137.6 degrees; to minimize shading of lower leaves by those above.
- Leaf area Index (LAI) – ratio of the total upper leaf surface area of a single plant or an entire crop divided by the surface area of the land on which the plant or crop grows (up to 7 is common for mature plants)
 - $LAI = \text{Total leaf area (m}^2\text{)} / \text{total ground area (m}^2\text{)}$.
 - Similarly using fish-eye photography: LAI is approximated by = area occupied by canopy (m²)/area of visible sky (m²) (dimensionless)
- Self-pruning – leaves under the upper canopy that are limited in light, and respire more than photosynthesize experience cell death, essentially self-pruning
- Leaf orientation affecting light capture
 - Low light – horizontal leaves capture sunlight more effectively than horizontal ones
 - Sunny regions, grasslands – horizontal orientation reduces the light hitting each leaf, light // to leaf surfaces, so no leaf receives too much, and light penetrates more deeply to lower leaves
- Root architecture and Acquisition of water and Minerals
 - Root growth can adjust to local conditions
 - For example, roots branch more in a pocket of high nitrate NO₃⁻ than low nitrate
 - Roots are less competitive with other roots from same plant than with roots from different plants
 - Root cells also respond by producing more proteins for more efficient uptake of nitrate across plasma membrane
 - Roots and the hyphae of soil fungi form mutualistic associations called mycorrhizae
 - Mycorrhizal fungi increase surface area for absorbing water and minerals, especially phosphate
- 36.2 Different mechanisms transport substances over short or long distances
 - The apoplast and symplast; transport continuums
 - Apoplast – consists of everything external to the plasma membranes of living cells and includes cell walls, extracellular spaces, and the interior of dead cells such as vessel elements and tracheids
 - Symplast – the entire mass of cytosol of all the living cells in a plant, as well as the plasmodesmata & the cytoplasmic channels that connect them
 - Three transport routes
 - Apoplastic
 - Water and solutes move along the continuum of cell walls and extracellular places
 - Symplastic
 - Water and solutes move along the continuum of cytosol, requiring substances to cross a plasma membrane once while entering the plant
 - Transmembrane route

- Water and solutes move out of one cell, across the next cell wall, and into the neighbouring cell, which may pass them to the next cell in the same route; repeated crossing of plasma membranes
- Not mutually exclusive, and some use more than one route to varying degrees
- Short distance transport of solutes across plasma membranes
 - Plasma membrane permeability controls short-distance movement of substances. (active and passive transport)
 - Membrane potential happens by pumping of H^+ ions in order to establish an electrochemical gradient
 - H^+ ions play the primary role in basic transport, instead of Na^+ in animals
 - Plant cells use energy of H^+ gradients to cotransport solutes and ions by active transport
 - Plant cells also have selective transport (ion channels that only allow certain ions to pass, mostly gated, responding to chemical, pressure, or voltage stimuli)
- Short distance transport of water across plasma membranes
 - To survive, plants must balance water uptake and loss
 - Net uptake/loss Occurs by osmosis (diffusion of free water that is not bound to solutes or surfaces, across a membrane)
 - Water potential – physical property that predicts direction in which water will flow, based on effects of solute concentration and physical pressure (high Potential to low potential)(potential being capacity to do work)
 - Water potential abbreviated as Ψ and measured in a unit of pressure called the mega Pascal (MPa)
 - $\Psi = 0$ MPa for pure water at sea level and at room temperature
 - $\Psi = 0.5$ MPa normally for plants
 - Both pressure and solute concentration affect water potential
 - Expressed as: $\Psi = \Psi_s + \Psi_p$
 - Solute potential (osmotic potential) (Ψ_s) of a solution directly proportional to its molarity. (the higher the amount of solute, the more bonded molecules there are, and therefore the less free molecules available to do work. Normally negative, as solute increases, Ψ_s decreases.
 - Pressure potential (Ψ_p) - physical pressure on a solution
 - Can be positive or negative , depending on the force exerted (sucking or pushing of water)
 - Turgor pressure – in living cells, the pressure exerted by plasma membrane against cell wall, and cell wall against protoplast (living part of cell, including the Plasma membrane). Critical for plant function as it helps to maintain stiffness of plant tissues, and serves as driving force for cell elongation
 - Water in hollow nonliving xylem cells is often under negative pressure of less than -2MPa
- Water Movement across plant cell membranes

- Water potential affects uptake and loss of water by plant cells
 - A flaccid cell placed in environment with a higher solute concentration, cell will lose water and undergo plasmolysis (protoplast shrinks and pulls away from cell wall, essentially a cell placed in a hypertonic solution – the solution has more solute and the water flows out)
 - Turgid - If a flaccid cell is placed in a solution with a lower solute concentration, the cell will gain water and become turgid
 - Wilting - Turgor loss in plants causes wilting, which can be reversed when plant watered
 - Aquaporins transport proteins in cell membrane that allow passage of water affecting rate of water movement across the membrane
- Summary
 - What can affect osmosis in plants?
 - proton pumps in the membrane,
 - a difference in solute concentrations,
 - aquaporins
 - difference in water potential
- 36.3 Transpiration drives the transport of water and minerals from roots to shoots via the xylem
 - Resource Acquisition and Transport in Vascular Plants
 - Adaptations for acquiring resources were key steps in evolution of vascular plants
 - Different mechanisms transport substances over short or long distances
 - Transpiration drives the transport of water and minerals from roots to shoots via the xylem
 - The rate of transpiration is regulated by stomata
 - Sugars are transported from sources to sinks via the phloem
 - The symplast is highly dynamic
 - Overview
 - Plants can move a large volume of water from their roots to shoots
 - Most water and mineral absorption occurs near root tips, where root hairs located and epidermis permeable to water
 - Absorption of water and minerals by root cells
 - Epidermal cells are water permeable
 - Root hairs account for much of the surface area of roots
 - After soil solution enters roots, it is transported through the extracellular spaces in the cortex which enhances the exposure of cortical cell membranes to the solution, ultimately creating a much greater membrane surface area, which in turn enhances uptake of water and selected minerals
 - Concentration of essential minerals greater in roots than soil because of active transport
 - Transport of water and minerals into the xylem
 - Endodermis is innermost layer of cells in the root cortex
 - Apoplastic barrier between the vascular cylinder and cortex. Last checkpoint for selective passage of minerals from cortex into vascular tissue

- Casparian strip of endodermal wall blocks apoplastic transfer of minerals from cortex to vascular cylinder
 - Casparian strip lined with suberin –a waxy material impervious to water and dissolved minerals
 - From symplast to apoplast: Endodermis is the gate keeper.
 - Water and minerals move from protoplasts of endodermal cells into their cell walls through.
 - Diffusion and active transport involved in this movement Water and minerals now enter tracheids and vessel elements
 - Bulk Flow transport via the xylem
 - Xylem sap, water and dissolved minerals, transported from roots to leaves by bulk flow
 - Transport of xylem sap involves transpiration, evaporation of water from plant's surface
 - Transpired water replaced as water travels up from roots
 - Is sap pushed up from the roots, or pulled up by the leaves? Both.
 - Pushing xylem sap; root pressure
 - At night no transpiration, but root cells continue actively pumping mineral ions into xylem of vascular cylinder,
 - Casparian strip prevents water loss into endodermis, cortex and soil.
 - With the mineral concentration in vascular cylinder is high we have a low water potential within vascular cylinder
 - Water flows into the vascular cylinder from the root cortex, generating root pressure...
 - ...Resulting in guttation, the exudation of water droplets that can be seen in the morning on the tips or edges of some plant leaves
 - For the most part xylem sap is not pushed up from the roots, but it is pulled up by transpiration
 - Pulling xylem sap; The Cohesion-Tension hypothesis
 - transpiration provides the pull for the ascent of xylem sap, and the cohesion of water molecules transmits this pull along the entire length of the xylem from shoots to roots
 - To explain bulk flow we have the cohesion-tension hypothesis,
 - Transpiration provides the pull for the ascent
 - Cohesion of water molecules transmits this pull along the entire length of the plant.
 - Xylem sap normally under negative pressure, or tension
 - Transpirational pull
 - Water vapour in airspaces of a leaf diffuses down its water potential gradient and exits leaf via stomata
 - As water evaporates, air-water interface retreats further into mesophyll cell walls
 - Surface tension of water creates a negative pressure potential
 - Negative pressure pulls water in the xylem into the leaf. Transpirational pull on xylem sap transmitted from leaves to roots. Water molecules

- Light
 - CO₂ depletion
 - An internal “clock” in guard cells
 - All eukaryotic organisms have internal clocks; circadian rhythms- 24-hour cycle
- Drought, high temperature, and wind can cause stomata to close during the daytime
 - Hormone abscisic acid produced in response to water deficiency and causes closure of stomata
 - Transpiration also results in evaporative cooling (lowering temp in leaf)
 - Prevents denaturation of various enzymes involved in photosynthesis and other metabolic processes
 - Plants adapted to arid environments are called xerophytes
 - Crassulacean acid metabolism (CAM), a specialized form of photosynthesis found in succulents of the family Crassulaceae and several other families – allowing for intake of CO₂ at night and therefore their stomata can remain closed during the day
- 36.5: Sugars are transported from sources to sinks via the phloem
 - The products of photosynthesis transported through phloem by process of translocation
 - Phloem sap - an aqueous solution high in sucrose (sugar – product of photosynthesis)
 - Sucrose travels from sugar source to sugar sink
 - Sugar source an organ that is a net producer of sugar (mature leaves)
 - Sugar sink an organ that is a net consumer or store of sugar, such as a tuber or bulb, or fruit, or young leaves
 - Movement from Sugar Sources to Sugar Sinks
 - A storage organ can be both a sugar sink in summer and sugar source in winter
 - Sugar must be loaded into sieve-tube elements before being exported to sinks, often by active transport (thanks to companion cells which enhance solute movement between apoplast and symplast)
 - Depending on the species, sugar may move by symplastic or both symplastic and apoplastic pathways
 - Flow is towards the sink; sometimes adjacent sieve tubes will have flow in opposite directions, depending on which sink they were created to feed.
 - Bulk Flow by Positive Pressure: The Mechanism of Translocation in Angiosperms
 - Phloem sap moves through a sieve tube by bulk flow driven by positive pressure called pressure flow, a hypothesis explains why phloem sap always flows from source to sink
 - The concentration of sugar gradient is the driver in this hypothesis
 - Experiments have built a strong case for pressure flow as mechanism of translocation in angiosperms
 - Self-thinning is the dropping of sugar sinks such as flowers, seeds, or fruits
- 36.6: The symplast is highly dynamic
 - overview
 - The symplast is a living tissue it is responsible for changes in plant transport processes, which can be triggered by many things, such as changes growth stages, environmental stresses, etc.
 - Changes in Plasmodesmatal number and pore size

- Can form during cytokinesis, or much later,
- Open and closes rapidly in response to turgor pressure, Ca^{2+} levels, or cytosolic pH
- Variable pore size - plasmodesmata can dilate in response to viral movement proteins enabling viral RNA to pass. Plant cell communication also regulate plasmodesmata pore size.
- Symplastic domains - a high degree of cytosolic interconnectedness existing only within certain groups of cells and tissues, exchanging informational molecules such as proteins and RNAs which serve to coordinate developmental cells with each domain.
- Phloem: An information superhighway
 - Phloem transports macromolecules and viruses, since the transport system is systemic, it can affect many/all of the plants organs, signaling things like infection defense, or flower growth
- Electrical signaling in the Phloem
 - Phloem, in some plants, can serve a nerve-like function; sending 'rapid' electrical signals in response to stimuli that affect another part of the plant.

CHAPTER 37

- What is nutrition?
 - Nutrition is the study of how organisms acquire food and use food to support all the processes required for their existence.
 - Nutrition is the study of the composition of nutrients and how the body uses them.
 - We will look at plant nutrition today and animal nutrition in a few weeks. Keep in mind the similarities and differences.
- 37.1 – Soil contains a living, complex ecosystem
 - Plants obtain most of their water and minerals from the upper layers of soil
 - This upper layer contains living microorganisms that can take centuries to form but can be destroyed in just a few years of mismanagement
 - To understand plant nutrition we begin with soil texture and composition
 - Soil texture
 - Soil particles are classified by size; from largest (coarse sand) to smallest (microscopic clay particles).
 - Soil particles are either sand, silt, or clay
 - Different sized particles are from the weathering of rocks. Two types of weathering
 - Mechanical fracturing
 - Water freezing in rock crevices
 - Root growth inside rock crevices
 - Chemical fracturing
 - Weak acids in soil break up rocks
 - Root roots secrete weak acids
 - Mineral particles then mix with microorganisms and humus to create topsoil
 - Soil is stratified into soil horizons
 - Topsoil consists of mineral particles, living organisms, and humus, (decaying organic material).
 - Canadian terminology for surface layers where leaf litter dominates (LHF)

- The litter layer (L) is crucial when predicting the % of seeds of a given species that will survive. A small seed in deep litter has very little chance
 - Fermentation Layer
 - Humidification layer
 - Ah Humus layer
- Argument about the crucial role of germinant length: imagine there is only one layer of leaves. . . Germinant needs water AND light
 - 2 cases
 - Seed under leaf (water is no problem but light can be)
 - Seed on top of leaf (light is no problem but water can be)
 - Large germinant is better in both cases
 - The length of the germinant is crucial
 - It determines whether the hypocotyls can push dried leaves out of the way or remain in darkness.
 - It determines whether the radicle can reach down to where the soil is still damp during a seven day period without rain, or conversely the too-short germinant desiccates for lack of moisture.
 - Plants are nourished by the soil solution.
 - Soil solution consists of water and dissolved minerals in the pores between soil particles.
 - Pores also contain air pockets
 - After a heavy rainfall, water drains from the larger spaces in the soil
 - Smaller spaces retain water because of its attraction to clay and other particles
 - Film of loosely bound water usually available to plants
- Texture
 - Loams are the most fertile topsoil and contain “roughly” equal amounts of sand, silt and clay (but note slightly less clay)
 - Sand is very coarse thus large air spaces. Efficient diffusion of oxygen to roots but sand does not bind water. After rainfall most of the water is lost. Great oxygenation, but no water. Roots dry up and die.
 - Clay is too fine and small air spaces. Clay binds to water tightly. After rainfall soil because waterlogged (flooded). Great access to water, but not oxygen. Roots suffocate.
 - Water-logging effects. The more saturated the soil, the less O₂ available for the plant roots.
- Topsoil Composition
 - A soil’s composition refers to its inorganic (mineral) and organic chemical components
 - Inorganic components
 - Cations (for example K⁺, Ca²⁺, Mg²⁺) adhere to negatively charged soil particles

- Organic soil particles prevents cations from leaching out of the soil through the percolation of water through the soil and into the groundwater
 - Minerals bound to soil particles are not available to plant roots.
 - Only minerals in the soil solution are available. Minerals are made available through cation exchange.
 - During cation exchange, cations displaced from soil particles by other cations. Displaced cations enter the soil solution and can be taken up by plant roots
 - Negatively charged ions (anions) (NO_3^- , H_2PO_4^- and SO_4^{2-}) do not bind to soil particles and are therefore easily lost to the groundwater through leaching after a large rainfall or over-irrigation.
 - Organic Components
 - Humus builds a crumbly soil that retains water but is still porous. Prevents clay from clumping together.
 - Increases soil's capacity to exchange cations and serves as a reservoir of mineral nutrients
 - Topsoil contains bacteria, fungi, algae, other protists, insects, earthworms, nematodes, and plant roots. They help to decompose organic material and mix the soil
- Soil conservation and sustainable agriculture
 - Soil management, by fertilization and other practices, allowed for agriculture and cities
 - In contrast with natural ecosystems, agriculture
 - depletes mineral content of soil
 - taxes water reserves
 - encourages erosion
 - American Dust Bowl of 1930s resulted from soil mismanagement (overuse of soil, and removal of grasses holding soil down.
 - Plant obtains water, oxygen and nutrients from the soil in addition soil anchors the plant.
 - At present, 30% of world's farmland has reduced productivity because of soil mismanagement
 - The goal of sustainable agriculture is to use farming methods that conservation-minded, environmentally safe, and profitable.
- Irrigation
 - Irrigation is a huge drain on water resources when used for farming in arid regions
 - For example, 75% of global freshwater use is devoted to agriculture
 - Primary source of irrigation water underground water reserves called aquifers
 - Depletion of aquifers can result in land subsidence, the settling or sinking of land
 - Irrigation can lead to salinization, the concentration of salts in soil as water evaporates, and Salinization makes it hard for plants to take up water from the soil! (recall chapter 36)
- Fertilization

- Soils can become depleted of nutrients as plants and nutrients they contain harvested
 - Fertilization replaces mineral nutrients that have been lost from the soil
 - Commercial fertilizers enriched in nitrogen (N), phosphorus (P), and potassium (K) they are readily available for the plants, but don't stay in the soil long. Leading to the excess minerals often leached from the soil and can cause algal blooms in lakes (killing fish populations)
 - Organic fertilizers composed of manure, fishmeal, or compost and they release N, P, and K as they decompose. Thus much slower release and less loss of nutrients to leaching
 - Adjusting soil pH
 - Most plants prefer slightly acidic soil with a high H^+ concentration that displaces positively charged minerals from soil particles making them readily available
 - If pH is too low toxic aluminium are more soluble and absorbed by roots preventing calcium uptake and stunting root growth
 - Controlling erosion
 - No till agriculture – a special plow creates narrow furrows for seeds and fertilizer
 - Phytoremediation
 - Non-destructive biotechnology that harnesses the ability of some plants to extract soil pollutants and concentrate them in in portions of the plant that can be easily removed for safe disposal.
- 37.2 Plants require essential elements to complete their life cycle
 - Overview
 - 80-90% mass of plants is water
 - 96% of the remaining dry mass is carbohydrates; cellulose and starch produced by photosynthesis. Carbon, hydrogen, and oxygen are the most abundant elements in dry plant residue
 - Inorganic substances only account for 4% of dry plant mass
 - Essential Elements
 - More than 50 chemical elements have been identified among inorganic substances in plants
 - Not all of these essential to plants
 - Only 17 essential elements, chemical elements required for a plant's life cycle
 - 9/17 are macronutrients because plants require them in high amounts, 6 of which are crucial to plant's structure
 - Oxygen, carbon, hydrogen, nitrogen, phosphorous sulfur
 - Potassium, calcium and magnesium not related to structure
 - Nitrogen contributes the most to growth an yields
 - Rest of 17 are micronutrients – only needed in tiny wuantites
 - Chlorine, iron, manganese, boron, zinc, copper, nickel, molybdenum, in some cases sodium
 - Mainly cofactors – non-protein helpers in enzymatic reactions
 - Researchers use hydroponic culture to determine which chemical elements essential
 - Symptoms of mineral deficiency

- Symptoms of mineral deficiency depend on nutrient's function and mobility within plant
 - Deficiency of a mobile nutrient usually affects older organs more than young ones
 - Deficiency of less mobile nutrient usually affects younger organs more than older ones
 - Most common deficiencies are nitrogen, potassium, and phosphorus
 - Improving plant nutrition by genetic modification
 - Plants can be genetically engineered to better fit the soil
 - Resistance to aluminum toxicity (caused by low pH soils. Plants can release organic anions that bind to toxic Al^{3+}) by releasing malic/citric acid
 - Flood tolerance
 - Smart plants
 - “Smart” plants inform farmer of nutrient deficiency before damage occurs
 - Blue tinge on leaves due to a promoter that reacts to lack of phosphorous
- 37.3 Plant nutrition often involves relationships with other organisms
 - Overview
 - Mutualistic relationship between plants and soil bacteria/fungi
 - Dead plants provide energy needed by soil-dwelling microorganisms
 - Secretions from living roots support a wide variety of microbes in the near-root environment
 - Bacteria and Plant nutrition
 - The layer of soil bound to the plant's roots is the rhizosphere
 - The rhizosphere contains bacteria that act as decomposers and nitrogen-fixers
 - Rhizobacteria
 - Free-living rhizobacteria thrive in the rhizosphere, and some can enter roots, occupying intracellular spaces
 - The rhizosphere has high microbial activity because of sugars, amino acids, and organic acids secreted by roots – unique to every micro-ecosystem
 - Rhizobacteria can play several roles
 - Produce hormones that stimulate plant growth
 - Produce antibiotics that protect roots from disease
 - Absorb toxic metals or make nutrients more available to roots
 - Bacteria in the nitrogen cycle
 - Nitrogen can be an important limiting nutrient for plant growth
 - Plants can absorb nitrogen as either NO_3^- or NH_4^+
 - Nitrate and ammonium are not derived from weathering rocks. Most of it comes from microbial action (some from lightening)
 - Most soil nitrogen comes from actions of soil bacteria
 - Ammonia producing bacteria
 - Nitrate producing bacteria
 - Nitrogen-fixing bacteria

- Ectomycorrhizae
 - Hyphae form a network into apoplast or extracellular space, but do not penetrate root cell – form a dense sheath over the surface of the root
 - Thicker, shorter, more branched, typically don't form root hairs
 - 10% of plant species form ectomycorrhizae, majority woody species; pine, spruce, oak, walnut, birch, willow, and eucalyptus
- Arbuscular mycorrhizae
 - Fungal hyphae penetrate cell wall but not plasma membrane to form arbuscules (dense branching after penetrating cell wall but not plasma membrane). Penetrate between epidermal cells and enter the root cortex. (like poking a finger into a balloon
 - Found in over 85% of plant species, most crop plants, including grains and legumes
- Farmers and foresters often inoculate seeds with fungal spores to promote formation of mycorrhizae
- Epiphytes, Parasitic Plants, and Carnivorous Plants
 - Some plants have nutritional adaptations that use other organisms in non-mutualistic ways
 - Three unusual adaptations are;
 - Epiphytes
 - Grows on another plant and obtains water and minerals from rain, mostly through their leaves, do not tap their host for sustenance, only use them for anchorage
 - Parasitic plants
 - Absorb water, sugars, and minerals from their living host plant
 - Roots function as haustoria; nutrient absorbing projections that tap their host plant.
 - Some have no chlorophyll (not photosynthetic), some are photosynthetic, some absorb minerals from hyphae of mycorrhizae associated with other plants
 - Carnivorous plants
 - Carnivorous plants are photosynthetic but obtain nitrogen by killing and digesting mostly insects

CHAPTER 38

- 38.1 - Flowers, double fertilization, and fruits are unique features of the angiosperm life cycle
 - Overview
 - Plant lifecycles characterized by alternation between multicellular haploid (n) generation and multicellular diploid (2n) generation
 - Diploid sporophytes (2n) produce spores (n) by meiosis; these grow (mitotically) into haploid gametophytes (n)
 - Gametophytes produce haploid gametes (n) by mitosis; fertilization of gametes produces a sporophyte
 - Sporophyte is what we see, much more longer lived than gametophytes
 - Tree derived traits of angiosperm reproduction (3Fs)
 - Flowers

- Double Fertilization
 - Fruits
- Flower structure and function
 - Life cycle:
 - 1. In angiosperms, the sporophyte is the dominant generation, the large plant that we see
 - 2. The gametophytes are reduced in size and depend on the sporophyte for nutrients
 - The angiosperm gametophyte is the most reduced of all plants, consisting of just a few cells.
 - 3. The angiosperm life cycle is characterized by “three Fs”: flowers, double fertilization, and fruits. These are the key derived traits of angiosperms.
 - Flowers are reproductive shoots of angiosperm sporophyte; they attach to a part of stem called receptacle
 - Flowers consist of four floral organs: sepals, petals, stamens, and carpels C.S.P.S. (p.s. always at the end)
 - Stamens and carpels reproductive organs; sepals and petals sterile
 - A stamen consists of a filament topped by an anther with pollen sacs (microsporangia) that produce pollen (male?) (staMENs) men->male
 - A carpel has a long style with a generally sticky stigma on which pollen may land
 - At the base of the style is an ovary containing one or more ovules (carpel-pull-hair pulling-female-like a woman from the ovaries up they show STYLE, and there is a STIGMA about what’s above)
 - A single carpel or group of fused carpels is called a pistil
 - Complete flowers contain all four floral organs
 - Incomplete flowers lack one or more floral organs, for example stamens or carpels
 - Clusters of flowers are called inflorescences, like the sunflower, or
 - Floral diversity is largely driven by adaptations to suit pollinators
- The Angiosperm Life Cycle: An Overview
 - Development of female gametophyte (embryo sac)
 - As a carpel develops one or more ovules develop within its ovary (swollen sac at base)
 - The embryo sac formation process begins in the tissue called megasporangium, when two integuments surround it, leaving only a small opening called the micropyle
 - Integuments; (layers of protective sporophytic tissue that will develop into the seed coat)
 - Gametophyte development begins when one cell in the megasporangium (of each ovule), the megaspore mother cell (megasporocyte), enlarges and undergoes meiosis, forming 4 haploid megaspores, of which only 1 survives, while the others degenerate
 - The nucleus of the surviving megaspore divides 3 times by mitosis without cytokinesis (1 cell, 8 haploid nuclei). It then is divided by membranes to form the embryonic sac (the hormone auxin (originating near the micropyle) controls cell fate)

- two cells called synergids flank the egg and help attract and guide the pollen tube to the embryo sac
- Development of Male Gametophytes in Pollen Grains
 - As the stamens are produced each anther develops 4 microsporangia (the pollen sacks), containing many diploid cells, called megaspore mother cell (megasporocytes), each which undergoes meiosis, and forming 4 haploid microspores.
 - Each microspore undergoes meiosis, producing a haploid male gametophyte consisting of only two cells; the generative cell, and the tube cell.
 - The pollen grain consists of
 - Tube cell,
 - Generative cell
 - Spore wall
 - Spore wall produced by both anther and microspore displays a unique elaborate pattern for each species
- Pollination
 - After a microsporangium breaks open and releases the pollen, the transfer of pollen to the stigma is called pollination
 - At time of pollination, if it succeeds, pollen grain produces a pollen tube by absorbing water and germinating. The pollen tube extends towards the ovary, discharging two sperm cells near the embryo sac (generative cell divides by mitosis to produce them)
 - In angiosperms, pollination is the transfer of pollen from an anther to a stigma
- Double fertilization
 - When the two sperm reach the female gametophyte, one sperm fertilizes the egg, creating a zygote. The other sperm fuses with two polar nuclei, to create a triploid nucleus in the center of the large central cell of the female gametophyte, which will eventually give rise to the endosperm (food storing tissue in the seed).
 - Double fertilization ensures that the endosperm is only produced in ovules where the egg has been fertilized
- Seed Development
 - After double fertilization, each ovule develops into a seed
 - The ovary develops into a fruit enclosing the seed(s)
 - Endosperm development usually precedes embryo development
 - In most monocots and some eudicots, endosperm stores nutrients that can be used by seedling
 - In other eudicots, food reserves of the endosperm exported to the cotyledons
- Methods of pollination
 - Pollination can be by wind, water, or animals
 - Coevolution; The joint evolution of two interacting species, each in response to selection imposed by the other.
 - Many species of flowering plants have evolved with specific pollinators
 - Shapes and sizes of flowers often correspond to pollen transporting parts of their animal pollinators

- Adaptations
 - Visual nectar guides
 - Color and shape of petals: The corolla attracts and controls pollinators.
 - Fused petals==corolla tube
 - Stamens hidden therefore the insect must crawl inside for nectar rewards and come in direct contact with anther
 - Post pollination color change
 - Trying to improve the efficiency of pollinators
 - Withdrawing nectar from those flowers that were already pollinated, and then modifying the color so that pollinators can learn to not waste their time;
 - Arrangement of Flowers
 - Clustering many small flowers tightly on an inflorescence. (e.g. the parsley family)
 - The pollinator need not spend so much energy flying.
 - The bulls eye;
 - To get to the nectar a long tongued pollinator must line up its mouth-parts using the style as a sight-line. So, the stigma and anthers are in the animal's face; the pollen will end up on the face.
 - Spathe
 - Landing pad for butterflies and birds
- Animal Pollinators
 - Beetles
 - Magnolia, a typical beetle-pollinated flower. Slow moving (compared to flies); dumb.
 - Find their way (mainly by scent) to relatively unspecialized flowers.
 - Little or no nectar; mainly they want the pollen, or they are eating filaments and styles.
 - Also, they often use flowers as meeting places for sex.
 - Devil's tongue is pollinated by large carrion beetles. The foul odor emitted by this plant is known to make people pass out.
 - Flies
 - Hover flies, bee flies, carrion flies
 - They are after nectar and occasionally pollen.
 - Two basic types of flower:
 - flowers often stinky (vertebrate dung; rotting meat);
 - flowers have sweet scents and copious nectar —e.g. hover flies
 - What a butterfly wants:
 - Sweet smell
 - Lots of nectar
 - Lots of adjacent flowers on an inflorescence
 - Bees and Wasps
 - Adult bees and wasps are more specialized as pollinators than most other insects.
 - Many species feed their larvae exclusively from nectar and pollen—
 - Flowers tend to smell sweetly and have copious nectar production.

- like most insects, they cannot see red, however nectar guides are quite common
- Bats
 - Flowers large (easily seen), robust (so the bat can hold on),
 - typically white (bats are nocturnal); strong odors
 - flowers often appended to a trunk or large branch
 - flowers open at sunset; close at dawn
 - Bats are often pollen and nectar eaters
- Pollen adaptations
 - The outer layer of grain is extremely resistant to chemical attack and decay. Also it is often ornamented
 - Pollen tube usually comes out of a pore or furrow on the grain
 - Pollen ranges from 2.5% to 61% protein content.
 - High protein content more to do with growing pollen tubes rapidly than rewarding pollinators
- Adaptations specific for animal pollinators
 - Compared to wind-pollination animal-pollinated grains are:
 - bigger
 - sticky
 - produced in smaller number by plants
 - The bulls eye;
 - To get to the nectar a long tongued pollinator must line up its mouth-parts using the style as a sight-line. So, the stigma and anthers are in the animal's face; the pollen will end up on the face.
 - Spathe
 - Landing pad for butterflies and birds
- Wind Pollinators (many grasses and trees)
 - Female flowers are surrounded by a husk of green leaves. Protruding from the end of the ear are all the styles from each individual female flower (the "silk"). (like corn hairs)
 - Male plants have hanging anthers
 - Corn silk (hairs) connect to one ovary, that will mature into a kernel if fertilized
 - Unlike grains of animal pollinated plants, these grains are not sticky; instead the stigma is sticky. Also small, inconspicuous flowers; often green or white
 - Silver maple (incomplete flowers)
 - Female: sticky stigmas on long styles
 - Male: long filaments to place the pollen-bearing anthers into the higher speed winds away from the flower
 - Pollen
 - Pollen: wind-pollinated plants have smaller grains (20 to 70 micrometers) than do animal-pollinated plants.
 - □ The former cause more problems for humans than the latter not because of the size difference but because of numbers: wind-pollinated species produce far more grains.

- Breaking of seed dormancy often requires environmental cues, such as temperature or lighting changes
- Several mechanisms can break seed dormancy.
 - Cold treatment (called stratification). Most of our tree species require this treatment. Prevents them from germinating in the fall (a small germinant would never survive the winter)
 - Mechanical treatment. Acids to erode waxes that are plugging the micropyle and hilum. Saltation: skipping along the sand –abrasion causes waxy plugs to fall off.
 - Exposure to light.
 - Fire
- Seed Germination and Seedling Development
 - Germination depends on imbibition, uptake of water due to low water potential of dry seed
 - Radicle (embryonic root) emerges first
 - Next, shoot tip breaks through soil surface
 - Exit point of the radicle is typically:
 - the micropyle (where the pollen tube entered ovule)
 - Or,
 - The hilum (where the vascular bundle has been attached).
 - The emerged plant is called the germinant.
 - Eudicot
 - A hook forms in hypocotyl, and growth pushes hook above ground
 - Light causes the hook to straighten and pull the cotyledons and shoot tip up
 - Monocot
 - In maize and other grasses, which are monocots, the coleoptile (sheath covering the embryonic/young shoot) pushes up through the soil
- Fruit
 - The fruit...
 - develops from the ovary
 - protects enclosed seeds
 - aids in seed dispersal by wind or animals
 - Pericarp: During fruit development, the ovary wall becomes the pericarp, the thickened wall of the fruit
 - A fruit may be classified as
 - Dry if the ovary dries out at maturity
 - Fleshy, if the ovary becomes thick, soft, and sweet at maturity
 - Fruits also classified by their development
 - Simple, single or several fused carpels
 - Aggregate, single flower with multiple separate carpels
 - Multiple, group of flowers called an inflorescence
 - An accessory fruit contains other floral parts in addition to ovaries
 - Simple Fleshy Fruits
 - Come from a single flower
 - Simple fruits develop from a single (or several fused) carpel
 - They may have a single or several ovules (seeds)

- Most fruits are simple fruits
- Further division
 - Berries: pericarp is fleshy, contains one to many seeds
 - Tomatoes blueberries, grapes, kiwi
 - Citrus fruit are modified berries with leathery aromatic and separable rind
 - Squash, watermelon are modified with leathery, rigid, inseparable rind
 - Drupes: stony wall produces around each seed
 - Cherry, peach, plum, almond, pecan
- Simple dry fruits
 - Peas, dandelions
- Aggregate fruits
 - The fruit is formed by several separate carpels of the same flower
 - Each ovary contains a single ovule that will become a seed
- Multiple fruits
 - Develop from a cluster of flowers
 - Individual fruits of the multiple cluster develop from one ovary and some accessory parts of the flower
- Fruit and seed dispersal
 - Fruit dispersal mechanisms include
 - Wind
 - Animals
 - Water
 - Biomechanical models for wind dispersal. What matters in determining the distance traveled?
 - Formula $x = (uz)/(f+w)$
 - z = release height
 - f = terminal velocity: ↓
 - u = horizontal wind speed: ->
 - w = vertical wind speed: ↓↑
 - x = where it lands
 - z = point of departure
 - Other things that matter in wind dispersed seeds. The attachment point to the maternal plant. Attachment zone called the abscission zone becomes increasingly brittle as the relative humidity (RH) drops
 - Abscission Zone develops very slowly in high RH; fast in low RH
 - vascular bundle does not become brittle in high RH
 - Seeds are dispersed with relative humidity is lowest and wind speeds highest.
 - All species show an abscission maximum somewhere between about 1200 and 1500
 - Orientation of the ovule when it opens matters
- Seed Aerodynamics
 - At very small seed masses, no wing or fibers are required.
 - But then the mortality rate is very high for germinants. Barely any endosperm to support grow. Thus plant needs to make millions of these small seeds.

- Intermediate seed sizes
 - Most efficient design... is a planar array of straight fibers. Like the dandelion seed.
 - At somewhat higher masses, the most efficient design is the asymmetric wing. (maple)
 - Dispersal by animals
 - Seeds indigestible but fruit is, so seeds dispersed by excrement of animal
 - Acacia seeds with elaiosome
 - Elaiosome rich in lipids. Great source of nutrition for ants
 - Caching animals.
 - Most seeds are cached underground for subsequent use.
 - Smaller rodents concentrate on the smaller seeds while the squirrels, are mainly after the larger seeds like acorns.
 - Plants hope that the caching animal will die or forget where it cached the seed. Only seeds that are not consumed will survive
 - Missing dispersal agents: do the dispersers of fruits like this still exist?
 - The fruit of the Sausage Tree (*Kigelia pinnata*) from Africa. Not clear what animal disperses this.
 - The 5 kg fruit has a fibrous non-sweet pulp with numerous small seeds.
 - Poor reproductive resource allocation
 - Idiot fruit (100 million years old)
 - Endemic to one area in NE Australia
 - Puts a lot of effort into a large fruit that is toxic to everything except a now extinct bird.
 -
- 38.2 - Flowering plants reproduce sexually, asexually or both
 - Overview
 - Many angiosperm species reproduce both asexually and sexually
 - Sexual reproduction results in offspring that are genetically different from their parents
 - Asexual reproduction results in a clone of genetically identical organisms
 - Asexual reproduction is an extension of indeterminate growth
 - Mechanisms of asexual reproduction
 - Fragmentation is separation of a parent plant into parts that develop into whole plants
 - This is a very common type of asexual reproduction and we will come back to it next week when we discuss plant hormones.
 - Due to the meristem tissue present in the plant and the parenchyma cells that can differentiate into any type of cell needed
 - Many animals can regenerate parts but few can do it when 95% of the biomass has been lost. (Plants are far simpler than animals; they are collections of reiterated parts (root/root hair; shoot/leaf)
 - Asexual reproduction is really common in plants.
 - Another form of asexual reproduction is layering. Lower branches along the ground get covered by mosses. Plants detect change in concentration of gases and start to produce roots. A new shoot emerges as the tip of the branch begins to grow up.
 - Aspen tree reproduces like this

- Asexual stems have an advantage over of sexual stems:
- Asexual stems have:
 - An intact, extensive root system
 - The root system is stocked with starch (a seed only has a starting capital of the carbohydrates stored in the endosperm and cotyledons).
 - The same traits as their parent plants had specific to their environment
- Apomixis is the asexual production of seeds from a diploid cell
 - Diploid cell in the ovule gives rise to the embryo. The ovules mature into seeds.
 - Dandelions are an example
 - This is odd because seed dispersal is usually something we see only in sexual reproduction
 - Biotechnology: Genetically modifying plants to undergo apomixis. Benefit? Seeds contain the entire desirable genome of the maternal plant.
- Advantages and Disadvantages of Asexual Versus Sexual Reproduction
 - Sexual reproduction generates genetic variation that makes evolutionary adaptation possible
 - However, only fraction of seedlings survive
 - Some flowers can self-fertilize to ensure every ovule will develop into a seed
 - Many species evolved mechanisms to prevent self-fertilization
- Mechanisms That Prevent Self-Fertilization
 - Many angiosperms have mechanisms that make it difficult or impossible for a flower to self-fertilize
 - Dioecious species have staminate and carpellate flowers on separate plants
 - Staminate: flowers lacking carpels, only have stamens
 - Carpellate: flowers lacking stamens, only have carpels
 - Others have stamens and carpels that mature at different times or are arranged to prevent self-fertilization
 - Most common is self-incompatibility, plant's ability to reject its own pollen
 - Genes for self-incompatibility called S-genes
 - In a population there can be dozens of alleles for the S-gene
 - Self-incompatibility results when pollen and stigma recognize each other as genetically related and pollen tube growth is blocked.
 - Recognition of self's pollen triggers a signal through a transduction pathway leading to a blocking of pollen tube growth
- Totipotent: Any cell in a multicellular organism that can divide and asexually generate a clone of the original organism.
- Vegetative Propagation and Agriculture
 - Humans have devised methods for asexual propagation of angiosperms
 - Most methods based on ability of plants to form adventitious roots or shoots
 - Clones from Cuttings
 - Many kinds of plants asexually reproduced from plant fragments called cuttings
 - Callus is a mass of dividing undifferentiated cells that forms where stem cut and produces adventitious roots

- Grafting
 - A twig or bud can be grafted onto plant of closely related species or variety
 - The stock provides the root system
 - The scion is grafted onto the stock
 - Test-Tube Cloning and Related Techniques
 - Plant biologists have in vitro methods to create and clone novel plant varieties
 - Callus can sprout shoots and roots in response to plant hormones
 - Transgenic plants genetically modified (GM) to express a gene from another organism
 - Protoplast fusion used to create hybrid plants by fusing protoplasts, plant cells with their cell walls removed
- 38.3 - Humans modify crops by breeding and genetic engineering
 - Overview
 - Humans have intervened in the reproduction and genetic makeup of plants for thousands of years
 - Hybridization common in nature and been used by breeders to introduce new genes
 - Maize, a product of artificial selection, is staple in many developing countries
 - Plant Breeding
 - Mutations can arise spontaneously or can be induced by breeders (through radiation and chemicals)
 - Plants with beneficial mutations used in breeding experiments
 - Desirable traits can be introduced from different species or genera
 - Plant Biotechnology and Genetic Engineering
 - Plant biotechnology has two meanings
 - Generally, it refers to innovations in the use of plants to make useful products
 - Specifically, it refers to use of GM organisms in agriculture and industry
 - Transgenic: organisms that have been engineered to express a gene from another species
 - Modern plant biotechnology not limited to transfer of genes between closely related species or varieties of same species
 - Reducing World Hunger and Malnutrition
 - Genetically modified plants may increase the quality and quantity of food worldwide
 - Transgenic crops have been developed that
 - Produce proteins to defend them against insect pests, but are not harmful to humans
 - Tolerate herbicides
 - Resist specific diseases
 - Nutritional quality of plants is being improved
 - “Golden Rice” is transgenic variety being developed to address vitamin A deficiencies among the world’s poor
 - Reducing Fossil Fuel Dependency
 - Biofuels made by fermentation and distillation of plant materials such as cellulose

- Biofuels can be produced by rapidly growing crops such as switch-grass and poplar
 - Biofuels would reduce net emission of CO₂
 - Environmental implications of biofuels controversial
- The Debate over Plant Biotechnology
 - A serious concern is possibility of introduced genes escaping into related weeds through crop-to-weed hybridization
 - This could result in “superweeds” that would be resistant to many herbicides
 - Efforts underway to prevent this by introducing
 - Male sterility
 - Apomixis
 - Transgenes into chloroplast DNA (not transferred by pollen)
 - Strict self-pollination
 - In plant biotechnology zero risk is unattainable.
 - The best scenario is for these decisions to be based on sound science rather than reflexive fears or blind optimism.

CHAPTER 39

- 39.1 – Signal transduction pathways link signal reception to response
 - Overview: Stimuli and a Stationary Life
 - A plants growth pattern must adjust to optimize its ability for resource acquisition –water, light, minerals.
 - A plant must also outcompete its neighbors.
 - The mere presence of a plant changes the environment of its neighbors and may alter their growth rate and form.
 - Plants receive specific signals and respond to them in ways that enhance survival and reproductive success.
 - A plants morphology and physiology is the outcome of complex interactions between environment and internal signals (under genetic control)
 - Phytochrome: specific pigment that works as a light receptor and starts the de-etiolation (greening) response
 - Signal transduction pathway
 - Morphological adaptations displayed by plants when growing in darkness, are collectively called etiolation.
 - If exposed to light, plants will undergo changes called de-etiolation, in which shoots and roots grow normally
 - The de-etiolation response to light involves a signal transduction pathway.
 - Three stages are: reception, transduction, and response
 - Reception
 - In de-etiolation, receptor is phytochrome capable of detecting light which is located in the cytoplasm
 - Transduction
 - Second messengers transfer and amplify signals from receptors to proteins that cause responses
 - Two types of second messengers play an important role in de-etiolation: Ca²⁺ ions and cyclic GMP (cGMP)
 - Phytochrome receptor responds to light by

- Opening Ca²⁺ channels, which increases Ca²⁺ levels in cytosol
 - Activating an enzyme that produces cGMP
 - Response
 - Signal transduction pathway leads to regulation of one or more cellular activities
 - In most cases, these responses to stimulation involve increased activity of enzymes
 - Can occur by:
 - Post-translational modification
 - Transcriptional regulation
 - Post-Translational Modification of Preexisting Proteins
 - Post-translational modification involves modification of existing proteins in signal response
 - Second messengers cGMP and Ca²⁺ activate protein kinases directly
 - Modification often involves phosphorylation of specific amino acids. (proteins)
 - They also have a switch –off factor which ceases the activity once removed from the light
 - Transcriptional Regulation
 - Specific transcription factors bind directly to specific regions of DNA and control transcription of genes in the following ways
 - Some transcription factors are called activators (increasing transcription of specific genes)
 - Other transcription factors are called repressors (decreasing transcription of specific genes)
 - Can be both activators and repressors.
 - De-Etiolation (“Greening”) Proteins
 - De-etiolation activates enzymes that
 - Function in photosynthesis directly
 - Supply chemical precursors for chlorophyll production
 - Affect levels of plant hormones that regulate growth
 - Plant hormones are internal signals that elicit a cellular level response.
- Concept 39.2: Plant hormones help coordinate growth, development, and responses to stimuli
 - Overview
 - Plant hormones chemical signals that modify or control one or more specific physiological processes
 - Definition of a hormone for plants is (almost) same as for animals. It is a substance that is:
 - produced at specific sites in very low concentrations
 - capable of being transported elsewhere
 - locally signaling that an adjustment in growth rate or cell type is required
 - While animal hormones are made in specific glands. Plant hormones are produced more generally at a type of site: e.g. leaves
 - The Discovery of Plant Hormones
 - Response resulting in curvature of organs toward or away from a stimulus called a tropism

- In late 1800s, Charles Darwin and his son Francis conducted experiments on phototropism, a plant's response to light
- Observed that a grass seedling could bend toward light only if tip of coleoptile present
- They postulated that a signal was transmitted from the tip to the elongating region
- In 1913, Peter Boysen-Jensen demonstrated that signal was a mobile chemical substance (did the gelatin vs mica split of tip and showed how chemical moved through membrane)
- In 1926, Frits Went extracted the chemical messenger for phototropism, auxin, by modifying earlier experiments (he used the basis of the Jensen experiment, and used agar instead of gelatin, but placed the agar on different sides of the stem, causing it to bend towards where the chemical was coming from)
- A Survey of Plant Hormones
 - Plant hormones produced in very low concentration
 - Minute amounts can greatly affect growth and development of plant organ
 - Hormones control gene expression and protein function
 - Affecting division, elongation, pattern formation and differentiation of cells
 - Each hormone has multiple effects, depending on site of action, concentration and developmental stage of the plant, however it is not so much the individual hormone as the combination and interaction of this combination of hormones.
 - Auxin
 - The term auxin refers to any chemical that promotes elongation of coleoptiles
 - Indoleacetic acid (IAA) is a common auxin in plants;
 - Auxin is produced in shoot tips and is transported down the stem
 - While it is the first plant hormone discovered, much remains unclear about auxin signal transduction and auxin biosynthesis.
 - Auxin transporter proteins move the hormone from the basal end of one cell into the apical end of neighboring cell.
 - Flow rate is 1cm/hour
 - Cell elongation in response to auxin: the acid growth hypothesis
 - Auxin stimulates proton pumps in plasma membrane
 - Proton pumps lower pH in cell wall, activating expansins. Expansins are enzymes that loosen wall's fabric by separating cross-linking polysaccharides from cellulose fibers
 - Voltage gradient also floods the cell with ions. The cell swells with water. With cellulose loosened, cell can elongate.
 - Auxin also alters gene expression and stimulates a sustained growth response
 - Auxin's Role in Plant Development: morphogenesis
 - Polar transport of auxin plays role in pattern formation of developing plants
 - Reduced auxin flow from a branch stimulates growth in other branches

- Auxin transport plays role in phyllotaxy, arrangement of leaves on stems
 - Shoot apex generates local peaks in auxin concentration that determine leaf primordium formation.
- Some practical Uses for Auxins
 - Applied to tomatoes grown in greenhouses to stimulate fruit growth
 - Why? Seeds produce auxin triggering fruit growth. Greenhouse plants have few seeds thus smaller fruits. To produce commercially viable tomatoes, plants are sprayed with auxin
 - An overdose of synthetic auxins can kill plants
 - For example 2,4-D is used as an herbicide on eudicots
- Cytokinin: Control of Cell Division and Differentiation
 - Cytokinins stimulate cytokinesis (cell division)
 - Cytokinins produced in actively growing tissues such as roots, embryos, and fruits
 - Cytokinins work together with auxin to control cell division and differentiation
 - Control of Apical Dominance: auxin
 - Cytokinins and auxin interact in the control of apical dominance, a terminal bud's ability to suppress development of axillary buds
 - If the terminal bud is removed, plants become bushier
 - Asexual regeneration is controlled by the ratio of auxin to cytokinin
 - There are only a few ways that trees recruit asexually. They are:
 - Layering
 - A branch gets buried. This branch puts out roots. The tip of this buried branch has its auxin: cytokinin ratio altered. The tip of the branch begins to grow straight up. (i.e. it is released from apical dominance because of its very low aux: cyt. ratio.
 - Basal sprouting
 - Root collaring.
 - Basal sprouts occur mainly around the base of the tree -called the root collar.
 - Normally, buds on the root collar are dormant and hidden within the bark.
 - Root collar buds almost always remain dormant as long as auxins are still being passed downward
 - Root suckering
 - New shoots arise from dormant buds along the root system.
 - All three modes are controlled by ratio of auxins to cytokinins.
 - Crown damage reduces the amount of auxin flowing downward.

- Consequence: The ratio of auxin-to-cytokinin is greatly lowered. This stimulates the awakening of dormant buds.
- Plant biotechnology...
 - Increasing cytokinin levels in transgenic plants with genes for enhanced cytokinin synthesis, can cause the release of lateral buds from apical dominance
- Anti-Aging Effects
 - Cytokinins slow aging of some plant organs
 - by inhibiting protein breakdown
 - stimulating RNA and protein synthesis
 - mobilizing nutrients from surrounding tissues
- Gibberellins
 - Have a variety of effects, such as stem elongation, fruit growth, and seed germination
 - Gibberellins produced in young roots and leaves
 - In many plants, both auxin and gibberellins must be present for fruit to develop
 - Gibberellins used in spraying of Thompson seedless grapes
 - Gibberellins increase the internodal distance of the stem. Grapes now have more room to grow.
 - After water is imbibed, release of gibberellins from the embryo signals seeds to germinate
- Abscisic acid (ABA)
 - Slows growth
 - Inhibits growth in response to environmental cues
 - Many of the roles of ABA are evolutionary adaptations to environmental challenges.
 - Two of the many effects of ABA
 - Seed dormancy
 - Seed dormancy ensures that seeds will germinate only in optimal conditions
 - You don't want the seed to germinate:
 - while still inside the fruit
 - In September (the tiny root system will never survive the winter), in the winter under snow cover; in the dry season in the tropics....
 - In some seeds, dormancy broken when ABA removed by heavy rain, light, or prolonged cold
 - Seeds exposed to prolonged cold and ready to germinate are said to be "stratified".
 - Precocious (early) germination can be caused by inactive or low levels of ABA
 - Drought tolerance
 - ABA primary internal signal that enables plants to withstand drought
 - ABA accumulation causes stomata to close rapidly

- In response to lack of water:
 - Mesophyll cells in leaves begin the synthesis of ABA.
 - ABA diffuses toward guard cells
 - ABA binds to surface protein on guard cells. Signal transduction pathway is initiated
 - Guard cells pump potassium (K⁺) out of the cell. Guard cells turn flaccid because of the loss of water.
- Ethylene
 - Plants produce ethylene in response to stresses such as
 - drought
 - flooding
 - mechanical pressure
 - Injury
 - infection
 - Effects of ethylene include response to mechanical stress, senescence, leaf abscission, and fruit ripening
 - Ethylene induces triple response, which allows growing shoot to avoid obstacles
 - Triple response consists of a slowing of stem elongation, a thickening of the stem and horizontal growth
- Senescence
 - Senescence is programmed death of cells or organs
 - Burst of ethylene associated with apoptosis, programmed destruction of cells, organs, or whole plants
 - Change in balance of auxin and ethylene controls leaf abscission, process that occurs in autumn when a leaf falls
 - Burst of ethylene production in fruit triggers ripening process
 - Ethylene triggers ripening, and ripening triggers release of more ethylene
 - Ethylene, triggers the production of various enzymes involved in ripening.
 - The ripening stage is crucial:
 - can influence which animal species choose their fruit,
 - as well as the timing of their consumption
 - Upon exposure to ethylene
 - Fruit begins to turn color as the chlorophyll is broken down by the chlorophyllase.
 - Colorless pigments such as flavonols are then converted into anthocyanins.
 - carotenoids are also produced
 - Anthocyanin and carotenoid pigments become the rich palette that provides us with the sky blue of an Italian plum, or the wonderfully nuanced reds and pinks of a ripened peach.
 - We all eat with our eyes first
 - Other changes: softening and sweetening of the fruit.

- Phytochromes as photoreceptors
 - Phytochrome pigments regulate many of plant's responses to light throughout its life
 - seed germination, flowering and shade avoidance
 - In 1930s, U.S. Department of Agriculture scientists determined action spectrum for light-induced germination of lettuce seeds
- Phytochromes and seed germination
 - The last light they are exposed to will determine germination
 - Red light increased germination, while far-red light inhibited germination
 - Photoreceptor responsible for opposing effects of red and far-red light a phytochrome
 - Phytochromes exist in two photoreversible states (Pr to Pfr)
 - Phytochromes conversion triggers many developmental responses
 - Red light triggers conversion of Pr to Pfr
 - Far-red light triggers conversion of Pfr to Pr
 - Conversion to Pfr faster than conversion to Pr (Pfr → Pr takes all night)
 - Sunlight increases ratio of Pfr to Pr, and triggers germination
- Phytochromes and Shade Avoidance
 - Phytochrome system also provides plant with information about light quality
 - Leaves in canopy absorb red light. Shaded plants receive more far-red than red light
 - In "shade avoidance" response, the phytochrome ratio shifts in favour of Pr when trees shaded
- Biological Clocks and Circadian Rhythms
 - Many plant processes oscillate during day
 - Circadian rhythms cycles about 24 hours long and governed by internal "clock"
 - Can be entrained to exactly 24 hours by day/night cycle
 - Clock may depend on synthesis of a protein regulated through feedback control and may be common to all eukaryotes
- Photoperiodism and Responses to Seasons
 - Photoperiod, relative lengths of night and day,
 - External stimulus plants use most often to detect time of year
 - The other is degree heat-sum days
 - Photoperiodism is a physiological response to photoperiod
 - Flowering often requires certain photoperiod
 - Plants that flower when a light period shorter than a critical length called short-day plants
 - Plants that flower when a light period longer than a certain number of hours called long-day plants
 - Flowering in day-neutral plants controlled by plant maturity, not photoperiod
 - But, we later discovered that the flowering response is controlled by night length, not day length
 - The photoreceptor involved is phytochrome
 - Critical Night Length
 - Short-day plants governed by set minimum number of hours of darkness

- Long-day plants governed by set maximum number of hours of darkness
 - Red light can interrupt the nighttime portion of the photoperiod
 - Flash of red light followed by flash of far-red light does not disrupt night length
 - Photoperiodism and control of flowering
 - Some plants flower after only a single exposure to the required photoperiod
 - Other plants need several successive days of the required photoperiod
 - Still others need environmental stimulus in addition to the required photoperiod
 - For example, vernalization is cold pre-treatment to induce flowering
 - Photoperiod detected by leaves, which cue buds to develop as flowers
 - Flowering signal called florigen
 - Florigen may be a macromolecule governed by FLOWERING LOCUS T (FT) gene
- 39.4: Plants respond to a wide variety of stimuli other than light
 - Overview
 - Plants must adjust to environmental circumstances via developmental and physiological mechanisms
 - Response to gravity known as gravitropism
 - Roots show positive gravitropism
 - Shoots show negative gravitropism
 - Positive gravitropism in roots: the statolith hypothesis
 - Plants may detect gravity by settling of statoliths –specialized plastids containing dense starch granules.
 - Some mutants lacking statoliths still capable of gravitropism
 - Why? Dense organelles, in addition to starch granules, may contribute to gravity detection
 - Mechanical Stimuli
 - Trees also respond to wind.
 - Thigmomorphogenesis refers to changes in form resulting from mechanical disturbance
 - Thigmotropism is growth in response to touch
 - Occurs in vines and other climbing plants
 - Environmental Stresses
 - These stresses have potentially adverse effects on survival, growth, and reproduction
 - Stresses can be abiotic (nonliving) or biotic (living)
 - Abiotic stresses include drought, flooding, salt stress, heat stress, and cold stress
 - Biotic stresses include herbivores and pathogens
 - Drought response...
 - reduce transpiration by closing stomata
 - Rolling leaves into tube-like shapes reducing exposed surface area
 - Growth of shallow roots inhibited, while deeper roots continue to grow
 - Flooding response
 - Enzymatic destruction of root cortex cells creates air tubes that help plants survive oxygen deprivation during flooding
 - Salt response

- Salt can lower the water potential of the soil solution and reduce water uptake
 - Plants respond to salt stress by producing certain solutes at high concentrations
 - Keeps water potential of cells more negative than that of the soil solution
 - Heat Response
 - Excessive heat can denature a plant's enzymes
 - Heat-shock proteins help protect other proteins from heat stress
 - Cold Response
 - Cold temperatures decrease membrane fluidity
 - Altering lipid composition of membranes is a response to cold stress
 - Freezing causes ice to form in plant's cell walls and intercellular spaces.
 - Response...
 - Many plants have antifreeze proteins
- 39.5: Plants respond to attacks by herbivores and pathogens
 - Overview
 - Plants use defense systems to deter herbivory, prevent infection, and combat pathogens
 - Plants counter excessive herbivory with
 - physical defenses, such as thorns and trichomes
 - Chemical defenses, such as distasteful or toxic compounds
 - Some plants even “recruit” predatory animals that help defend against specific herbivores
 - Tannins.
 - Tannins causes indigestion
 - Tannins bind with the digested proteins (derived from the ingested plant material) within the animal's gut and render those proteins useless to the animal.
 - Not all the proteins are bound in this way, the animal does derive some nutrition from the plant but its growth rate is greatly slowed.
 - Human Intervention
 - Our ingenuity: Through careful breeding, we have pushed the plants to use nitrogen for the part of their tissue we are interested in (seed, leaf, fruits) rather than for defense (defense compounds always contain nitrogen).
 - In consequence: As our domesticated plants became more palatable, they required ever more help in fighting off the attacks of herbivores and granivores.
 - Our solution: massive use of pesticides.