Plant Growth and Development

Figure 1 shows the remarkable plant commonly known as the walking palm tree. The walking palm requires high amounts of sunshine. When environmental conditions change so that the walking palm is in the shade, it responds in a way that moves the plant to a sunnier site. The projections from its trunk that you see in Figure 1 are adventitious roots. The walking palm always grows more adventitious roots on stems that receive more sunlight. In contrast, any adventitious roots on shaded roots die off. The growth and loss of the adventitious roots moves the stems and leaves so that the entire plant appears to walk toward sunlight. This is an amazing example of how plants respond to changes in their environment.

In order to produce new roots, cells in the palm stem must undergo both growth and differentiation. **Growth** is simply the process of increasing in size, much like blowing up a balloon. **Differentiation** is the process by which a cell becomes specialized to perform a particular function. For the walking palm to move, cells in the stem must differentiate to form all the cell types found in a mature adventitious root.

Figure 1 The walking palm is found in Costa Rica, as well as in other parts of Central America.

Types of Growth

Unlike most animals, most plants continue to grow in height for their entire lives. The increase in height comes from **apical meristems**, which are regions of actively dividing cells found at the apices (tips) of plants. Most plants have apical meristems at the tips of their buds, stems, and roots. All growth from the apical meristems is called **primary growth**. Primary growth always increases the height of a plant, but not its width. In contrast, **secondary growth** is growth that arises from **lateral meristems**, which are areas of actively dividing tissue in the stems and roots. Secondary growth increases the girth (width) of a plant. Some plants do not have lateral meristems, and those plants do not undergo secondary growth. **Figure 2** shows the general locations of primary and secondary meristems in a typical woody plant.

growth the process of cell enlargement

differentiation the process of cell specialization

apical meristem plant tissue composed of actively dividing cells; responsible for primary growth and located at the tip of the root(s) and shoot(s) of a plant

primary growth plant growth originating from the apical meristems throughout the life of the plant; results in increases in length and any growth in the diameter of stems and roots that occurs in the first year

secondary growth growth that occurs from lateral meristems and results in an increase in girth

lateral meristem (cambium) plant tissue consisting of actively dividing cells that produce secondary growth

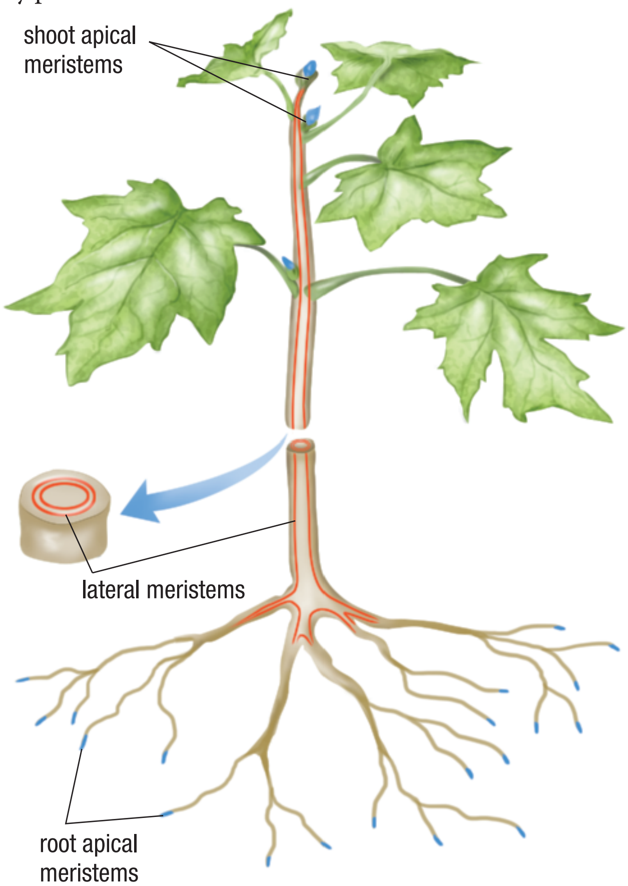

Figure 2 Apical meristems are found at the tips of roots and in shoot buds, and lateral meristems are found mainly in the stems of woody plants.

Primary Growth

Primary growth increases the length of a plant shoot or root. It begins as the cells of the apical meristems divide by mitosis (**Figure 3**). Cell division increases the number of cells. Once cell division has occurred, each cell grows longer. The elongated cells then begin to become specialized (differentiate) into different cell types, such as parenchyma, epidermal, or vascular cell types.

The shoot apical meristem produces the tissues that form stems, leaves, and the organs responsible for sexual reproduction, such as flowers in angiosperms. The differentiation of a cell is, in part, determined by the cell's location. For example, cells on the outermost part of the shoot become epidermal cells, and some of the inner cells will become vascular tissue.

The root apical meristem produces the cells of the root cap and all other cell types in the root. The zones of cell division, elongation, and differentiation (also known as maturation) are more clearly defined in the root (**Figure 4**). The root cap protects the meristem as the root pushes through the soil. Most of the increase in a root's length happens in the zone of elongation. Cell elongation can push the root cap and apical meristem through the soil as much as several centimetres a day.

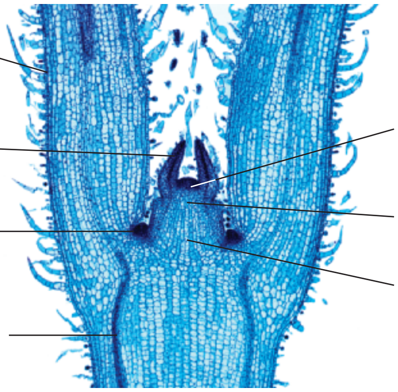

Figure 3 In the shoot, cells in the apical meristems divide; then the newly formed cells elongate and begin to differentiate.

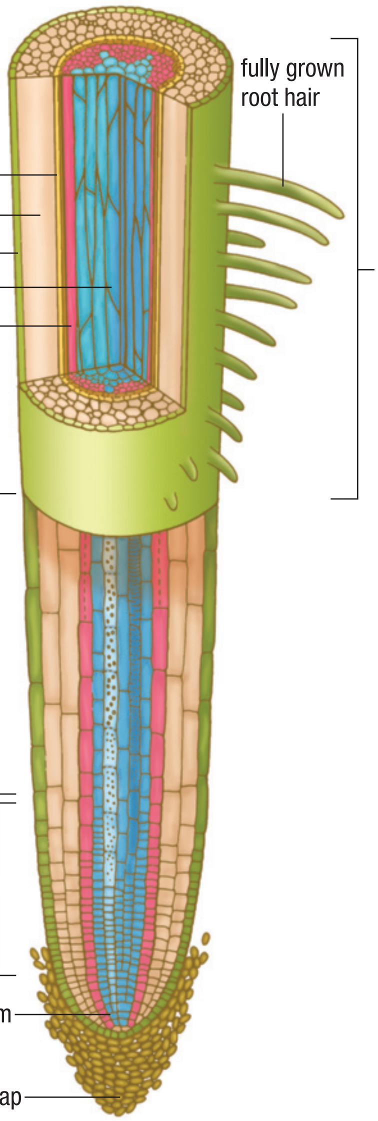

Figure 4 Primary growth from a root apical meristem

All tissue formed from apical meristems is called primary tissue. For example, phloem and xylem that arise from an apical meristem are called primary phloem and primary xylem. As you will see, this helps to distinguish this tissue from tissue produced by lateral meristems.

Secondary Growth

Secondary growth only happens in woody species after the plant's first year. Wood is a product of secondary growth. Secondary growth arises from a lateral meristem, and all tissues that are formed by it are called secondary tissues. Lateral meristems are never at the apex of the shoot or root. Vascular cambium is an example of a lateral meristem. It gives rise to secondary phloem and secondary xylem cells.

After the first year of growth, primary and secondary growth happen simultaneously (**Figure 5**). Woody species continue primary growth and increase in length (height). They also increase in diameter through secondary growth from two lateral meristems. One is the cork cambium, which produces the cells that form the bark. The other is the vascular cambium, which produces secondary xylem and phloem. Vascular cambium is found between the phloem and the xylem in the stem. Each cell division in the vascular cambium produces one new xylem cell and one new phloem cell.

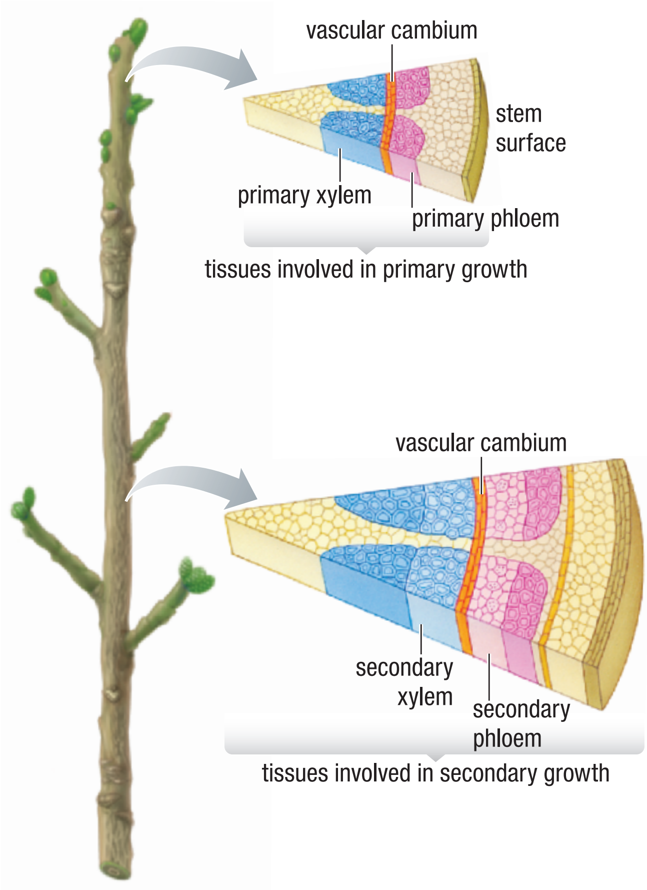

Figure 5 Primary and secondary growth in a woody stem

Each year, the vascular cambium produces new secondary xylem and phloem. The secondary vascular tissue eventually crushes the primary phloem. The amount of growth will vary from year to year depending on the environmental conditions. These variations in environmental conditions produce growth rings of varying thickness that we see in the cross-section of a tree (**Figure 6**). Thus, growth rings can provide valuable information about past climate conditions in a region. A growth ring from a dry year will be a lot thinner than a growth ring from a rainy year. Secondary growth (and thus growth rings) also occurs in roots of woody species.

Figure 6 Growth rings in a conifer tree. Each growth ring consists of a light band and a dark band.

CAREER **LINK**

Plant Physiologist
Plant physiologists conduct research on many aspects of plant growth and development, including how plants respond to environmental factors. To find out more about a career as a plant physiologist,

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Environmental Factors That Affect Plant Growth and Differentiation

The walking palm in Figure 1 is an unusual example of how the environment can affect plant growth. All plants respond to changes in their environment in some way. The main environmental factors that affect plant growth and development are light, water, temperature, and nutrient availability. These factors vary naturally across our planet. The presence of plants and other organisms can change these factors for individual plants, as occurs in succession. Human activity can also change these factors. For example, plants growing in a greenhouse will experience very different environmental conditions than plants growing outside the greenhouse.

Light

You may have seen plant "grow lights" for sale at hardware stores or aquarium stores. Without these special lights, indoor plants may become pale and elongated. Why? We know that plants use the energy in sunlight for photosynthesis. Sunlight is actually a spectrum of different wavelengths of light, each with a different energy level (**Figure 7**). In the visible range of the spectrum, we see these different wavelengths as different colours of light. The "grow bulbs" emit light at wavelengths that promote desirable plant growth.

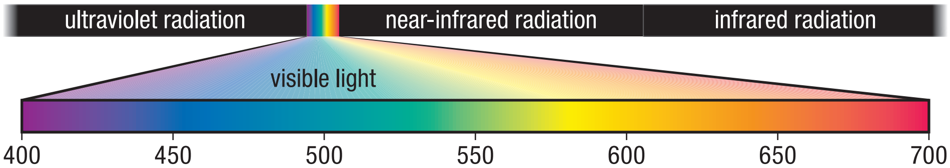

Figure 7 The spectrum of wavelengths in sunlight

In any environment, the particular wavelengths of light (light quality) that reach a plant will vary. For example, the wavelengths that reach a plant at high noon will be different from those reaching the same plant in the early evening. The intensity (brightness) and length of the day also vary. In regions with seasons, such as Canada, light conditions change significantly during the year. Because indoor light levels are typically much lower than outdoor light levels, our houseplants are very shade-tolerant species.

Figure 8 Hikers enjoy the midnight sun on Baffin Island, Nunavut. This picture was taken in late June at about 1:00 or 2:00 a.m.

SEASONAL CHANGES IN LIGHT

The farther a place is from the equator, the more dramatic are the changes in light quality and quantity throughout the year. In Canada's Arctic regions, for example, there is continual darkness from October to March, but continual sunlight in the summer months (**Figure 8**). As the day length changes, the wavelengths of light that reach Earth's surface also change. Plants are able to detect changes in the light conditions through molecules called photoreceptors. A **photoreceptor** is a molecule that reacts when struck by light of a certain intensity and/or wavelength. Different photoreceptors react to light of different wavelengths. As day length changes, the ratio of red light (660 nm wavelength) to far-red light (730 nm wavelength) received at Earth's surface also changes. Photoreceptors respond to this change, and this signals the plant to change its growth and/or development.

photoreceptor a molecule that detects light; different photoreceptors detect different wavelengths of light

Many developmental changes in plants are regulated by light. For example, photoreceptors play an important role in the changes in deciduous trees we see each spring and fall. The seeds of some plants, such as lettuce, require specific light conditions to germinate. Other seeds, such as those of many lilies, will not germinate in the presence of light.

PHOTOPERIODISM

photoperiodism a plant's response to changing day length

Photoperiodism is a plant's response to changes in day length. In some species, timing of flowering is an example of photoperiodism. For example, tulips and chrysanthemums often only initiate flowering when days are short (under 12 h). Plants that flower only when days are short are called short-day plants. Other plants, such as spinach, are long-day plants and flower only when there are 12 h or more of daylight. In other species, such as tomato and rose plants, flowering is not affected by day length at all. These are called day-neutral plants.

Photoperiodism can ensure that a plant flowers only when other environmental conditions are likely to be best for reproduction. It may ensure that a plant flowers when its pollinators are present or when there is likely to be a lot of rain, such as in spring. Photoperiodism can also determine where a plant can survive. A long-day plant, such as spinach, would never flower near the equator, because the days are never long enough.

Nutrients

Plants do not need to "eat" food. Instead, plants assemble all of their own carbohydrates, fats, proteins, and other needed molecules from simple inorganic substances. These simple inorganic substances are referred to as plant nutrients and must be obtained from the environment. There are two categories of plant nutrients: macronutrients and micronutrients. **Macronutrients** are nutrients that are needed in larger quantities (more than 1000 mg/kg of dry mass). Nitrogen (N), phosphorus (P), and potassium (K) are macronutrients. Farmers and gardeners often add these nutrients to soil by applying fertilizer. The numbers you see on bags of fertilizer refer to the relative concentrations of these three nutrients (**Figure 9**).

macronutrients plant nutrients needed in large quantities

Figure 9 The numbers on these bags of fertilizer refer to the percentage of nitrogen, phosphorous, and potassium, in that order.

Table 1 lists plant macronutrients and the symptoms of nutrient deficiency. Note that the first three macronutrients in Table 1 are absorbed from the gases in the atmosphere (carbon and oxygen) or are obtained from water itself (hydrogen and oxygen). The remaining nutrients are obtained as dissolved ions from water in the soil and are taken up by the plant's roots. **Figure 10** shows a plant suffering from chlorosis, which is yellowing of older leaves. This is a symptom of either nitrogen or magnesium deficiency.

Figure 10 The chlorosis of the leaves of this canola plant is due to nitrogen deficiency.

Table 1 Plant Macronutrients and Their Functions

Element	Commonly absorbed forms	Some known functions	Some deficiency symptoms
carbon (C)	CO_2	synthesis of all organic compounds	rarely deficient; available from the atmosphere
hydrogen (H)	H_2O	synthesis of all organic compounds	available from water; incapable of growth without it
oxygen (O)	CO_2, H_2O, O_2	release of energy through cellular respiration	available from the atmosphere and as a product of photosynthesis; cells die without it
nitrogen (N)	NO_3^-, NH_4^+	production of proteins, nucleic acids, chlorophyll	stunted growth, chlorosis
phosphorus (P)	$H_2PO_4^-$, HPO_4^{2+}	production of nucleic acids, membranes	purplish veins, stunted growth, fewer seeds or fruit
potassium (K)	K^+	activation of enzymes, cellular transport mechanisms	reduced growth, curled or spotted older leaves, burned leaf edges
calcium (Ca)	Ca^{2+}	formation and maintenance of cell walls; membrane transport mechanism	deformed leaves, poor root growth, death of buds
sulfur (S)	SO_4^{2-}	production of proteins	pale green leaves or chlorosis, slow growth
magnesium (Mg)	Mg^{2+}	production of chlorophyll; activation of enzymes	chlorosis, drooping leaves

micronutrients plant nutrients needed in small quantities

Micronutrients are nutrients that plants need in only very small amounts (less than 100 mg/kg of dry mass). There are eight micronutrients: boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc. These nutrients are involved in a wide range of cellular processes, including chlorophyll synthesis, cell division, and enzyme production.

Research This

The Three Sisters

Skills: Researching, Analyzing, Evaluating, Communicating, Identifying Alternatives, Defending a Decision SKILLS HANDBOOK A5.1

The Iroquois peoples in North America protected the nutrient content of the soil they used for agriculture by growing certain plants together. The best known of these were called the three sisters: squash, corn, and beans. Each of these species supported the growth of the other in a certain way. These three species also supplied much of the nutrients needed to support the human population.

1. Working in a group, find out how the three sisters were grown and what role each of the plants played (**Figure 11**).

A. How did the three sisters help maintain the soil? T/I

B. Did growing the three sisters together have any other advantages? T/I

C. Describe how you could plant a three sisters garden. T/I A C

D. The three sisters are an example of companion planting. Find a general definition for companion planting. T/I

E. Do you think people should use companion planting in their gardens? Explain why or why not. T/I A

Figure 11 The three sisters

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Temperature

The rate of all cellular processes is affected by temperature. In general, there is a specific temperature range at which these processes perform best. The opening and closing of the stomata are affected by temperature. Transpiration is highest on hot sunny days when the stomata are open (**Figure 12(a)**). If the plant cannot pull enough water from the soil to replace the water lost through transpiration, it will start to wilt. To prevent excess water loss, the stomata close (**Figure 12(b)**). If the temperature is above or below the plant's optimum range, the plant will grow more slowly.

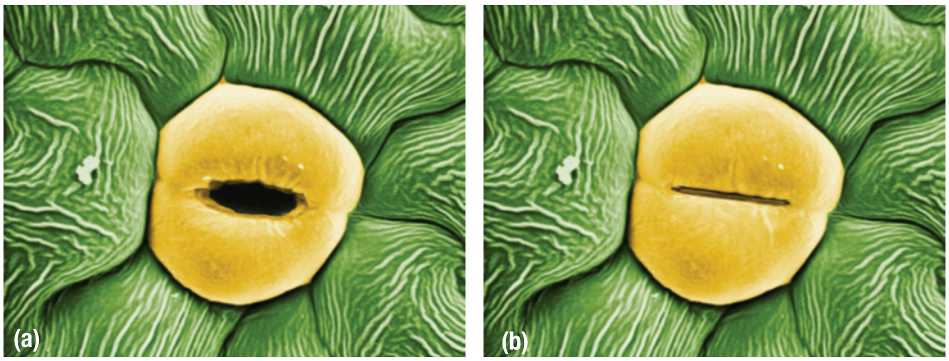

Figure 12 (a) An open stoma allows water vapour to leave the leaf. (b) A closed stoma prevents transpiration from occurring.

For many plants, temperature also acts as a signal to begin a developmental stage. For example, the seeds of many tree species, such as loblolly pine, will germinate only after undergoing a period of cold treatment (**Figure 13**). This requirement increases the chances that the seed will germinate in the spring, when there is a greater chance that the seedling will survive.

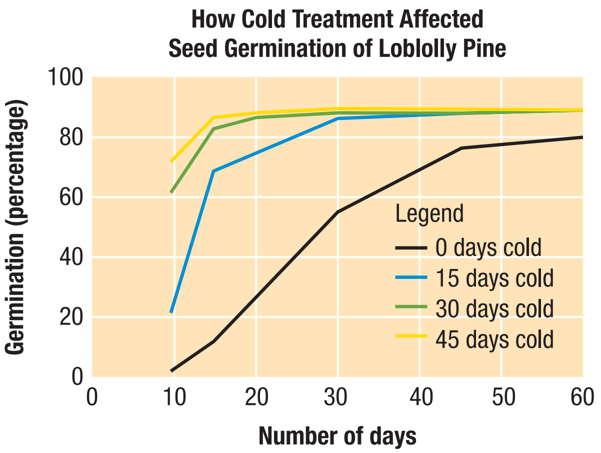

Figure 13 In this experiment, seeds of loblolly pine were moistened and then stored at 4 °C for 0 to 45 days. They were then left at room temperature for 60 days. The number of seeds that germinated over the 60-day period was counted to get the percentage germination.

The timing of the flowering of many angiosperms is affected by temperature. This increases the chance that flowering occurs when environmental conditions will support seed formation. For example, species that depend on pollinators must be in flower when their pollinators are present. If these species flower too early or too late for their pollinators, they will be unable to produce fertile seeds.

CLIMATE CHANGE

Earth's average temperature has increased over the last century and is predicted to increase further. This increase is mainly due to human activity. In 2010, scientists analyzed 400 000 records of first flowering dates from 405 angiosperm species in the United Kingdom. They found that for every 1 °C increase in temperature, flowering occurred five days earlier, on average. Over the last 25 years, flowering occurred 2.2 to 12.7 days earlier than in any previous 25 year period since 1760. Earlier flowering can break the link between flowering date and the appearance of insect or bird pollinators. For example, the serviceberry is a common flowering shrub in Ontario and an important source of food for many wildlife species (**Figure 14**). It relies on photoperiod to time its flowering. Unlike many other species, temperature does not influence when it flowers. The serviceberry used to be the first shrub to flower in spring. But because average temperatures have risen, today other plants flower at the same time as the serviceberry does, so it has to compete for pollinators.

Soil

Soil plays three roles: (1) it provides a medium in which plant roots can anchor, (2) it retains water, in which nutrients are dissolved, and (3) it provides the root with air. The characteristics of soil can dramatically affect plant growth and development. Soil that is very sandy does not hold water well, so it dries out quickly. Soil with too much clay does not have many air spaces and holds too much water, which can cause the plant to drown. Soil must also have sufficient humus. Humus is organic matter made up of the partially decomposed remains of organisms. Humus is the main source of many nutrients needed by the plant, particularly nitrogen. These nutrients are released by the action of soil micro-organisms and fungi.

Investigation 13.5.1

Temperature, Light, and Seed Germination (page 620)
After reading about seeds, you can complete Investigation 13.5.1.

In this controlled experiment you will investigate how radish seeds germinate under different conditions.

Investigation 13.5.2

Factors Affecting Plant Growth and Differentiation (page 621)
Now that you have learned about some of the factors that influence plant growth, you may want to do Investigation 13.5.2.

In this student-directed controlled experiment you will choose an environmental factor and investigate its effect on plants.

Figure 14 Climate change means the serviceberry must compete for pollinators.

Figure 15 Plants can be grown without soil. These cucumber plants are growing in a nutrient solution.

The pH of soil also affects plant growth and development. Soil can be acidic (low pH), basic (high pH), or neutral (pH of 7.0). The pH of soil really refers to the pH of the water in the soil. Soil pH determines whether the macronutrients and micronutrients will dissolve in the soil water and be in a form that can be taken up by the roots. Most plants prefer mildly acidic soil.

However, soil is not necessary for a plant to survive. Commercial growers sometimes produce plants in mixtures that include no soil, or even in nutrient solutions (**Figure 15**).

13.5 Summary

- Growth is a change in the number and size of cells. Differentiation is a change in the function of a cell (specialization).
- Primary growth arises from cell division in apical meristems. Secondary growth arises from lateral meristems.
- The quality, quantity, and timing of light affect growth and development in many plants.
- Healthy plant growth and development depend on specific macronutrients and micronutrients.
- Temperature affects the rate of growth and also promotes or inhibits particular stages of development in many plants.
- Soil characteristics and the pH of soil water affect plant growth and development.

13.5 Questions

1. In your own words, write definitions for the following terms: growth, differentiation, primary growth, secondary growth, apical meristem, lateral meristem K/U C
2. During an investigation, a student makes a cross-section of root in the region close to the tip that has no root hairs. Predict the cell and tissue types the student will see. Give reasons for your predictions. K/U T/I A
3. What are the three most important nutrients for plant growth? K/U
4. Compare and contrast primary and secondary growth in a woody stem. K/U A
5. Most commercial fertilizers contain only macronutrients. Why? K/U
6. The leaves on a plant in your garden begin to turn yellow. From this observation alone, can you predict which nutrient the plant lacks? Explain. K/U A
7. Over the last 30 years, there has been a relatively modest increase in the acidity of soil water (due to acid rain). However, scientists have found a significant decrease in the growth of forests around the world. Form a hypothesis as to why this is happening. K/U A
8. Soil pH can vary considerably, and air pollution in the form of acid rain can alter the pH of soils. Use the Internet and other sources to determine the ideal soil pH for a variety of different plant species. Report your findings to the class. T/I C
9. Organic farmers use a variety of sources of nutrients to maintain healthy soil. Visit a local garden centre or go online to find out what sorts of organic fertilizers are available. What might be some advantages and disadvantages of using these fertilizers? T/I A
10. In 2008, heat and drought in the Black Sea region of Eastern Europe caused widespread crop loss, such as the sunflower crop shown in **Figure 16**. These conditions caused a huge increase in the price of many food staples in the region. Which do you think caused the most crop damage: the increase in temperature or the lack of water? Explain. Was the increase in food prices caused entirely by the crop failure? K/U A

Figure 16 A damaged sunflower crop in the Black Sea region

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