13.8 External Factors Affecting Plant Growth

Plants, like all organisms, must obtain chemical nutrients from their environment. However, unlike heterotrophic organisms, most plants are able to build their own carbohydrates using raw inorganic materials. They do require a source of light for energy, but their nutrient demands are quite simple. They require carbon dioxide and water, which are essential for photosynthesis, as well as a supply of other basic nutrients needed for the formation of energy-rich organic compounds. Like all aerobic organisms, plants also require oxygen for cellular respiration. They obtain carbon dioxide and oxygen from the air, and water and other nutrients from the soil.

Light Requirements

Earth is constantly being bombarded by sunlight. Each day, an immense amount of radiant energy reaches Earth from the Sun. Of this total, less than 1% is captured by plants in the process of photosynthesis. Green plants trap this light energy using a variety of pigments. Terrestrial plants contain chlorophyll as well as a variety of other pigments, including carotenoids. Chlorophyll absorbs light toward the red and blue area of the visible light spectrum, while carotenoids absorb light toward the blue–green area of the spectrum.

photoperiod: the number of daylight hours

Both the quantity and quality of light influence a plant's ability to perform photosynthesis. The quantity of light is limited by natural environmental factors, such as latitude and competition from taller plants. The quality of light is influenced by shading by other plants, cloud cover, time of day, and angles of incidence during different seasons. The duration of natural lighting is dictated by the seasons. This variable **photoperiod**, with lengthening daylight hours in spring and shortening daylight hours in the fall, affects the productivity and reproductive life cycles of plants. Photoperiodism is the physiological responses of organisms to the varying photoperiods. Different plants react differently to photoperiod length. Short-day plants flower and reproduce when the photoperiods are shortening, while long-day plants flower and reproduce when the photoperiods are lengthening (**Figure 1**). An example of a short-day plant is the chrysanthemum; a long-day plant example is spinach.

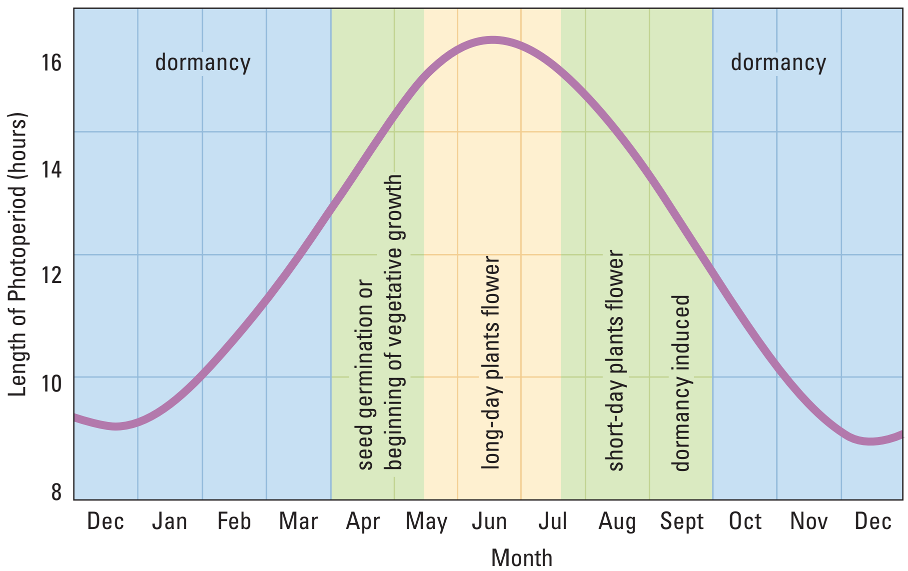

Figure 1
Relationship between number of hours of daylight and plant growth and development. Note that both short- and long-day seeds germinate at the same time, but flowering times differ. The data reflects the responses of plants growing in the upper regions of the Northern Hemisphere.

In artificial environments such as greenhouses or other indoor environments, both the quantity and quality of lighting may be dramatically altered relative to what is happening in the natural environment. The control of lighting and other factors such as temperature, humidity, and soil nutrients permits greenhouse operators to provide whatever growing conditions their plants require whenever the operators wish. By careful regulation of these external factors, plants like greenhouse tomatoes can be stimulated to produce flowers and fruit in the middle of winter in northern Ontario and even at Eureka on Ellesmere Island in the high eastern Arctic, where total darkness prevails several months of the year.

Investigation 13.8.1

The Effect of Light on Plant Growth

INQUIRY SKILLS

- ○ Questioning
- ○ Hypothesizing
- ● Predicting
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Evaluating
- ● Communicating

In this investigation, you will design and conduct an experiment to examine the effects of one variable on the growth rate of seedlings. You will grow your plants in a standard potting soil mix under artificial light. Note: Time the planting of your seeds so that they are just beginning to emerge from the soil when you are ready to begin your experiment.

Questions

Choose one of the following:
How does light duration affect the growth rate of plants?
How does intensity of light affect the growth rate of plants?
How does quality of light affect the growth rate of plants?

Predictions

Choose one of the following that is related to the question you have chosen:
Predict the number of hours of light which will cause your seedlings to grow the most.
Predict the growth difference which will result from a two-hour difference of light per day.
Predict the effect of very bright light on plant growth compared with less intense light.
Predict the brightness which will result in the greatest growth of your seedlings.
Predict the effect of different colours of light on the growth of your seedlings.

Materials

potting soil and trays
adjustable lighting fixtures with timers
light meter
light bulbs of various intensities
bean, radish, or other seeds
assorted coloured cellophane sheets (red, green, yellow, etc.)

Design

(a) Choose only one independent variable for your work: photoperiod, light intensity, or light quality (colour).

(b) Determine how you will adjust your chosen independent variable.
(c) Decide on the method you will use to measure growth rate.
  - What will you measure as a growth indicator? Will you measure more than one thing?
  - How will you record your results?
  - How will you report your results (e.g., in a graph or table format)?
(d) What variables will you need to control? Think carefully to make sure your list is complete and think about how you will control them.
(e) Describe your control setup and what and how you will measure the control.
(f) Decide how many seedlings you will use for each setup.

Procedure

1. Submit your experimental design to your teacher for approval before continuing with the experiment. Your submitted design must have each of the following:
   - title
   - question
   - prediction
   - materials list
   - procedure, including a description of your control setup, methods of varying the independent variable, methods of measuring and recording changes in the dependent variable, and a description of all the variables you will control and how you will accomplish these tasks
2. Conduct your experiment over a period of one to two weeks. Do not allow your plants to become too dry. Keep the soil moist but well drained.

Analysis

(g) How did your chosen variable influence the growth rate of your plants compared to your control?
(h) Describe the findings of students who chose to test a different variable.
(i) How might these results be useful to the operator of a greenhouse? How might some of these results also be useful to a farmer growing field crops?

Evaluation

(j) How did your results compare with those of other students in the class who chose the same variable? Suggest reasons for any differences.
(k) Why was it important to use more than one seedling for both your test group and your control group? What number of seedlings would you suggest if you were going to repeat the investigation? Why?
(l) Growth rates of plants can be measured using several features of the plant. Explain which feature would be the most convenient to measure. Explain which feature would give the most valid measurement of growth.
(m) Suggest ways that you could improve your experimental design.

Soil Nutrients

macronutrients: 9 nutrients required by plants in relatively large quantities (greater than 1000 mg/kg of dry mass)

micronutrients: 8 nutrients required by plants in relatively small quantities (less than 100 mg/kg of dry mass)

There are a minimum of 17 elements now considered by plant nutritionists to be essential for the healthy growth and reproduction of most vascular plants. The nine **macronutrients** are those elements needed in relatively large quantities (greater than 1000 mg/kg of dry mass), while the eight **micronutrients** are those needed in much smaller amounts (less than 100 mg/kg of dry mass). Of the nine macronutrients, carbon, oxygen, and hydrogen, which are the major components of most organic molecules, are obtained primarily from carbon dioxide and water. These elements make up over 95% of the dry mass of plants. The remaining macronutrients (**Table 1**) and all eight micronutrients are obtained as dissolved ions from the soil.

Table 1: Selected Macronutrients

Macronutrient	Functions	Deficiency symptoms	Comments
nitrogen	constituent of amino acids and thus all proteins as well as nucleic acids and chlorophyll; very important for leaf growth	chlorosis: the yellowing of old leaves due to a reduction in chlorophyll	obtained from nitrate or ammonium ions; nitrogen gas cannot be used directly by plants
potassium	involved in water balance, including the operation of the stomata; required for protein synthesis	retarded growth; weak stems; chlorosis of older leaves	present in large amounts in most soils but often in insoluble form
phosphorus	component of ATP, nucleic acids, phospholipids, and some proteins; critical for mitosis and cell division	lack of or poor seed and fruit development; leaves become dark and reddish; stunted growth	present mostly in fruit and seeds as well as in meristematic cells
calcium	constituent of cell walls; involved in membrane permeability	pronounced abnormalities; stunted growth, especially of roots; weakened condition	neutralizes harmful soil acids; presence can facilitate the uptake of potassium
magnesium	component of chlorophyll and **coenzymes**	chlorosis; sometimes reddening of leaves	enhances the uptake of phosphorus
sulfur	component of most proteins	stunted growth; yellow young leaves	usually plentiful in the soil

Studies have shown that for some plants, the nitrogen–phosphorus ratio is more important than the actual amounts of those nutrients. The eight micronutrients—iron, chlorine, boron, manganese, zinc, copper, molybdenum, and nickel—play vital roles in plant physiology. Some of these elements function mostly as **cofactors**, while others have a structural role in specific molecules. They are needed in only minute amounts, yet their absence can cause death or seriously weaken a plant.

Plant nutrient requirements are variable. Recent studies have found that a number of plant species may require elements such as sodium and cobalt, while dicots have been found to have a greater demand for calcium and boron than monocots.

Careful observation of specific symptoms can help in the diagnosis of mineral deficiencies, which can then be confirmed by soil tests. In natural soils, most nutrients are either present in the form of minerals or are locked up in dead organic matter. Nutrients are released in the form of inorganic ions through the physical and chemical weathering of rocks and the decomposition of organic matter by fungi and bacteria. Many nutrients which form positively charged ions, such as potassium ions (K^+), calcium ions (Ca^{2+}), and magnesium ions (Mg^{2+}), bind to negatively charged clay particles within the soil (**Figure 2**, page 538). For plants to absorb these **cations**, they must be released from the clay particles. This release is accomplished in part by hydrogen ions (H^+), which are released from root hairs into the soil. The hydrogen ions exchange places with the positive nutrient ions. The released nutrient ions are then available for uptake by plants. Negatively charged nutrient ions such as nitrate ions (NO_3^-) and sulphate ions (SO_4^{2-}), which are the main sources of nitrogen and sulfur, are not held by soil particles. As a result, they are more easily absorbed by plant roots. However, they are also more easily **leached** away by heavy rains or irrigation. Mycorrhizae, as discussed in Chapter 10, seem to play an important role in the absorption of phosphorus in the form of phosphate ions (PO_4^{3-}) for most plants.

coenzymes: organic molecules necessary for the activity of some enzymes

cofactors: substances necessary for the activity of another substance, usually an enzyme. Coenzymes are organic cofactors.

cations: ions with a positive charge

leached: washed away as a soluble substance by rainwater or a watering system

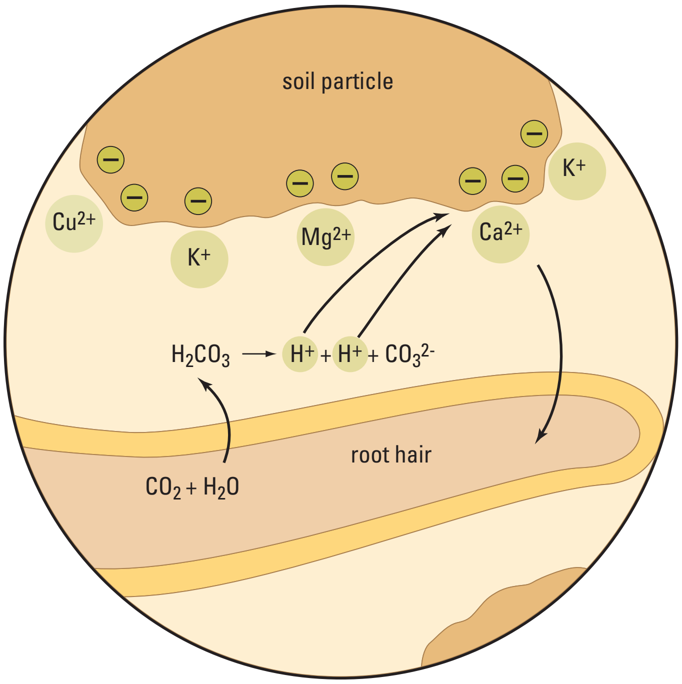

Figure 2
Cation exchange mechanism

When plants are eaten, all the nutrients which they incorporated into their bodies are cycled through herbivores and carnivores. When any living organism releases wastes or dies, decomposers in the environment eventually break down the wastes or bodies and return these nutrients to the soil.

Nitrogen: A Special Case

The nitrogen demands of plants are high, surpassed only by the need for water and carbon dioxide. As nitrogen is a primary component of proteins, those plants which contain a high percentage of protein have a correspondingly high demand for nitrogen. One main reservoir of nitrogen in the environment is the organic matter of living and dead organisms. Dead organic matter is broken down by various bacteria and fungi in a series of reactions which converts the nitrogen compounds first into ammonium ions (NH_4^+), then into nitrite ions (NO_2^-), and subsequently into nitrate ions (NO_3^-), which are readily absorbed by plants through their roots.

The other major reservoir of nitrogen is the atmosphere, which is 79% nitrogen. Unfortunately, the nitrogen gas in air is in a form that is not useful to most living organisms. Atmospheric nitrogen, however, is added to the soil through the action of **nitrogen-fixing bacteria**. These specialized species of bacteria are able to convert nitrogen gas (N_2) from the atmosphere into ammonium ions, which then convert into nitrite ions, and finally into nitrate ions. Although some of these special bacteria live free in the soil, the most important nitrogen-fixing bacteria form symbiotic relationships with plants. These bacteria grow within plant root cells, forming **nodules** (**Figure 3**, page 539). Although many plant species form such relationships, the best known are the **legumes**, such as peas, beans, clover, and alfalfa. The bacteria supply the legumes with nitrates and the bacteria receive a supply of carbohydrates from the plants. The legumes only receive a small portion of the nitrogen compounds manufactured in the nodules. Estimates for the amount of nitrogen added to Earth's soil each year by these bacteria are very large. Natural ecosystems are balanced; thus, other processes must remove nitrogen from the soil. These processes include the removal of plants (such as harvesting of food crops),

nitrogen-fixing bacteria: bacteria that can convert atmospheric nitrogen gas (N_2) into ammonium ions (NH_4^+). They tend to live in nodules on the roots of legumes and have a symbiotic relationship with the legumes.

nodules: swellings on the roots of legumes that contain symbiotic nitrogen-fixing bacteria

legumes: a group of angiosperms, including peas, beans, clover, and alfalfa, which tend to have nodules containing nitrogen-fixing bacteria on their roots erosion, leaching of nitrogen compounds from the soil, and the action of certain bacteria which convert the nitrate ions back to nitrogen gas.

Figure 3
A legume root showing nodules containing nitrogen-fixing bacteria

Practice

Understanding Concepts

1. How do plant nutritional requirements differ fundamentally from those of almost all other organisms?
2. How can technology be used to manipulate photoperiod and why would we want to do this?
3. What are the six soil nutrients needed by plants in the largest quantities?
4. What vital role do nitrogen-fixing bacteria play in the environment?

Applying Inquiry Skills

5. Explain how one year of intensive farming can reduce soil nutrients more than several years of wild plant growth.
6. What might happen if there were no nitrogen-fixing bacteria in the soil in a given area?

SUMMARY External Factors Affecting Plant Growth

1. Unlike animals, plants can create their own carbohydrates from inorganic material.
2. Photosynthesis depends partly on the quantity, the quality (colour), and duration of light.
3. Macronutrients are required in large amounts, micronutrients in small amounts.
   - Carbon, oxygen, and hydrogen are primarily obtained from air and water.
   - All other nutrients are obtained as dissolved ions from the soil.
   - Observation of symptoms can indicate which nutrient is deficient.
4. A cation exchange system exchanges hydrogen ions (H^+) from the roots for cations such as potassium ions (K^+), calcium ions (Ca^{2+}), and magnesium ions (Mg^{2+}), which are bound to clay particles in the soil.
5. Negatively charged ions, such as nitrate ions (NO_3^-) and sulphate ions (SO_4^{2-}), are absorbed quite easily.
6. A plant's greatest demands are for water and carbon dioxide; nitrogen is the next greatest demand.
7. Nitrogen is made available when organic matter breaks down. Atmospheric nitrogen is added to soil through the action of nitrogen-fixing bacteria, which live in nodules on legume roots or free in the soil.

Section 13.8 Questions

Understanding Concepts

1. Explain how both the quantity and quality of light influence plant growth.

(continued)