SBI3U-C

Lesson 14

Plant Growth and Development

Introduction

Plant growth is the process by which a plant grows from a seed into its mature form. We need to understand plant growth and development, because that is what provides us with food and natural resources like wood. Plant growth is dependent on many factors including climate, soil, nutrients, and bacteria. You will learn how each of these affects plant growth and how we manage them to get the results we want. You will also learn how plant hormones are used to direct the growth and development of plants.

Plant growth depends on the climate. As humans change the global climate, we change the growing conditions for many species of plants faster than they can adapt. You will examine the impact of climate change on Canada's forestry industry and analyze a report on the possible impact of climate change on the world's plant biodiversity.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Importance of Plant Growth	½
Conditions Needed for Plant Growth	1
Plant Adaptations	1
Plant Hormones	½
Key Questions	1

What You Will Learn

After completing this lesson, you will be able to

- describe the formation and importance of soil
- describe the various factors that are required for plant growth and development
- describe the effects of plant hormones
- describe the effects of global warming on Canadian forests and the forest industry

Importance of Plant Growth

As you learned in the previous lesson, humans can't survive without plants. Besides food, plants provide us with other critical natural resources to fuel our expanding economies. One of the most important of these is wood. In Canada, the harvesting of wood through the forestry industry is a major economic force in many communities, particularly in the boreal and coastal forests of the North and West. This industry depends on successful growth of forests, now and in the future.

Figure 14.1: Photograph of clear-cutting in a boreal forest

Source: Wikipedia

Forestry is regulated in Canada to help reduce the environmental impacts of clear-cutting (Figure 14.1) and other practices. Sadly, in other parts of the world, particularly in areas with tropical rainforest, there is a lot of unregulated and illegal logging. The result is that most of the earth's remaining tropical forests are under threat of destruction. Even if illegal logging and clear-cutting were to stop tomorrow, forests everywhere still face another danger: climate change.

The consequences of climate change for Canada's forests and the forestry industry are potentially very dramatic. Two of the most immediate are forest fires and outbreaks of insects. Fire is a natural and critical part of healthy forest ecosystems in Canada (Figure 14.2), but climate change appears to be causing more large-scale fires than usual. As the climate warms, forests in Canada experience drier conditions, and even severe droughts, which make fires more likely.

Figure 14.2: Forest fire in a western coniferous forest

Source: Wikipedia

Additionally, the frequency, duration, and extent of insect infestations of forests are predicted to increase with climate change. One already has: the mountain pine beetle lays its eggs in the bark of pine trees of western Canada and the larvae burrow into the tree, creating holes that eventually lead to the death of the tree (Figure 14.3).

Figure 14.3: A pine tree infested with mountain pine beetles. You can see the holes burrowed through the bark.

Source: Wikipedia

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

18. What are two advantages of preserving Canada's natural forests? Suggested answer

19. Describe two threats to Canada's forests. Suggested answer

Conditions Needed For Plant Growth

Three conditions must be met for plant growth to flourish: there must be soil, nutrients, and, in many cases, a particular kind of bacteria known as rhizobia.

Soil

Soil is more than the layer of "dirt" that lies on top of the ground. It is a complex living community that is vital to the growth and development of plants. Soil, and the organisms that live in it, determine the nutrient and water availability for plants. For example, soil organisms decompose organic matter, cycle nutrients, enhance soil structure, and control the populations of other organisms, both beneficial and harmful. In turn, plant residues and the by-products of growing roots feed soil organisms.

Some functions of a healthy soil ecosystem include

- decomposing organic matter into humus,
- retaining water,
- retaining nitrogen and other nutrients,
- making retained nutrients available to the plant,
- binding soil particles together for optimal structure,
- protecting roots from diseases and parasites, and
- producing hormones that help plants grow.

Soil Structure

Soil is made of three components: minerals, organic matter (plant and animal), and the organisms that live in its upper layers. Soil is formed slowly as rock (the parent material) erodes into tiny pieces near the earth's surface by the natural weathering action of wind, water, glaciers, and change in temperature. These weathering agents break rock into finer and finer grains that are eventually deposited on the ground in layers. Decaying organic matter then mixes with the inorganic material (rock particles, minerals, and water) to form soil.

There are many different types of soil, and each one has unique characteristics such as colour, texture, structure, and mineral content. The depth of the soil also varies. The type of soil in an area helps determine what plants can grow there.

Soil Formation

Microorganisms in the soil convert the decaying plant material into organic molecules that can be used by other organisms. Some are simple molecules, such as sugars, amino acids, and cellulose, which are readily consumed by many organisms. For this reason, they do not remain in the soil for a long time. Other more complex molecules from plants, such as resins and waxes, are more difficult for soil organisms to break down and, eventually, these residues help form humus.

Humus

Humus is the result of successive steps in the decomposition of organic matter. The term humus is often used by gardeners to mean the organic material that makes soil brownish, but not all of that is humus. Humus is made up of the non-cellular parts of organisms after they decompose. During decomposition, everything else in the cell breaks down and gets recycled into other organisms, leaving the humus in the soil. In nature, humus accumulates in soil because it lasts for hundreds or even thousands of years.

Many of the substances in humus enhance plant growth. Some of these substances function as natural plant hormones (such as auxins and gibberellins, which you will learn about later), and are capable of improving seed germination, root initiation, and uptake of plant nutrients. Other substances help create the physical conditions that keep the soil moist, cool, and capable of supporting a diversity of important soil organisms.

Soil pH

Soil pH is a measure of the acidity or alkalinity of soil, and is measured in pH units. All plants have different pH preferences. Mosses, for example, grow well in acidic soil.

The pH level of the soil directly affects the availability of essential nutrients for plant growth. When soil is acidic, minerals such as zinc, aluminum, manganese, and copper are soluble and available for plant uptake. If the soil becomes too acidic, these minerals can be absorbed in excessive quantities, becoming toxic to plants. Alkaline soil, on the other hand, may contain a higher quantity of bicarbonate ions, and this can affect optimum growth in plants by interfering with the normal uptake of other ions. The most common range of soil pH is 4 to 8 pH, and the range for optimal availability of plant nutrients for most crops is 6.5 to 7.0 pH.

Soil Compaction

Soil compaction occurs when soil particles are pressed together, reducing the space between them (also called pore space). Heavily compacted soils such as those found in urban centres contain few large pores, and have a reduced rate of both water infiltration and drainage from the compacted layer. This occurs because large pores are the most effective way for water to move through the soil. In addition, the exchange of gases slows down in compacted soils, causing an increase in the likelihood of problems related to poor aeration. Plants have a hard time growing in compacted soil because their roots must exert greater force to penetrate the compacted layer.

Careers in Soil Science

Because of the complexity and importance of soils, the study of it has its own scientific discipline. A scientist who studies soil is called a pedologist. Professional education in soil science is offered at major universities in Canada. For example, the universities of Saskatchewan, Manitoba, Guelph, and Québec (Laval) all have programs where you can study soil science in departments like geography, renewable resources, or earth sciences. Most universities offering soil-science programs award Bachelor's, Master's and Ph.D. degrees. Some of the major areas of study include soil biology, soil chemistry, soil physics, soil fertility, soil classification, mineralogy and conservation, soil contamination and remediation, land classification, and forest soils.

Support Questions

20. How is soil formed? Suggested answer

21. What is a soil scientist called? Suggested answer

22. List four functions of soil organisms. Suggested answer

23. List four functions of a healthy soil ecosystem. Suggested answer

24. Why is knowledge of soil pH important? Suggested answer

Nutrients

Unlike animals—which obtain their nutrition from the food they eat—plants obtain their nutrition from the soil and atmosphere. Using sunlight as an energy source, plants are capable of making all the organic macromolecules they need by modifying the sugars they form through photosynthesis. However, plants require several mineral elements for growth, and must take up these minerals through their root systems. The elements that are necessary for plants to complete their life cycle are called essential plant nutrients. Each of these nutrients has a critical function in plants, and is required in varying amounts in plant tissue.

Macronutrients are nutrients required in the largest amount in plants; these include nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. Micronutrients are required in smaller amounts; these include iron, copper, manganese, zinc, boron, molybdenum, and chlorine. Nutrient deficiency or toxicity symptoms often differ among species and varieties of plants. A nutrient deficiency occurs when the nutrient is not present in sufficient quantity to meet the needs of the growing plant. Nutrient toxicity occurs when a nutrient is present in excess quantity, and decreases plant growth or quality.

Table 14.1, below, describes the general symptoms of nutrient deficiency and excess often observed for primary macronutrients.

Plant nutrient	Type	Visual symptoms
Nitrogen (N)	Deficiency	Light green to yellow appearance of leaves (chlorosis), especially older leaves; stunted growth; poor fruit development.
	Excess	Dark green foliage which may be susceptible to lodging, drought, disease, and insect invasion. Fruit and seed crops may fail to yield.
Phosphorus (P)	Deficiency	Leaves may develop purple coloration (anthocyanosis); stunted plant growth; delayed plant development.
	Excess	Excess phosphorus may cause micronutrient deficiencies, especially iron or zinc, resulting in chlorosis or necrosis.
Potassium (K)	Deficiency	Older leaves turn yellow initially around margins (chlorosis) and die (necrosis); irregular fruit development.
	Excess	Excess potassium may cause deficiencies in magnesium and possibly calcium, resulting in chlorosis and possibly stunted growth.

Table 14.1: Symptoms of primary macronutrient deficiency or excess in plants

An example of a plant suffering from nitrogen deficiency (chlorosis) is shown in Figure 14.4. This is the most common nutrient deficiency people see in their garden plants.

Figure 14.4: A young cabbage plant exhibiting the pale green leaves typical of nitrogen deficiency

Source: Wikipedia

Organic vs. Inorganic Fertilizers

A fertilizer is any material, organic or inorganic, natural or synthetic, that provides the necessary nutrients for plant growth. Fertilizers can be applied to soil before seeds are sown, at the time of planting, or while the plants are growing. Fertilizers can also be added when transplanting vegetables, flowers, trees, shrubs, and other types of plants to new soil. Fertilizers may contain any or all of the nutrients required for plant growth, but almost all fertilizers contain the three essential nutrients of nitrogen (N), phosphorus (P), and potassium (K). The concentrations of these three nutrients are usually listed on the labels of commercial fertilizers so you can decide which fertilizer is best for your plants. The concentrations are often shown as a ratio among the elements N, P, K; for example, 10N:5P:5K.

Organic fertilizers are made from natural materials such as manure, crop residues, household waste, compost, and woodland litter. Inorganic (or mineral) fertilizers are traditionally mined from mineral deposits such as lime (calcium), potash (potassium), or phosphate rock (phosphorus). Inorganic fertilizers can also be manufactured through chemical processes, often using fossil fuels as the source, to produce nitrogen fertilizer.

There are advantages and disadvantages to using each type of fertilizer. The main advantage of using organic fertilizers is that, compared to mineral fertilizers, they are usually found on the farm naturally and available at low cost. Other advantages of using organic fertilizer include increased organic matter in the soil, reduced erosion, better water retention, and that their effect can last for years after their application. The main disadvantage of organic fertilizers is that they are generally slower acting than inorganic fertilizers.

The main advantages of inorganic fertilizers are that they make nutrients rapidly available to plants and that the exact amount of a given element can be measured before feeding plants. The main disadvantage to using inorganic fertilizers is that the nutrients are released very quickly into the soil after application, which means they may run off or leach out of the soil during rain or irrigation to pollute local streams. They can also rapidly build up in the soil, forming salts that can eventually become toxic to plants.

Support Questions

25. On a bag of fertilizer at the store, you notice the following information: 50N:25P:25K. What do the letters N, P, and K stand for? Suggested answer

26. You notice a plant in your house with the following characteristics: purple coloration on leaves, stunted plant growth, and delayed plant development.

a) Is this a result of an excess or a deficiency of a nutrient?

b) What is the nutrient? Suggested answer

27. What leaf colour do you expect to find on plants grown in solutions lacking nitrogen? Suggested answer

28. Why is nitrogen such an important nutrient for plants? Suggested answer

29. What is a fertilizer? Suggested answer

30. List five benefits of using organic fertilizer. Suggested answer

31. State one advantage and one disadvantage of using an inorganic fertilizer. Suggested answer

Rhizobial Bacteria

Nitrogen is one of the most important chemical elements for plants. If there is not enough nitrogen available in the soil, plants look pale and their growth is stunted. One source of nitrogen in the soil comes from the air. The atmosphere contains more than 78% nitrogen in the form of nitrogen gas (N_2); however, plants can't use nitrogen in this form directly.

Some plants have the ability to form a symbiotic relationship with a type of bacteria called rhizobia to help them convert nitrogen gas in the air into ammonia (NH_4^+), which is a form that plants can use. The bacteria live inside the root hairs of the plant and naturally produce ammonia in a process called nitrogen fixation (or "fixing" nitrogen). The plant forms nodules (lumps) around where the bacteria are living. These nodules are the sources for the ammonia that get taken up by the plant's roots.

The relationship is symbiotic: the plants benefit by obtaining nitrogen for growth, and the bacteria benefit from being protected inside the plant's roots and obtaining some of the food produced by the plant. The majority of nitrogen-fixing plants on earth are legumes like beans, clover, and peas (Figure 14.5). Some trees, like the alder, also fix nitrogen in this way.

Figure 14.5: The snow pea is a crop that also helps to fertilize the soil through nitrogen fixation.

Source: Wikimedia Commons

Nitrogen fixation by rhizobia is of great importance to agriculture in several ways. First, legumes such as peas, beans, lentils, soybeans, alfalfa, and clover help feed the meat-producing animals of the world as well as humans. Legumes also grow well in poor soils where there is not enough fixed nitrogen to support other types of plants, so they are used to enrich soils for uptake by later crops. After harvest, the legume roots are left in the soil to decay, releasing organic nitrogen compounds for the next generation of plants.

Farmers take advantage of this natural fertilization by planting a leguminous crop one season, followed by a non-leguminous one in the same field the next season. This process, known as crop rotation, reduces the need for commercial fertilizers, which saves money and helps prevent the problems brought about by excessive use of commercial fertilizers.

Support Questions

32. Why do farmers rotate a leguminous crop with a non-leguminous one? Suggested answer

33. How do rhizobial bacteria help add nitrogen to the soil? Suggested answer

Plant Adaptations

Deforestation and climate change are occurring so quickly that plants now have little or no time to adapt to their altered environments. How plants may adapt to rapid climate change is an area of intense research. Many scientific reports and articles are being written on this topic. For example, an analysis of more than 5000 plant species reveals that woody plants, such as trees and shrubs, adapted to past climate change much more slowly than herbaceous plants did. In some cases, this failure to adapt could lead to the total elimination of certain types of plants found at certain latitudes.

These scientific articles can be difficult to read and understand at first, but with practice you can learn how to summarize their findings. You will gain some practice at this in the next section.

Writing a Science Article Summary

The best way to learn how to summarize a science article is through practice. In this section, you will be asked to write a summary of a scientific article. To do this, you must answer the four questions of research, which you will recall from Lesson 10.

1. What was done?
2. Why was it done?
3. What was found?
4. What does it all mean?

Read the following article from Science*Daily*, then answer the Support Questions that follow.

Woody Plants Adapted To Past Climate Change More Slowly Than Herbs

Science*Daily* (Sep. 27, 2009)—Can we predict which species will be most vulnerable to climate change by studying how they responded in the past? A new study of flowering plants provides a clue. An analysis of more than 5000 plant species reveals that woody plants—such as trees and shrubs —adapted to past climate change much more slowly than herbaceous plants did. If the past is any indicator of the future, woody plants may have a harder time than other plants keeping pace with global warming, researchers say.

In a new study, biologists at the National Evolutionary Synthesis Center and Yale University teamed up to find out how flowering plants adapted to new climates over the course of their evolution. By integrating previously published genealogies for several plant groups with temperature and rainfall data for each species, they were able to measure how fast each lineage filled new climate niches over time.

When they compared woody and herbaceous groups, they found that woody plants adapted to new climates 2 to 10 times slower than herbs. “Woody plants eventually evolved to occupy about the same range of climates that herbaceous plants did, but woody plants took a lot longer to get there,” said lead author Stephen Smith, a postdoctoral researcher at the National Evolutionary Synthesis Center in Durham, NC.

The researchers trace the disparity to differences in generation time between the two groups. Longer-lived plants like trees and shrubs typically take longer to reach reproductive age than fast-growing herbaceous plants, they explained. "Some woody plants take many years to produce their first flower, whereas for herbs it could take just a couple months," said co-author Jeremy Beaulieu, a graduate student at Yale University.

Because woody plants have longer reproductive cycles, they also tend to accumulate genetic changes at slower rates, prior research shows. "If genetic mutations build up every generation, then in 1000 years you would expect plants with longer generation times to accumulate fewer mutations per unit time," said Smith. This could explain why woody plants were slower to adapt to new environments. If genetic mutations provide the raw material for evolution, then woody plants simply didn't accumulate mutations fast enough to keep up. "If woody and herbaceous plants were running a race, the herbs would be the hares and the woody plants would be the tortoises," said Beaulieu.

By understanding how plants responded to climate change in the past, scientists may be better able to predict which groups will be hardest hit by global warming in the future. Unlike the tortoise and the hare, however, in this case slow and steady may not win the race. "Woody groups are obviously at a disadvantage as the climate changes," Beaulieu explained.

Does this mean that ecosystems dominated by trees—such as rainforests—will be more likely to disappear? Possibly. "If we look to the past for our clues, chances are trees will continue to respond much slower than herbs—as much as 10 times slower," Smith said. "But if the rate of climate change is 100 times faster, then they could all be in trouble. The kind of change we're experiencing now is so unprecedented," he added. While this study focused on long-term change over the last 100 million years, most climate models predict significant warming in the next century, the researchers explained. "That time frame may be too quick for any plant," Beaulieu said.

The National Evolutionary Synthesis Center (NESCent) is an NSF-funded collaborative research center operated by Duke University, the University of North Carolina at Chapel Hill, and North Carolina State University.

Source: Science*Daily*

Support Questions

34. What was done? Suggested answer

35. Why was it done? Suggested answer

36. What was found? Suggested answer

37. What does it all mean? Suggested answer

Plant Hormones

A hormone is any chemical substance produced in one part of an organism that has a target elsewhere in the organism. Plant hormones play a central role in controlling the way plants grow and develop. Plant hormones regulate the growth of the individual parts and integrate them to produce the forms we recognize as plants.

Auxins

Auxins are a class of plant hormones produced in the meristems (growth areas) of plants. They are responsible for promoting cell elongation, a process that is required before differentiation of a cell can occur. Auxins support elongation by promoting the intake of water, which increases the elasticity of the cell as it copes with the greater amount of water taken in. Auxins have two main functions: to promote tissue growth and to control bud formation.

Role in Root and Shoot Growth

One of the most common auxins is indole acetic acid (IAA), which affects the root and shoot tips of the plant. Depending on where it is located, IAA either promotes or inhibits growth. One effect of adjusting the level of IAA is to allow the plant to bend toward or away from light. This movement is called phototropism. This happens because auxins like IAA are found in the shoot tip and are broken down by exposure to sunlight. The part (or side) of the shoot tip exposed to direct sunlight will have less auxin while the part (or side) in the shade will have more. The extra auxin present on the shaded side promotes more cell division and elongation, which makes the shaded side longer, causing the plant to bend toward the sunlight (Figure 14.6). This can help the plant seek sunlight when it is competing in the shadows of other plants.

Figure 14.6: Cactus plant showing effects of phototropism

Source: Wikimedia Commons

Role in Bud Formation

Most plants have lateral buds located at nodes (where leaves attach to the stem). Buds are embryonic meristems maintained in a dormant state. The presence of auxins, like IAA, in the lateral areas of the plant (in between the root and shoot tip) can prevent lateral growth. If the apical bud is removed, the source of IAA is removed. Since this means the auxin concentration is much lower, the lateral buds can now grow. That is why when you cut the top off some plants you notice that the lower parts suddenly start growing new branches.

Auxins are also responsible for the leaves falling off deciduous trees in autumn. As the days grow colder and the rate of photosynthesis drops, the auxin levels decline. A lack of auxin in the lateral areas of the stem results in the formation of a separation layer (abscission) where the leaf petiole joins the stem. This abscission weakens the leaf's connection with the plant and soon causes it to fall off.

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(18 marks)

43. Three factors that affect plant growth are soil health, nitrogen fixation, and sunlight. Explain how each factor works to effect the growth of plants. **(9 marks: 3 marks for each explanation)**

44. The following experiment was carried out at ILC laboratories to measure the effect of different nutrient solutions on bean root growth. Three nutrient solutions were made:

(1) a solution containing all required nutrients;

(2) a solution containing all required nutrients except nitrogen; and

(3) distilled water.

The results recorded for root length and leaf colour were as follows:

Solution (1): 47 mm; deep green

Solution (2): 17 mm; pale green-yellow

Solution (3): 14 mm; pale green-yellow

Interpret the results for each solution. In your answer for each,

a) explain how the solution ranked in relation to the other two;

b) state the evidence that supports your answer; and

c) explain why the plant grew the way it did. **(9 marks: 3 marks for each solution)**

Now go on to Lesson 15. Send your answers to the Key Questions to the ILC when you have completed Unit 4 (Lessons 13 to 16).