PHYSIOLOGY OF TREES

Objectives

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Physiology is the branch of science that deals with life processes. This chapter deals with the life processes of trees. Among these processes is the production and storage of plant foods. The process by which energy from sunlight is captured and plant foods are produced is the most basic of all life processes. The survival of all plant and animal life depends upon it. Other processes that sustain plant life are plans growth, and plant reproduction. Each of these processes plays a vital role in forestry.

OBJECTIVES

After completing this chapter, you should be able to

- explain the importance of photosynthesis in sustaining plant and animal life.
- describe two kinds of high energy molecules that are produced by the light reactions during photosynthesis.
- identify some products that are formed in plants from the simple sugars that are formed during photosynthesis.
- explain the importance of dehydration synthesis in the formation of starch.
- distinguish between the structures of starch and cellulose molecules.
- name the type of cell division that accounts for most of the growth in trees.
- describe the process of meiosis in the production of male and female gametes.
- distinguish between sexual and asexual propagation of plants.
- explain the difference between a hugh forest and a low forest.
- compare the different forms of vegetative reproduction.
- explain how tissue culture technology is used to propagate plants.

TERMS FOR UNDERSTANDING

anaphase
asexual reproduction
ATP
callus tissue
Calvin cycle
cellulose
centriole
centromere
chlorophyll
chromatid
coppice method
dehydration synthesis
diploid
embryo sac
fertilization
gamete
haploid
high forest
homologous chromosome
homologue
hydrogen ion
interphase
layering
light reaction
lipid
low forest
megaspore
megaspore mother cell
meiosis
metaphase
micropyle
microspore
microspore mother cell
mitosis
NADPH
photosynthesis
polar nuclei
pollen grain
propagation
prophase
respiration
sexual reproduction
spindle
spore
sprout method
starch
telophase
tetrad
tissue culture
vegetative reproduction

LIFE FUNCTIONS OF PLANTS

Photosynthesis

All living organisms require energy to sustain life. Some of them, such as animals, fungi and some parasites, obtain energy by eating or extracting energy from other organisms. Plants are unique among organisms because they are able to convert energy obtained from sunlight into food. Trees and other plants capture the energy found in sunlight through a process called **photosynthesis**, a chemical reaction in plant leaves that captures energy from the sun, and combines it with carbon dioxide from the atmosphere to form plant tissues.

Photosynthesis produces two of the most basic needs of animals: food and oxygen.

Animals use the plant tissues produced during plant growth as sources of food. Oxygen is a waste product from the photosynthesis process, but it is a life sustaining element for many other forms of living things. Oxygen is used in animal cells to release energy from nutrients obtained from plant sources. Even those animals that eat flesh of other animals obtain their nutrition indirectly from plants.

Chlorophyll is the green substance found in plants capable of capturing energy from sunlight. Plants use this energy to make sugar from carbon dioxide and water. Chlorophyll is a substance located in a plant cell structure called a **chloroplast**. Chlorophyll is more abundant in the leaves than in any other part of the plant. It is required in two important chemical reactions that convert light energy to chemical energy. These two reactions are called **light reactions**.

The first light reaction occurs when light is absorbed by chlorophyll molecules. This is followed by several steps that lead to the formation of a high energy molecule called **adenosine triphosphate** (ATP). ATP stores electrons in the form of chemical energy in the electrical bonds that attract and hold its phosphate molecules together.

The second light reaction occurs at the same time that light energy is converted to chemical energy during the formation of ATP. Some of the water molecules located in the leaf are split to create oxygen, electrons, and positively charged hydrogen particles called **hydrogen ions**. The hydrogen ions use energy obtained from electrons to bond with a molecule called NADP (nicotinamide adenine dinucleotide phosphate), forming another kind of high-energy, molecule called **NADPH**.

The next phase of photosynthesis is called the **Calvin cycle** during which carbon dioxide from the environment reacts with ATP and NADPH obtained from the light reactions to form simple sugars. These sugars may be used as energy, sources for the plant, or converted to more complex sugars, starches, oils and proteins for storage.

During hours of darkness, stored plant materials tend to decrease. When the photosynthesis process is interrupted, the enzyme reacts with oxygen and reverses the process of photosynthesis. This process is called **respiration**.

Energy Storage

The storage of energy reserves is an active process in plants. It involves the transport of the sugars formed during photosynthesis from the plant leaves to its roots, stems, fruits and seeds. In these locations, the sugars are converted to starches or cellulose. Starches are usually converted back to sugars as plant nutrients during seasons when photosynthesis does not occur rapidly enough to meet the needs of the plant.

Transport of sugars within a plant occurs through the system of tubes located in the phloem issue. Sugar molecules that are dissolved in water move through this system to the different plant tissues. A tree usually converts some sugar molecules to starch molecules as part of its food reserves that are stored in the cortex tissue of roots and in the seeds. A starch molecule is formed when large numbers of glucose molecules bond together in long branching chains. As each glucose molecule becomes attached to a starch molecule a molecule of water is removed. For this reason, the chemical reaction that forms starch from sugars is referred to as **dehydration synthesis**.

Large amounts of the glucose manufactured by a tree are also used to make the **cellulose** molecules that becomes wood fibers. This is a very important biological process to the forest industry. It is this process that forms the xylem tissue in a tree that eventually becomes lumber products. A single cellulose molecule consists of an unbranched chain in which up to 3000 glucose molecules are bonded together.

Plants store some energy in the form of **lipids** such as fats, oils and waxes. Most oils found in trees or other plants are found as deposits in the seeds. For example, the nuts formed by the conifers and many of the hard woods are high in plant oils. Energy deposits in the form of fats and oils contain highly concentrated sources of stored energy. Birds and mammals of many kinds depend on seeds and nuts as sources of energy in their diets.

Growth

Growth occurs in plants as plant tissues become longer or thicker. This is accomplished through cell division and, in some cases, through cell elongation. Cells divide to form new cells throughout the life span of an organism. The type of cell division that occurs

to cause growth in a tree or other forest plant is called **mitosis**. Several steps occur during mitosis. Cells exist for most of their life in a resting or non-reproductive stage called **interphase**. The first stage of active cell reproduction is known as **prophase**. During prophase, the membrane around the nucleus disappears, and the chromosomes appear. Each chromosome is replicated, and each half of the doubled chromosome is known as a **chromatid**. The point where the chromatids are attached is called the **centromere**.

The next step in cell reproduction is **metaphase**. The chromosomes are pulled to the center of the cell by fibers attached to cell structures called **centrioles** that have migrated to opposite sides of the cell. These fibers or **spindles** are attached to the centromeres that connect the pairs of chromosomes together. The chromatids are pulled apart by the spindles as the cell elongates. This step of cell division is known as **anaphase**. A full set of chromosomes becomes evident on opposite sides of the cell during anaphase.

Telophase is the last phase of mitosis. The cell becomes constricted with the cytoplasm shared equally by the two new cells that are forming. A full set of chromosomes eventually becomes separated into each new cell. The membrane around each cell nucleus forms once again, and in plant cells a cell wall begins to develop between the two new cells.

Cells divide through the process of mitosis to form clusters of cells. Cell clusters become specialized to form different kinds of tissues in the organism such as phloem or xylem. Mitosis accounts for most of the growth that occurs in plants, trees and other organisms. Some plant growth occurs in the zone of elongation found in young roots and the tips of growing stems. This type of growth was discussed earlier in this chapter.

Reproduction

A term associated with reproduction in plants is **propagation**. Propagation may occur in nature, or it may be controlled and manipulated by forest workers. In either situation, it occurs in plants in two distinct ways, sexual reproduction and asexual or vegetative reproduction. The most common form of plant reproduction in trees found in forest environments is **sexual reproduction**. This involves the production of seeds by mature trees. Natural reproduction of seeds occurs in most flowering species of trees.

Cell division that occurs to produce seeds is different from the cell division that occurs as plants grow. Part of the seed production process is the formation of reproductive cells, also known as **gametes**. This form of cell division utilizes a process called **meiosis**. The first step in meiosis occurs when chromosomes are duplicated and become aligned in the middle of the cell with their matching chromosomes, also known as **homologous chromosomes** or **homologues**.

Once chromosomes have become aligned, meiotic divisions begin. In the first division, one homologue from each pair of duplicated chromosomes is separated into a different cell mass. The division of cytoplasm is equal in the formation of male gametes known as **spores**. In female gamete pro-duction, this division of cytoplasm is unequal. One of the cell masses is larger than the other.

Each half of a duplicated chromosome is called a **chromotid**. The second meiotic division results in the separation of the paired chromatids in each cell mass resulting in four cell masses from the two that existed after the first meiotic cell division. Once again, the division of cytoplasm between cell masses is equal in the formation of male gametes (spores), but unequal in the formation of female gametes (ova).

The new gamete formed through meiosis consists of one chromatid from each original chromosome pair. It is a **haploid** cell because it contains only half of the genetic material of the cell from which it was formed. The parent cell is a **diploid** cell, meaning that it contains both homologues of each chromosome.

Sexual Reproduction

Most trees and other plants reproduce by sexual reproduction through the formation of flowers. A fertile seed is produced when a **pollen grain** (male gamete) from a male flower part called the stamen merges its genetic material with that of the female gamete or ovule. The process by which this occurs is called **fertilization**. After the ovule has been fertilized, it matures into a seed capable of growing into a new plant.

The stamen consists of the anther and the filament or stalk. The stamen is the male portion of a flower. The anther is the organ in

which pollen grains develop and mature. It is supported and connected to the receptacle, or base of the flower, by the filament. Several anthers are usually present in a flower, and each anther contains four pollen sacs in which pollen grains develop.

Pollen formation begins with the production of **microspore mother cells** inside the pollen sacs. These are diploid cells that contain chromosome pairs. As they begin pollen formation, each cell divides through the process of meiosis that was discussed earlier. A **tetrad** consisting of a cluster of four haploid cells is formed. Later, these four cells pull apart forming four cells called **micro-spores**. The nucleus of each microspore divides one more time, forming a pollen grain consisting of two cells. One cell contains the generative nucleus from which two sperm cells will develop during fertilization of the ovules. The other cell contains the tube nucleus, which is destroyed once it enters the ovule.

Ovule formation begins when a **megaspore mother cell** is produced inside the ovule. It is a diploid cell. This cell divides during meiosis forming four haploid cells called **megaspores**, of which three die. The remaining megaspore grows in size, and its nucleus divides to form two nuclei. Two more divisions occur, and a total of eight nuclei are produced. Each of these nuclei is haploid. Next the eight nuclei move to different locations in the ovule. Three of the nuclei gather near a small opening in the ovule called the **micropyle**. One of these nuclei enlarges and becomes the egg cell. Three other nuclei migrate to the opposite end of the ovule. They will eventually develop cell membranes along with two of the nuclei near the egg cell. The other two nuclei are called **polar nuclei**, and they migrate to the center of the chamber where they form a single cell. They will produce food for the tiny plant embryo.

A total of seven cells is formed, encornpassing the eight original nuclei. These seven cells together comprise the female gamete. This structure is also called the **embryo sac**. At this stage of reproduction, the ovule is mature. Once the pollen grains and the ovules have matured, pollination and fertilization can occur.

Asexual Reproduction

One characteristic of plants that is different from many other living organisms is the capability of a plant to replace missing parts by growing new parts. This process is called regeneration. Some kinds of trees can be propagated from leaf, root or stem tissue. This is a form of **asexual reproduction**, also known as **vegetative reproduction**.

A forest that has been regenerated from the roots, stumps or branches of other trees is known as a **low forest**. A forest been propagated from seeds is called a **high forest**. Both of these types of forests are common in intensively managed plantation forests. Vegetative reproduction has been widely practiced in the forests of Europe since ancient times. Several different vegetative reproduction methods are used to regenerate North American forests.

The **coppice method** or **sprout method** of regenerating trees is practiced by cutting all of the trees in a particular stand at the same time. This is necessary, because live trees are believed to release hormones into the soil that inhibit sprouting. They also compete with young tree sprouts for nutrition. When all of the trees of a particular species are cut, a new generation of trees is frequently induced to grow from the stumps of the old trees. The best example of the coppice method as an effective management practice is in the aspen forests of the Great Lakes region. Entire stands of aspen shoots arise from root suckers when care is taken to cut all of the trees.

The stump-sprout method of forest regeneration is the most commonly practiced form of vegetative reproduction in silviculture. With the exception of the Redwood, vegetative reproduction is ineffective in conifers, but for many other species of trees regeneration from sprouts is both common and effective. For the best results, all of the trees should be cut during the dormant season.

Stump-sprouting is an effective reforestation method, but it does have some problems associated with it. Sprouts that arise too far above the ground seldom develop into useful trees. Sprouts that arise from stumps where stump rot was present in the harvested trees are sometimes at risk of developing rot in the shoots of the young trees. This risk appears to be different among different species of trees. The risk of stump rot can also be reduced by using seedling sprouts instead of stump sprouts. The difference in these two forest regeneration methods is that stumps of trees less than two inches in diameter appear

to consist mostly of sapwood, and little or no heartwood is present from which the stump rot problem arises.

Seedling roots appear to provide more vigorous root systems for saplings resulting in faster growth rates in comparison with the stump-sprout method of propagation. In general, timber rotations should be shorter for stump-sprout stands than for trees produced from seed. This is because the root systems are more likely to die before the trees become large enough for saw-logs. The system works fine, however, for such uses as pulpwood or fuel-wood.

Another form of vegetative reproduction effective in forest regeneration is called layering. This occurs when live branches are buried in the debris on the forest floor. When adequate moisture and sunlight are available, roots are often generated, and live stems arise from the buried plant material.
It has been observed that the shoots arising from plant material from older trees is more vigorous than those produced from young trees. It is also recommended that cuttings be harvested during the period when a tree is dormant. This practice results in more vigorous sprouting than is observed when late spring or summer cuttings are used.

Tissue Culture

A relatively recent technology that will impact forestry is **tissue culture**. This is a method of propagating plants asexually by reproducing entire plants from a single plant cell. This is not unlike the sprouting method of plant propagation, but it is much more sophisticated. Sprouts arise from callus tissue which is undifferentiated plant tissue that has lost its identity as root, stem or leaf tissue. Callus tissue can be manipulated in the laboratory to become either root or stem tissue depending on the plant hormones that are introduced into its environment.

CAREER OPTION: GENETIC ENGINEER

A career in genetic engineering involves changing the genetics of living organisms by isolating desirable genes such as those that provide resistance to diseases. Such genes, along with their resistant qualities, are removed from their original chromosomes and inserted in the chromosomes of other plants that lack resistance to the troublesome disease. A college degree in the combined fields of engineering and the biological sciences or biotechnology is required for entry into this emerging profession. It is anticipated that people engaged in this career will develop new technologies that lead to widespread changes in the kinds of trees that are produced in our future forests.

In combination with genetic engineering techniques, genes that control the expression of desirable traits in specific trees can be introduced into the chromosomes of unrelated trees. This raises the possibility for the fast growth rates of poplar trees to be expressed in the more valuable hardwood trees. We can certainly expect the development of genetically engineered trees that will be resistant to many of the insects and diseases that now devastate some of our forests.

LOOKING BACK

Physiology is the branch of science that deals with life processes. Among the processes discussed in this chapter is photosynthesis, including the production of high energy ATP and NADPH from the two light reactions, and the production of simple sugars during the Calvin cycle. Energy storage is a process that occurs as simple sugars are converted to more complex molecules such as starch and lipids (fats, oils and waxes). Plant growth occurs as plant cells divide through the process of mitosis. A second form of cell division called meiosis occurs in the division of cells to form gametes. Sexual reproduction occurs when male and female gametes join to produce a new plant. Asexual reproduction, also known as regeneration, occurs when new plants are formed from vegetative plant parts. A new method of propagating plants asexually is known as tissue culture. This high tech process generates new plants from single plant cells.

QUESTIONS FOR DISCUSSION AND REVIEW

Essay Questions

1. Explain the importance of the process of photosynthesis in sustaining plant and animal life.
2. What are the two high energy molecules that are found during the light reactions as part of the photosynthesis process?
3. Name some products that are formed in plants from the simple sugars that are produced during photosynthesis.
4. Describe the formation of starch from simple sugars through the process of dehydration synthesis.
5. Name the type of cell division that accounts for most of the growth in trees, and list the steps in the process.
6. Describe the process of meiosis during the formation of male and female gametes.
7. What are the differences between sexual and asexual propagation of plants?
8. How is a high forest different from a low forest?
9. Compare the different forms of vegetative reproduction.
10. What steps are involved in the propagation of plants using tissue culture technologies

Multiple Choice Questions

1. Energy from sunlight is captured and stored in plant tissues through the process of:
   a. Meiosis
   b. Photosynthesis
   c. Dehydration synthesis
   d. Mitosis

2. The green substance found in plant cells that plants use to capture energy from sunlight is called:
   a. Chloroplast
   b. NADPH
   c. Chlorophyll
   d. Cellulose

3. A high energy molecule that is formed during the first light reaction is:
   a. ATP
   b. NADPH
   c. Cellulose
   d. Chlorophyll

4. The phase of photosynthesis during which carbon dioxide reacts with ATP and NADPH forming simple sugars is:
   a. Respiration
   b. Dehydration synthesis
   c. Light reactions
   d. Calvin Cycle

5. Dehydration synthesis is a plant process that is responsible for the formation of:
   a. Starch
   b. Glucose
   c. Cellulose
   d. Chloroplast

6. The fats, oils and waxes that are formed in plants are formed mostly in:
   a. Cellulose
   b. Starch
   c. Seeds
   d. Lignin

7. Which of the following terms is not a stage of mitosis?
   a. Prophase
   b. Comatose
   c. Telophase
   d. Metaphase

8. Meiosis is a form of cell division in which:
   a. Gametes are produced
   b. Asexual reproduction occurs
   c. Plant growth occurs
   d. Callus tissue is formed

9. When sexual reproduction occurs in plants, the name of the male gamete that fertilizes the egg cell is:
   a. Anther
   b. Pollen
   c. Coppice
   d. Chromatid

10. Which of the following terms is Q associated with propagation of plants from live plant parts?
   a. Regeneration
   b. Asexual reproduction
   c. Vegetative reproduction
   d. Megaspore mother cell

11. In plant tissue culture, a term that describes the plant tissue from which new plants develop is called
   a. Sprouts
   b. Filament
   c. Embryo sac
   d. Callus

LEARNING ACTIVITIES

1. Prepare some planting pots and obtain some fresh cuttings from the suckers of a poplar tree or other similar tree species. Make sure there is a well developed bud on each cutting. Have the students "plan" their cuttings beneath a layer of soil and care for them for several weeks. The soil should be kept damp, and the pots should be placed in warm locations for best results. Observe the plantings daily and record the results.

2. Obtain several different kinds of medium to large flowers from a greenhouse or floral shop. Divide the class into small groups and assign each group to identify and label the parts of their flower using straight pins with labels attached. Rotate the groups around the room until they have inspected the flowers at each station, checking to be sure that the flower parts have been correctly identified. Have each student draw and label the parts of a flower.