Chapter 38: The Plant Body

Chapter Synopsis

Plant meristem cells are analogous to stem cells in animals. They are small, unspecialized cells from which other plant cells differentiate. Cell division in apical meristems result in elongation of the root and shoot. They give rise to three types of embryonic tissue: protoderm that becomes epidermis, procambium that becomes primary vascular tissue, and ground meristem that becomes ground tissue parenchyma cells. Division in lateral meristems produce an increase in girth of shrubs and most trees. Woody plants have two cylinders of lateral meristems: cork cambium produces the cork cells of the outer bark and vascular cambium cells give rise to secondary vascular tissue. The basic plan of a plant includes root and shoot, the latter being composed of stems, leaves, flowers, and fruit. Although the development of the basic plant form and structure is rigidly controlled, some aspects of leaf, stem, and root development are flexible. Plants undergo continuous development that is greatly affected by external rather than internal events. Plants must be highly responsive to their environment as they cannot generally pick up their roots and grow somewhere else. The three basic plant tissue types include dermal tissue (epidermis), ground tissue (parenchyma cells), and vascular tissue (xylem and phloem).

Epidermal cells derived from dermal tissue cover all parts of the primary plant body. It may contain specialized cells. Guard cells are paired, chloroplast-containing cells located on either side of the stoma. Trichomes are hair-like outgrowths that help regulate heat and water balance. Root hairs are extensions of single cells on the outer surface of growing roots. They greatly increase a root's surface area and are the entry point for most of a plant's water. Plant ground tissue exhibits several characteristic kinds of cells including parenchyma, collenchyma, and sclerenchyma. Parenchyma and collenchyma are capable of further cell division, while the other types generally are not. Sclerenchyma fibers and sclerids are lignified, structural elements that possess tough, secondary walls. Xylem and phloem comprises a plant's vascular tissue. Xylem conducts water upward from the roots and is composed of tracheids or vessel elements. Phloem conducts photosynthetic products away from areas of storage or manufacture. It is composed of sieve cells or sieve-tube members. Both xylem and phloem contain additional fiber and parenchyma cells.

Roots have a simpler anatomy than stems and do not produce projections analogous to leaves or flowers. Developing roots have four distinctive regions: the root cap, the zone of cell division, the zone of elongation , and the zone of maturation. Primary growth in the root occurs at the root tip, surmounted by the root cap. The root endodermis is the innermost portion of the root cortex and is surrounded by a waxy band called the Casparian strip. This layer determines what minerals and nutrients enter the root xylem. The pericycle lies just inside the endodermis and is the source of lateral roots. Monocots have vascular bundles that form a ring through the central portion of the root. Secondary root growth is initiated in the vascular cambium. Division of cells produces xylem cells that move toward the interior of the stem and phloem cells that move toward its exterior. Dicot roots have a central column of xylem with radiating arms. Alternating strands of phloem are located between the arms of xylem. Root modifications include aerial roots, pneumatophores, contractile roots, parasitic roots, food and water storage roots, and buttress roots.

Woody stems are familiar parts of plants to which leaves and flowers are attached. Leaves are attached at nodes, separated by regions called internodes. Leaf buds are terminal if attached to the tip of a twig and axillary if formed along the length of it. Axillary buds form lateral branches. When bud scales, stipules, or leaves fall off a twig they leave characteristic visible scars on the surface of the twig. Gas exchange in stem periderm occurs through lenticels visible on the outer bark. Stems that exhibit primary growth are composed of ground tissue divided into the centrally located pith and the outer cortex. The vascular tissue is embedded in the ground tissue as scattered bundles in monocots and as a cylindrical outer ring in dicots. Primary and secondary growth occurs much the same as in roots. A special form of secondary growth occurs in only a few monocots. Vascular cambium produces xylem and phloem in the same manner as in roots. Cork is renewed constantly when the cork cambium produces cork and phelloderm. Commercial wood is composed of accumulated secondary xylem. Softwoods are conifers while hardwoods are angiosperms. Bulbs, corms, rhizomes, runners and stolons, tubers, tendrils, and cladophylls are examples of stem modifications.

Leaves are the primary photosynthetic organs of plants. They grow outward from marginal meristems forming a blade with a central midrib. The veins are vascular tissues that run through the leaf in a parallel pattern in monocots and a netted pattern in dicots. The interior of a leaf is called the mesophyll and is composed of chloroplast-laden palisade and spongy parenchyma. These cells are interspersed with intercellular spaces that connect to the stomata and permit gas exchange with the environment. Many plants seasonally lose their leaves to conserve water. Evergreen plants lose their leaves continuously with a complete turnover in as long as seven years. Modified leaves include bracts, spines, reproductive leaves, window leaves, shade leaves, and insectivorous leaves.

CHAPTER OBJECTIVES

- ä Understand the importance of the three kinds of plant meristem cells.
- ä Indicate the identity and function of the three basic tissue types in plants.
- ä Explain primary growth and understand how it differs from secondary growth.
- ä Describe each of the plant cell types, its function, and indicate whether the cell is capable of further division.
- ä Know what types of cells are present in xylem and phloem and how each functions.
- ä Describe the four zones of growth in roots.
- ä Identify the most obvious components of external stems.
- ä Understand the importance of vascular cambium and cork cambium in secondary growth.
- ä Understand what wood is, how it is formed, and what is indicated by its annual growth rings.
- ä Structurally differentiate among monocot, herbaceous dicot, and woody dicot stems and between monocot and dicot roots.
- ä Describe the structure of a typical leaf and how that structure relates to the process of photosynthesis.
- ä Understand how leaf growth differs from that of roots and stems.

KEY TERMS

alternate branching
apical meristem
axillary bud
blade
bract
Casparian strip
collenchyma cell
companion cell
compound leaf
cork cambium
corm
cortex
cuticle
cutin
endodermis
epidermal cell
epidermis
fiber
fibrous root system
gap
ground meristem
ground tissue
guard cell
intercalary meristem
internode
lateral meristem
leaf
leaflet
lenticel
lignin
lignified
mesophyll
node
opposite branching
outer bark
palisade mesophyll
palmately compound
palmately veined
parenchyma
parenchyma cell
pericycle
petiole
phloem
phylotaxy
pinnately compound
pinnately veined
pit
pith

plasmodesmata
primary meristem
primary phloem
primary plant body
primary tissue
primary xylem
primordia
procambium
protoderm
ray
root
root cap
root hair
root system
sclerenchyma cell
sclerid
secondary growth
secondary phloem
secondary tissue
secondary xylem
sessile
shoot system
sieve area
sieve cell
sieve plate
sieve tube
sieve-tube member
simple leaf
spine
spongy mesophyll
stem
stele
stipule
stoma (pl. stomata)
suberin
taproot system
terminal bud
tracheid
transpiration
tricome
vascular bundles
vascular cambium
vascular tissue
vein
vessel
vessel member
whorled branching
xylem
zone of cell division
zone of elongation
zone of maturation

CHAPTER OUTLINE

38.0 Introduction

I. PLANTS HAVE A FUNDAMENTAL UNITY OF STRUCTURE — fig 38.1

A. Unity in Construction
1. Growth
2. Manufacture and transport of food
3. Regulation of development

B. Fundamental Differences Between Roots and Shoots

38.1 Meristems elaborate the plant body plan after germination

I. MERISTEMS

A. General Features of Meristems
1. Composed of small, unspecialized cells with dense cytoplasm and large nuclei
2. Analogous to stem cells in animals
3. One cell remains in meristem, other becomes part of plant body
   a. Population of meristem cells constantly renewed
   b. Share common pathways of gene expression with stem cells
4. Two kinds of meristems exist in plants
   a. Apical meristems: Cell divisions result in elongation of the root and shoot
   b. Lateral meristems: Produce increase in girth of shrubs and most trees

B. Apical Meristems
1. Located at the tips of stems and roots — fig 38.2,3
2. Primary growth produces primary plant tissues
   a. Apical meristems divide, causing increase in plant length
   b. Forms primary plant body, made up of primary tissues
   c. Comprises young, soft shoots and roots of trees and shrubs
   d. Comprises entire plant body of herbaceous plants
3. Apical meristem cells are delicate and need protection
   a. Root apical meristem protected by root cap
      1) Root cap cells sloughed off as root moves through soil
      2) Cells replaced by new ones

b. Shoot apical meristem protected by a variety of mechanisms fig 38.4
   1) Epicotyl or hypocotyl bends as seedling emerges to minimize force on shoot tip
   2) Monocots have a coleoptile sheath forming a protective tube around shoot
   3) Leaf primordia cover shoot apical meristem in later development

4. Apical meristems give rise to three types of embryonic tissues
   a. Protoderm: Differentiates into epidermis
   b. Procambium: Differentiates into primary vascular tissues (xylem, phloem)
   c. Ground meristem: Differentiates into ground tissue parenchyma cells
5. Some plants have intercalary meristems
   a. Example: Horsetails, corn
   b. Arise in stem internodes, add to internode length

C. Lateral Meristems
1. Many plants also exhibit secondary growth via lateral meristems
   a. Includes trees, shrubs, and some herbs
   b. Are cylinders of meristematic tissue in stems and roots fig 38.5
2. Most dramatic in woody plants have lateral meristems
   a. Two peripheral cylinders of actively dividing cells
   b. Cork cambium: Produces cork cells of outer bark
   c. Vascular cambium: Gives rise to secondary vascular tissue
      1) Found just beneath bark
      2) Forms between xylem and phloem in vascular bundles
      3) Adds secondary vascular tissue on opposite sides of vascular cambium
   d. Secondary xylem is main component of wood
   e. Secondary phloem lies near outer surface of woody stem
      1) Removing tree's bark damages phloem
      2) May ultimately kill tree
3. Tissues called secondary tissues, collectively called the secondary plant body

II. ORGANIZATION OF THE PLANT BODY

A. Basic Plant Body Plan fig 38.2
1. Primary and secondary plant growth produces adult sporophyte
2. Plant bodies do not necessarily have fixed size
   a. Number of leaves, roots, branches, and flowers vary within a species
   b. Development of form and structure rigidly controlled
   c. Some aspects of leaf, stem, and root development are flexible
   d. Number, location, size, structure of leaves and roots influenced by environment
3. Vascular plant composed of root system and shoot system fig 38.6
   a. Root system
      1) Anchors plant and penetrates soil
      2) Absorbs water and ions critical to nutrition
   b. Shoot system
      1) Stems: Serve as framework to position leaves
      2) Leaves: Primary location for photosynthesis
      3) Flowers: Serve reproductive functions, become fruit and seeds
4. Reiterative unit of vegetative shoot: Internode, node, leaf, axillary buds
   a. Axillary buds are apical meristems derived from primary apical meritstem
   b. Allow plant to branch or replace main shoot if it is excised or damaged
   c. Can reiterate development of primary shoot
   d. Axillaries may produce flowers or floral shoots in the reproductive phase

B. Three Tissue Types in Plants
   1. Dermal tissue
      a. Composed of epidermis
      b. Outer protective covering, usually one cell layer thick
      c. Fatty cutin layer forms the cuticle
      d. Some plants add waxy layer outside cuticle
      e. Bark forms outer protective layer in plants with secondary growth
   2. Ground tissue
      a. Primarily thin-walled, parenchyma cells
      b. Initial spherical shape, assume other shapes after division and packing of cells
      c. Live for many years
      d. Function in storage, photosynthesis, secretion
   3. Vascular tissue
      a. Conducts materials throughout plant
         1) Xylem: Water and dissolved minerals
         2) Phloem: Materials needed for growth, carbohydrates, hormones, amino acids
      b. Xylem and phloem differ in structure and function

III. PRIMARY AND SECONDARY GROWTH

A. Evolution of Vascular Plant Primary and Secondary Tissues
   1. Meristems give rise to all other plant cells
   2. Earliest vascular plants were not divided into stems, leaves, roots
   3. Evolution of secondary growth resulted in tree-like growth forms fig 38.7
      a. Resulted in development of forests, domination of land plants
      b. Evolved independently in several groups of vascular plants

B. Conducting Systems of Early Land Plants
   1. Sieve tube members conduct carbohydrates away from area of manufacture or storage
   2. Vessel members and tracheids transport water and minerals up from roots
   3. Both kinds of cells are elongated and occur in strands, forming tubes
      a. Sieve tube members characteristic of phloem tissue
      b. Vessels and tracheids characteristic of xylem
   4. In primary tissue, two types are associated with each other in same vascular strand
   5. In secondary growth, the two types are not in direct association
      a. Phloem found on periphery
      b. Xylem found in central core
   6. Roots and shoots have different patterns of vascular tissue and secondary growth

38.2 Plants have three basic tissues, each composed of several cell types

I. DERMAL TISSUE

A. Epidermal Cells Cover All Parts of Primary Plant Body
   1. Originate from protoderm
   2. Outer wall has cuticle that varies in thickness

B. Epidermis Contains Specialized Cells
   1. Guard cells: Paired sausage-shaped cells flanking stoma
      a. Contain chloroplasts, other cells do not
      b. Stomata occur in leaf epidermis, occasionally on stems and fruit fig 38.8
      c. Stomal openings allow passage of photosynthetic gases, water vapor

d. More numerous on lower surfaces to minimize water loss
e. Form from asymmetric cell division
   1) Controlled by some sort of intercellular communication
   2) Lack of control causes mutation called *too many mouths* fig 38.9
f. Stoma open and shut in response to external factors
   1) Include light, temperature, availability of water
   2) Open during active photosynthesis, allow passage of CO_2 and O_2

2. Trichomes: Hair-like epidermal outgrowths fig 38.10
   a. Occur in stems, leaves, and reproductive organs
   b. Surface appears woolly or fuzzy
   c. Help regulate heat and water balance
   d. Vary in form
      1) Some are single cells, others are several cells
      2) Glandular trichomes may secrete sticky or toxic substances to deter herbivory
   e. Intensive investigation in Arabidopsis
      1) Four genes specify site of trichome formation and initiation fig 38.11
      2) Eight genes needed for extension growth
3. Root hairs: Tubular extensions of single cells fig 38.3
   a. Found behind tips of growing roots
   b. An extension not a separate cell, no crosswall separating it from epidermal cell
   c. Provide intimate contact between root and soil particles
   d. Greatly increases root's surface area, efficiency of absorption
   e. New root hairs produced as old ones slough off
   f. Responsible for most absorption in herbaceous plants
   g. Are very different from lateral roots
      1) Lateral roots are multicellular
      2) Have origins deep within root
   h. When secondary growth occurs
      1) Cork cambium produces bark of tree trunk or root
      2) Replaces stretched and broken epidermis with radial expansion
4. Epidermal cells lack plasticity of other cells
   a. May fuse to epidermal cell of another organ
   b. Dedifferentiate

II. GROUND TISSUE

A. Parenchyma fig 38.12a

1. Have large vacuoles, thin walls, average of 14 sides at maturity
2. Most common type of primary tissue, may occur in secondary tissues
3. Possess only primary cell walls
   a. Laid down while cell still maturing
   b. Less specialized than other cell types
4. Often have special functions
   a. Secrete nectar and resins
   b. Store latex, proteins, metabolic wastes
5. Have nuclei, are capable of further division
   a. Commonly store food and water
   b. Are alive at maturity, may live to be 100 years old
6. May contain chloroplasts
7. Called chlorenchyma when found in leaves and outer parts of stems

B. Collenchyma fig 38.12b
1. Living at maturity, contain living protoplasts
2. Elongated cells with unevenly thickened walls
3. Flexible cells, provide support, bend without breaking
   a. Form strands or cylinders beneath epidermis, along leaf veins
   b. Example: Strings of celery leaf stalk

C. Sclerenchyma
1. Possess thick, tough secondary walls
2. Usually lack living protoplasts at maturity
3. Secondary walls often impregnated with lignin
   a. Adds rigidity to cells
   b. Cells are thus lignified
   c. Common in cells with supportive or mechanical function
   d. May be deposited in primary and secondary cell walls
4. Two types of sclerenchyma, both serve to strengthen tissues
   a. Fibers
      1) Long slender cells that form strands
      2) Example: Strands of flax woven to produce linen
   b. Sclerids fig 38.12c
      1) Varied in shape, frequently branched
      2) Example: Gritty texture of pears

III. VASCULAR TISSUE

A. Xylem
1. Principal water conducting tissue
2. Consists of hollow, dead cells fig 38.13
   a. Vessel members are cylindrical, arranged end to end
   b. Tracheids taper at ends and overlap each other
   c. May be only conducting cells in some plants, (but not angiosperms)
3. Water conducted in an unbroken stream from roots to leaves
   a. At leaves, much water passes into film on outside of parenchyma cells
   b. Diffuses in form of water vapor into intercellular spaces
   c. Exits from leaves, mainly through stomata
   d. Process called transpiration
4. Water in xylem contains various dissolved minerals and inorganic ions
5. Also provides mechanical support for plant body
   a. Primary xylem derived from procambium
   b. Secondary xylem derived from vascular cambium
   c. Wood is accumulated, secondary xylem
6. Vessels found almost exclusively in angiosperms
   a. In primitive plants, are elongated cells that resemble fibers
   b. In advanced plants, vessel members are shorter and wider
7. Vessels and tracheids have thick, lignified secondary walls
   a. Lack living protoplasts at maturity
   b. Not living at maturity
   c. Lignin secreted by cell to strengthen cellulose wall before protoplast dies
8. In tracheids, water flows through pits in secondary walls
   a. No secondary cell wall material deposited
   b. Pits of adjacent cells occur opposite one another
9. Vessel elements join end-to-end, have open or perforated end walls
   a. Vessels conduct water more efficiently than tracheids
   b. Vessels evolved from tracheids are specialized for conduction

c. Some fibers evolved from tracheids are specialized for support
d. Ancient angiosperms have only tracheids, modern ones have vessels
e. Plant mutation that prevents xylem differentiation, but not tracheids
   1) Wilt soon after germination
   2) Unable to transport water efficiently

10. Xylem also includes fibers and parenchyma cells
    a. Parenchyma cells produced in horizontal rows called rays
       1) Produced by ray initials on vascular cambium
       2) Function in lateral conduction and food storage
       3) In woody cross sections radiate from center like wheel spokes
    b. Fibers are abundant in dense and heavy wood, like oak
11. Types and arrangement of xylem cells used to identify many species of plants
12. Xylem fibers are a major component of modern paper, not phloem fibers of early paper

B. Phloem
1. Located toward outer part of roots and stems
2. Principle food conducting tissue
   a. Girdling a plant removes strip of bark down to vascular cambium
   b. Plant dies due to starvation of roots
3. Conducting cells: Sieve cells and sieve-tube members fig 38.14
   a. Sieve cells occur in seedless vascular plants and gymnosperms
   b. Sieve-tube members found in angiosperms
4. Both types possess clusters of pores called sieve areas
   a. More abundant on overlapping ends of cells
   b. Connects protoplasts of adjoining sieve cells and sieve-tube members
   c. Both types of cell are living, but most lack nucleus at maturity
5. Sieve-tube member pores may be larger, called sieve plates
   a. Occur end-to-end, forming longitudinal series called sieve tubes
   b. Less specialized than sieve-tube members
   c. Pores are all same size
   d. Sieve-tube members more advanced, more efficient
6. Sieve-tube members associated with companion cells
   a. Specialized parenchyma cells
   b. Carry out metabolic functions that maintain sieve-tube members
   c. Possess components of normal parenchyma cells, including nuclei
   d. Plasmodesmata connect their cytoplasm with conducting cells
   e. Albuminous cells in nonflowering plants serve same function
7. Fibers and parenchyma cells often abundant

38.3 Root cells differentiate as they become distanced from the dividing root apical meristem

I. ROOT STRUCTURE

A. Plants Possess Three Vegetative Organs: Roots, Stems, Leaves
1. Roots have simpler pattern of organization and development than stems
2. Developing roots have four regions fig 38.15
   a. Root cap
   b. Zone of cell division
   c. Zone of elongation
   d. Zone of maturation

B. The Root Cap
1. Has no equivalent in stems
2. Composed of two types of cells

a. Columella cells: On inside, columnar shape
b. Lateral root cap cells: On outside, replenished by root apical meristem
3. May be obvious structure in plants with larger roots
4. Protects delicate tissues as root extends into soil
a. Golgi bodies secrete slimy substance, passes through walls to outside
b. Cells replaced from inside
c. Form mucilaginous lubricant that eases root through soil
d. Provides medium for growth of nitrogen-fixing bacteria in some plants
5. New root cap produced when old one is artificially or accidentally removed
6. Also functions to perceive gravity due to highly specialized columella cells
a. Endoplasmic reticulum in the periphery, nucleus at middle or top of cell
b. Have amyloplasts that collect on sides of cells facing pull of gravity
c. Amyloplasts change position if potted plant is put on side
d. Root bends in direction of gravity
e. Only two columella cells needed to sense gravity
1) Experiments in *Arabidopsis*
2) Use laser to kill columella cells
f. Calcium ions in amyloplasts may influence distribution of auxin growth hormone
g. May be multiple signalling since response still occurs in absence of auxin
h. Electrical signal may move from columella cell to cells in elongation zone

C. The Zone of Cell Division
1. Apical meristem is inverted dome of cells at center of root tip
a. Protected by root cap
b. Activity takes place toward edges of dome
c. Cells divide, often rhythmically, every 12 to 36 hours
d. May reach peak division once or twice per day
e. Cells are essentially cuboidal with small vacuoles, large central nuclei
f. Rapidly dividing cells are daughter cells of apical meristem
2. Quiescent center cells are located in the center of the root apical meristem
a. Cells divide infrequently
b. Outer surface cells divide much more rapidly than interior cells during growth
3. Subdivides into three primary meristems
a. Protoderm
b. Procambium
c. Ground meristem
4. Patterning of tissue systems controlled by specific genes in studies of *Arabidopsis*
a. Patterning begins in this zone
b. Expression not fully revealed until cells reach zone of maturation
5. Examples of patterning genes: fig 38.16
a. *WEREWOLF*: Patterning of epidermal cell types, with and without root hairs
b. *SCARECROW*: Important in ground cell differentiation
1) Necessary for asymmetric cell division that gives rise to two cylinders from one
2) Outer layer becomes ground tissue with storage function
3) Inner layer forms endodermis, regulates flow into core of root
6. Cell development in this region based on position
a. If position changed, cell develops differently
b. Will develop according to new position

D. The Zone of Elongation
1. Cells become several times longer than wide. Causes roots to lengthen
2. Small vacuoles merge, occupy nearly 90% of cell volume
3. No further increase in cell size above this point
4. Mature parts of root remain stationary, root increases only in girth

E. The Zone of Maturation
   1. Elongated cells differentiate into specific cell types
   2. Cells at root surface cylinder mature into epidermal cells
      a. Have very thin cuticle
      b. Many epidermal cells develop a root hair
         1) Protuberance not separated by crosswall from epidermal cell
         2) Increase root surface area and absorptive capacity
         3) Usually alive and functional for only a few days, sloughed off
      c. New root hairs produced on new cells toward zone of elongation
   3. Nitrogen fixing symbiotic bacteria enter plant via root hairs
      a. Instruct plant to create nodule around bacteria
      b. Fix atmospheric nitrogen into form usable by legume plant
   4. Parenchyma cells produced by ground meristem immediately interior to epidermis
      a. Parenchyma tissue called the cortex
      b. May be many cells wide, functions in food storage
      c. Inner boundary of cortex differentiates into cylinder of endodermis fig 38.17
      d. Primary walls of endodermis impregnated with suberin, fatty waterproof substance
         1) Suberin produced in bands called Casparian strips fig 38.18
         2) Surround adjacent endodermal cell walls perpendicular to root surface
         3) Blocks transport through cells
         4) Materials can only pass through two surfaces parallel to root surface
         5) Passage of material controlled by cell membranes
   5. All tissues interior to the endodermis are collectively called the stele
      a. Pericyle is immediately interior and adjacent to endodermis
         1) Cells can divide even after maturity
         2) May give rise to lateral or branch roots
         3) May give rise to part of vascular cambium in dicots
   6. Primary root growth may exhibit a number of patterns
      a. Dicot root cross-section fig 38.19
         1) Have central core of primary xylem, often star-shaped
         2) Have one or more arms radiate toward pericycle
      b. Monocot cross-section (and few dicots)
         1) Primary xylem forms ring of vascular bundles
         2) Surrounds central cylinder of pith at center of root
      c. Strands of primary phloem alternate between xylem arms
         1) Involved in food conduction
         2) Possess this pattern in dicot and monocot roots
   7. Pattern in dicots and plants with secondary growth fig 38.20
      a. Vascular cambium arises from cells between primary xylem and phloem
         1) Develops from part of pericycle and parenchyma cells
         2) Cells to inside become secondary xylem
         3) Cells to outside become secondary phloem
      b. Secondary tissues eventually form concentric cylinders
      c. Primary phloem, cortex, epidermis crushed, sloughed off with new secondary tissue
      d. In woody plant pericycle, cork cambium contributes to bark fig 38.30
   8. With secondary dicot root growth, everything outside stele lost, replaced with bark

II. MODIFIED ROOTS

A. Most Plants Produce One of Two Types of Root Systems
   1. Taproot system has one large root with several to many branches
   2. Fibrous root system has many smaller roots with the same diameter

B. Some Plants Produce Special Root Modifications with Special Functions
1. Aerial roots
a. Epiphytic orchids have roots that extend out into the air
1) Unconnected to the ground, not parasitic
2) Epidermis is several cells thick to reduce water loss
3) May also be green and photosynthetic
b. Prop roots
1) Located on lower part of stem of some monocots like corn
2) Grow down into ground, anchor against wind
c. Adventitious roots
1) Climbing ivies produce roots from stems, anchor them to substrate
2) Any root that arises along stem or location other than base of plant
3) Root formation dependent on shoot's developmental stage
4) Cannot produce roots when in adult phase
2. Pneumatophores fig 38.21a
a. Found on plants growing in swamps and wet places
b. Are spongy outgrowths from underwater roots
c. May extend above water, facilitate oxygen supply to underwater roots
3. Contractile roots
a. Roots of certain plants like lily bulbs and dandelion roots
b. Contract by spiralling, pull plant deeper into soil each year
c. Roots may contract to a third of their original length
4. Parasitic roots
a. Dodder and other plant stems lack chlorophyll
b. Produce peg-like roots called haustoria, penetrate host plants
c. Establish contact with host, parasitize them
5. Food storage roots
a. Xylem of branch roots of plants like sweet potatoes produce extra parenchyma cells
b. Store large quantities of carbohydrates
c. May be combinations of stem and root: Carrot, beet, parsnip, radish, turnip
d. Possess multiple rings of secondary growth
6. Water storage roots fig 38.21b
a. Produced by certain members of pumpkin family
b. Stored water used when soil water supply is inadequate
7. Buttress roots fig 38.21c
a. Produced by certain varieties of fig and tropical trees
b. Found at base of trunk, provides stability

38.4 Stems are the backbone of the shoot, transporting nutrients and supporting the aerial plant organs

I. STEM STRUCTURE

A. External Form
1. Shoot apical meristem initiates stem tissue fig 38.22
a. Intermittently produces bulges called primordia
b. Develop into leaves, shoots, or flowers
2. Stem is axis from which plant organs grow
a. Leaves show specific arrangements
1) Spiral around stem
2) Pairs opposite each other
3) Whorls of three or more

3. Spirals are most common, exhibit mathematical ratio
    a. Leaves 137.5° apart, called the golden mean
    b. Also shown in shell coiling, classical architecture, and some forms of modern art
    c. Pattern called phylotaxy, may optimize exposure of leaves to sun
4. A node is the region of leaf attachment
    a. Stem area between nodes is the internode
    b. Two basic leaf parts
        1) Blade: Flattened portion
        2) Petiole: Slender stalk
        3) If petiole is missing, leaf is sessile (attached)
5. Axillary bud is produced in each axil
    a. Axil: Angle formed by leaf between the attachment and the stem
    b. Product of primary shoot apical meristem
    c. When associated with leaf primordia, called a terminal bud
    d. Develop into branches, or form meristems that develop into flowers
6. Monocot and herbaceous stem structure
    a. Stems do not make cork cambium
    b. Stems are usually green and photosynthetic
    c. Outer layers of cortex contain chloroplasts
    d. Stems have stomata, various types of trichomes
7. Woody stems persist for many years, develop distinctive markings
    a. Terminal buds extend length of shoot during growing season
        1) Most buds protected over winter by bud scales (geraniums are unprotected)
        2) Bud scales drop off leaving bud scale scars
    b. Stipules
        1) Paired butterfly-like organs near base of leaf
        2) May fall off and leave stipule scars
    c. Deciduous leaves fall off and leave leaf scars with tiny bundle scars
8. Features of leaf scars distinctive and help identify plants in winter — fig 38.23

B. Internal Form
1. Stems possess apical meristem at tip, produces primary tissue to increase stem length
2. Three primary meristems develop from apical meristem
    a. Protoderm produces epidermis
    b. Ground meristem produces parenchyma cells
        1) Pith: Parenchyma in center of stem
        2) Cortex: Parenchyma cells away from center
    c. Procambium produces primary vascular tissue
        1) Primary xylem and primary phloem
        2) Surrounded by ground tissue
3. Trace: Strand of xylem and phloem
    a. Branches off from main xylem and phloem
    b. Enters developing leaf or bud
    c. Leaves spaces called gaps
4. Vascular cambium develops between primary xylem and phloem in dicots — fig 38.24
    a. Vascular cambium connects ring of primary vascular bundles
    b. Bundles scattered in monocots — fig 38.25
        1) Cannot logically connect bundles to allow uniform increase in girth
        2) Without vascular cambium, monocots have no secondary growth
5. Cells of vascular cambium divide to produce secondary tissues
    a. Mostly secondary xylem and phloem
    b. Production of xylem is extensive in trees, called wood
        1) Rings in tree stump show annual growth patterns
        2) Cell size depends on growth conditions

6. Woody dicots and gymnosperms have cork cambium arising in outer cortex
   a. Produces box-like cork cells to outside
   b. May produce parenchyma-like phelloderm cells to inside
   c. Periderm: Cork cambium, cork, and phelloderm — fig 38.26
   d. Cork tissues are impregnated with suberin, die, and comprise outer bark
      1) Cork tissue cuts off water and food to epidermis
      2) Epidermis dies and sloughs off
7. Gas exchange
   a. In young stems, occurs through stomata
   b. In older stems, occurs through unsuberinized lenticels on outer bark — fig 38.27

II. MODIFIED STEMS — fig 38.25

A. Most Stems Grow Erect
1. Stem modifications important in vegetative propagation
2. Modified stems cut into segments, grow into new plants
3. Identifying stems versus roots
   a. Stems
      1) Have leaves at nodes
      2) Have internodes between nodes
      3) Have buds in axils of leaves
   b. Roots lack leaves, nodes, axillary buds

B. Types of Modified Stems
1. Bulbs
   a. Include onions, lilies, tulips — fig 38.28a
   b. Swollen underground stems, really large buds with adventitious roots on base
   c. Fleshy leaves attached to small stem
   d. Onions have papery scale-like leaf bases surrounding fleshy leaves
2. Corms
   a. Include crocus, gladiolus
   b. Superficially resemble bulbs, but do not have fleshy leaves
   c. Mostly underground stem with few nonfunctional leaves and adventitious roots
3. Rhizomes
   a. Include perennial grasses, ferns, irises
   b. Horizontal underground stems — fig 38.28b
   c. Each node has scale-like leaf with axillary bud
   d. Photosynthetic leaves may be produced at tip
   e. Adventitious roots produced along entire length, mostly on lower surface
4. Runners and stolons
   a. Include strawberry plants — fig 38.28c
   b. Are horizontal stems, found above ground
   c. Terms are sometimes interchangeable
   d. Stolon describes underground stem with long internodes like white potatoes
   e. Potato itself is modified stem, a tuber
5. Tubers
   a. Carbohydrates accumulate at tips of stolons, produce tubers
   b. Stolons die after tubers are mature — fig 38.28d
   c. Potato eyes are axillary buds arising in the axil of scale-like leaves
   d. Ridge adjacent to eye is a leaf scar
6. Tendrils
   a. Include grape, Boston ivy — fig 38.28e
   b. Twine around supports and aid in climbing
   c. Pea and pumpkin tendrils are modified leaves or leaflets

7. Cladophylls
   a. Produced by cacti fig 38.28f
   b. Flattened photosynthetic stems
   c. Leaves are modified as spines

38.5 Leaves are adapted to support basic plant functions

I. LEAF EXTERNAL STRUCTURE

A. General Features of Leaves
1. Initiated as leaf primordia from apical meristems fig 38.2
2. Principal sites of terrestrial photosynthesis
3. Grow via cell division and enlargement within blade, some cell division
   a. Determinate structures where growth stops at maturity (like our arms and legs)
   b. Arrangement, form, size, internal structure differ greatly
   c. Patterns have adaptive value dependent on environment
4. Are extensions of shoot apical meristem and stem development
   a. First emerge as primordia, not yet committed to be leaves
   b. In culture experiments, primordia can be induced to become shoots
5. Form two morphological categories reflecting evolutionary origin
   a. Microphyll: Leaf has one vein
      1) Vein does not leave gap where it branches from stem vascular cylinder
      2) Mostly small in size
      3) Generally associated with phylum Lycophyta
   b. Megaphyll: Possess several to many veins
      1) Possessed by most plants
      2) Conducting tissues leave gap in stem's vascular cylinder when it branches

B. External Leaf Anatomy
1. Blade: Flattened portion of leaf
   a. Reflects shift from radial symmetry to dorsal-ventral symmetry
   b. Analyzing mutants like *phantasia* to understand how transition occurs fig 38.29
2. Petiole: Slender stalk
3. Stipules: Paired organs near base of petiole
   a. May be leaf-like or modified as spines or glands
   b. Vary in size
   c. Development independent of rest of leaf
4. Petioles usually absent in leaves of grasses and other monocots
5. Veins: Xylem and phloem strands run throughout leaf fig 38.30
   a. Parallel in monocots
   b. Netted in dicots
6. Forms shown by leaf blades
   a. Simple leaves are undivided, fig 38.31a
      1) May have teeth or indentations
      2) May be deeply lobed as in maples and oaks
   b. Compound leaves consist of distinctly separate leaflets
      1) Like leaves of ashes, box elders, and walnuts
      2) Development of simple versus compound being studied with mutation
      3) Axis of leaflet called rachis (equivalent to midrib of simple leaf)
      4) Pinnately compound leaves are arranged in pairs on common axis fig 38.31b
      5) Palmately compound leaves radiate from common point fig 38.31c
   c. Veins of leaf blades have similar arrangement
      1) Pinnately veined
      2) Palmately veined

7. Leaves have unique arrangements along length of stem fig 38.32
   a. Alternate leaves usually spiral around stem, one leaf per node
   b. Opposite leaves occur in pairs on opposite sides of stem, two leaves per node
   c. Whorls are a circle of leaves at same level of a node

II. LEAF INTERNAL STRUCTURE

A. Leaf Surface
1. Covered by transparent epidermis, cells generally lack chloroplasts
2. Has waxy cuticle, may have various glands and trichomes
3. Lower epidermis contains numerous stomata fig 38.33
   a. Flanked by guard cells
   b. Function in gas exchange, water regulation

B. Structure and Organization of the Leaf Interior
1. Mesophyll: Tissue between epidermis through which veins run
2. Dicot leaves have two distinct types of mesophyll
   a. Palisade parenchyma
      1) Columnar parenchyma near upper epidermis fig 38.34
      2) One to several rows of barrel-shaped or cylindrical cells
      3) Chlorenchyma cells, contain chloroplasts
      4) Hanging leaves have palisade parenchyma on both sides of leaf
   b. Spongy parenchyma
      1) Parenchyma cells between palisade parenchyma and lower epidermis
      2) Loosely arranged cells with many air spaces
      3) Intercellular spaces are connected to stomata
      4) Function in exchange of gas and water vapor
3. Monocot mesophyll not differentiated, little distinction of upper and lower surfaces
   a. Anatomy correlates with modification of photosynthetic pathways
   b. Maximizes amount of CO_2 relative to O_2
   c. Reduces energy loss due to photorespiration
4. Leaf anatomy balances water loss, gas exchange, transport of photosynthetic products

III. MODIFIED LEAVES

A. Plants Live in a Wide Variety of Environments
1. Necessitate leaf modifications to adapt to specific habitats
2. Have evolved remarkable modifications

B. Types of Modified Leaves
1. Floral leaves (bracts)
   a. Poinsettias and dogwood have inconspicuous yellow-green flowers
   b. Large, modified leaves or bracts are mistaken for flowers
   c. Perform same function as showy petals fig 38.35
   d. Bracts can also be small and inconspicuous
2. Spines
   a. Modified leaves on cactus, barberries fig 38.28f
   b. Reduction of leaf surface reduces water loss, deters predators
   c. Thorns of honey locust are modified stems
   d. Prickles of raspberries and roses are epidermal or cortex outgrowths
3. Reproductive leaves
   a. *Kalanchoë* produce tiny, complete plantlets at margins of leaves
   b. Plantlet will grow into complete plant
   c. Walking fern produces new plantlets at tips of fronds

4. Window leaves
    a. Plants in arid regions produce succulent conical leaves with transparent tips
    b. Leaves often are buried in sand, tips admit light into hollow interiors
    c. Photosynthesis occurs beneath surface of ground
5. Shade leaves
    a. Leaves in the shade are larger in surface area
    b. Are also thinner, with less mesophyll than normal light leaves
    c. Both kinds of leaf on same plant have same genes
    d. Shows major effect of environment on plant development
6. Insectivorous leaves
    a. Trap insects and digest soft parts
    b. Plants often grow in bogs deficient in elements, provided by insects
    c. Pitcher plants have cone-shaped leaves, accumulates rainwater
    d. Sundews have sticky glands that entrap insects
    e. Venus flytrap has trigger hairs that close leaf on insect

INSTRUCTIONAL STRATEGY

PRESENTATION ASSISTANCE:

It is imperative that students understand the basic tissue types before proceeding on to anything else. It is paramount to understand the structure of each cell particularly in terms of cell walls and nuclei as this directly relates to cell and tissue function.

For those who find it difficult to remember which conductive element transports water and which transports "pfood" — phloem and photosynthesis both begin with the letter p.

Primary growth is relatively easy to understand, we are all familiar with watching grass grow. Secondary growth is a more difficult concept, especially since it occurs in two regions, the vascular cambium and the cork cambium. Although the net result is an increase in diameter, cells are not just produced in an outward direction. Phloem cells are produced outwardly, but are pushed against the inwardly dividing cells of the cork cambium.

VISUAL RESOURCES:

Three dimensional models are very helpful, although they are generally better suited to small lectures or laboratory use. In large lecture situations, overheads of 3-D drawings are most appropriate.

Secondary growth is difficult for beginning students. They especially don't understand that when a cell divides one of the daughter cells moves inward and the other outward. One could illustrate this on an overhead using "cells" cut from colored pieces of acetate, with color differentiation being associated with cell type and cell position.

In small classes, a similar thing can be done using students. You play the part of the vascular cambium and sequentially grab two students, one becomes a xylem cell and the other a phloem cell, each gets pushed in a different direction.