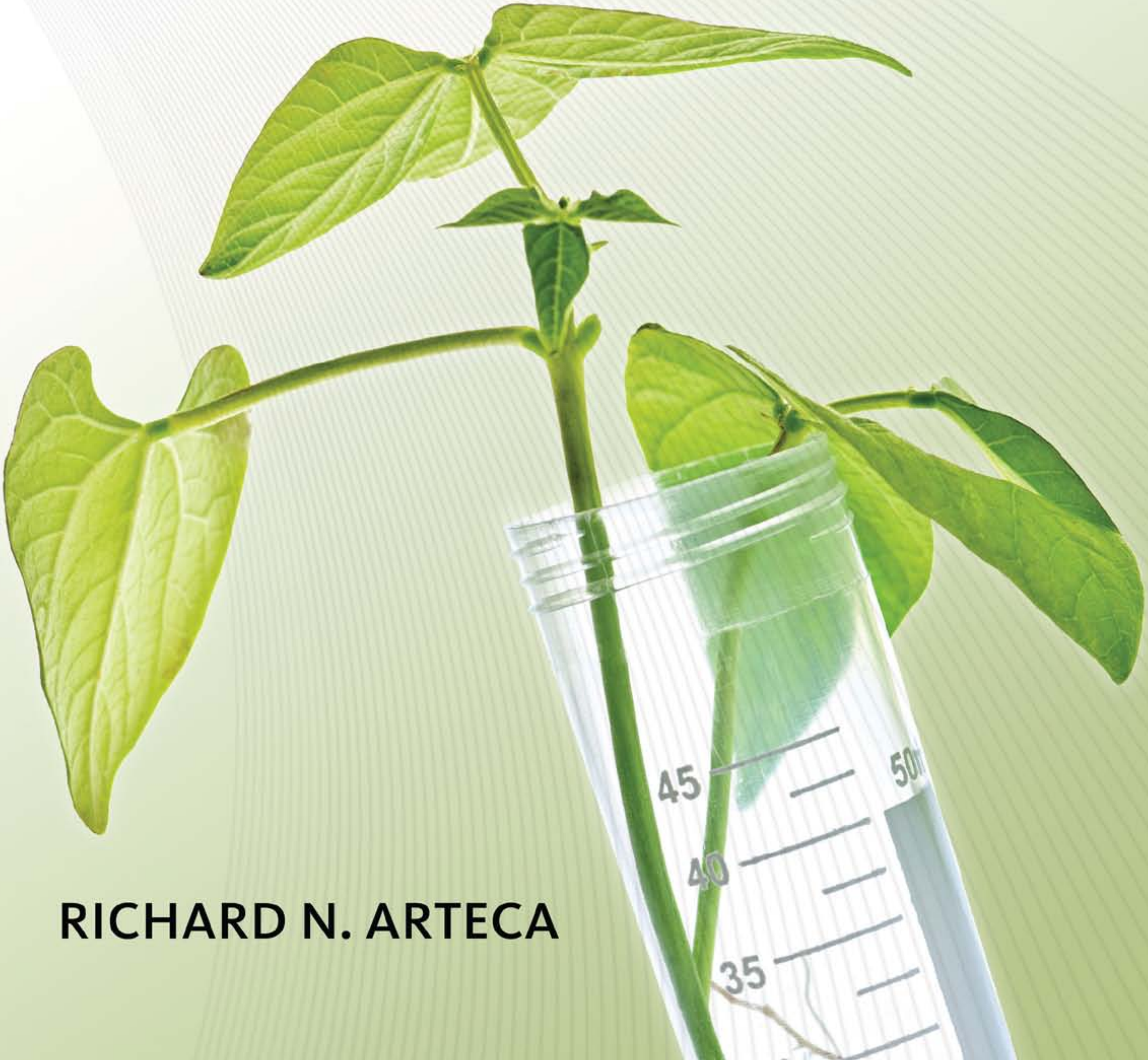
INTRODUCTION TO HORTICULTURAL SCIENCE

SECOND EDITION



RICHARD N. ARTECA

Introduction to Horticultural Science

Second Edition

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Richard N. Arteca

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Introduction to Horticultural Science, Second Edition

Richard N. Arteca

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DEDICATION

To my loving wife, Jeannette, for
her dedication to the completion of this book
and the countless hours spent preparing
figures, editing, organizing, and doing whatever
it took to get the job done.

Table of Contents

Preface

Presently, no horticultural science texts adequately cover the subject in enough detail for use as a college textbook for a horticultural science class, which is a general science option for students at universities. The main feature that sets this text aside from existing textbooks is its completeness. *Introduction to Horticultural Science* can be used at the college level as a required textbook for an introductory course in horticulture that serves as a general science option. The number of students taking introductory horticultural science courses is growing continually; for example, 400 to 500 students take my Hort 101 course each year, and this number increases each year. This textbook provides an excellent survey of all aspects of horticultural science, including gene jockeying, flower arranging, vegetable production, landscape construction, organic agriculture, hydroponics, and much more. Although this text is designed for college students, it is also useful for high school students preparing for college.

The beginning chapters provide information needed to understand the importance of horticulture in today's world. Chapter 1 discusses the green plant and what an amazing organism it is. This is followed by the origin of agriculture and the domestication of plants in Chapter 2; the horticulture industry and available careers in Chapter 3; and the relationship between horticulture and the environment in Chapter 4. A general understanding of a plant's growth and development, plus the factors that can affect it, is an important part of horticulture and is presented in the next set of chapters. The classification of plants and plant anatomy are covered in Chapter 5. Chapters 6, 7, 8, 9, 10, and 11 cover plant propagation; media, nutrients, and fertilizers; plants and their environment; plant growth regulators; postharvest physiology; and pest management, respectively. Plant biotechnology and genetically modified organisms are covered in Chapter 12. These chapters provide a strong foundation to understand the factors required for a plant to grow. The remaining chapters are applying this knowledge to the specific areas of horticulture. Chapter 13 covers the factors involved in choosing a site for any horticulture operation. Chapters 14 and 15 contain information on greenhouse structures and growing crops in a greenhouse; Chapter 16 discusses nursery development, facilities, and production of nursery crops. Chapters 17 and 18 pertain to floral design and interiorscaping. Designing, installing, and maintaining landscapes are covered in Chapters 19, 20, and 21, respectively. Chapter 22 discusses warm season and cool season turfgrass selection, establishment, care, and maintenance; Chapter 23 covers olericulture (vegetable crops); and Chapter 24 discusses pomology (fruit and nut crops). Chapters 25 and 26 cover organic gardening and hydroponics, two areas of horticulture that have become very popular in recent years.

Each chapter contains a variety of different types of review questions, which will be helpful in digesting the information contained in the chapter. A supplement is also available to instructors with answers to questions in each of the chapters. In addition to questions, activities are given at the end of each chapter so students can explore a given topic in more detail. At the end of most chapters, a list of references is included for further study. In addition, this text is an excellent resource for anyone interested in horticultural science.

NEW TO THE SECOND EDITION

Several additions have been made to the second edition of *Introduction to Horticultural Science*. The first noticeable change is the use of color images. Many new images were also added and tables have been revised. Statistics have been updated. Substantial content changes have been made throughout the book. Although the field of horticulture has been around for thousands of years, it is constantly changing and evolving.

Economic and environmental concerns relating to water and land are impacting the horticulture industry at every level. Information helpful to the home gardener has been added. A section on how to properly dispose of pesticide waste and recycling plastic pesticide containers in the agricultural community has been added to Chapter 4, "The Relationship between Horticulture and the Environment." Chapter 6, "Plant Propagation," now includes a section on practical methods used to initiate germination prior to planting and treatment techniques with auxin to induce rooting in cuttings. Chapter 7, "Media, Nutrients, and Fertilizers," contains information on how to change the pH of soils, organic fertilizers, improving soil quality with organic matter, soil management for home gardens, and composting. Compounds used for weed control in crops and home gardens were added in Chapter 9, "Plant Growth Regulators." Chapter 10, "Postharvest Physiology," has new sections on controlling ethylene in postharvest environments, postharvest handling for the home gardener and consumer, as well as a food safety section for the commercial grower and consumer. Chapter 11, "Pest Management," has been expanded to include the use of beneficial organisms for pest control by the home gardener. Chapter 12, "Plant Biotechnology and Genetically Modified Organisms: An Overview," has expanded the sections concerning the impact of genetically engineered plants on agricultural practices such as environmental concerns, Bt crops, pesticide use, honeybees, and cropping systems.

Updates in the chapters containing the applied information have also been made in this edition. Chapter 13, "Site Selection for Horticultural Operations," covers the economic and environmental factors affecting the selection of a horticulture operation. Chapter 15, "Growing Crops in the Greenhouse," has a new section on commercially used plant growth regulating compounds used in ornamental crops grown in a greenhouse. The production and care of houseplants by the homeowner was added to Chapter 18, "Interiorscaping." Chapter 19, "Designing Landscapes," has a new section on factors to consider when designing and maintaining a water-efficient landscape. Chapter 22, "Warm and Cool Season Turfgrass Selection, Establishment, Care, and Maintenance," now includes a section on the use of plant growth regulators as management tools in turf. New sections were added to Chapter 23, "Olericulture," and Chapter 24, "Pomology: Fruit and Nut Production," on the use of plant growth regulators to produce olericulture and pomology crops to modify the crop's growth and development. Two topics that have increased in popularity in recent years are organic gardening and hydroponics. Chapter 25, "Organic Agriculture," is a new chapter on the topic of organic agriculture covering its history, requirements needed to be classified as "organic," and management practices used to control growth and pests. Chapter 26, "Hydroponics," is also a new chapter and covers the history of hydroponics, nutrient solutions used, different types of hydroponic systems, and how to set up a simple hydroponic system.

ACKNOWLEDGMENTS

A special thank you is extended to all who have contributed to the second edition of *Introduction to Horticultural Science*, including the reviewers and colleagues for providing useful feedback and suggestions, the publishing team at Cengage Learning for their guidance and patience, and finally to my wife Jeannette for the endless hours spent on research and revisions.

Richard N. Arteca, PhD

About the Author

Richard N. Arteca is Professor of Horticultural Physiology in the Department of Plant Sciences at The Pennsylvania State University and has been there for more than 35 years. He received his PhD at Washington State University in 1979 and his MS and BS at Utah State University in 1976 and 1972, respectively. His appointment breakdown at Penn State is research and teaching. Dr. Arteca has published more than 80 publications in refereed journals and is internationally known for his work in biotechnology and genetic engineering. Some examples of his work include leading one of the initial research groups to develop cell culture systems for the production of the antitumor compound taxol, which is commonly used today in chemotherapy against breast cancer and other forms of cancer. Another example of his work is the biological, molecular, and genetic regulatory mechanisms involved in the plant's response to externally applied stimuli. Dr. Arteca's teaching appointment includes three classes: Introductory Horticulture (Hort 101), Plant Growth Regulators (Hort 420), and Advanced Plant Growth Regulators (Hort 520). Introductory Horticulture is a very popular course taught as a resident education course and as a world campus course (which has been taught online for more than a decade).

The Green Plant, What an Organism!

chapter 1

Objectives

After reading this chapter, you should be able to

- list and discuss the many reasons why plants are important.
- discuss the important plant processes and why they are so special.

Key Terms

abscission
aesthetic beauty
aspirin
biotechnology
dormancy
erosion
flowering
food source
fruit growth and development
fuel
genetically modified organisms
gravitropism
growth retardation
habitat
herbicide
negative gravitropism
pesticide
pharmaceuticals
photosynthesis
phototropism
plant growth regulator
positive gravitropism
purifying air
quiescence
rest
seed
seed germination
senescence
statolith
stress reduction
thigmotropism
viable
weed
weed control
wetland

ABSTRACT

The green plant is an amazing organism. This chapter presents a number of reasons why plants are important and summarizes the main processes in plants, including seed germination, photosynthesis, phototropism, thigmotropism, dormancy, senescence, flowering, abscission, fruit growth and development, growth retardation, weed control, production of important chemicals by plants, and biotechnology.

INTRODUCTION

This chapter discusses a wide range of reasons plants are so important to our existence. Plants provide us with food, shelter, and pharmaceuticals, while purifying the air we breathe. They are aesthetically beautiful and have been scientifically proven to reduce stress in our daily lives. Plants prevent erosion of the limited amount of topsoil on the Earth's surface, provide habitat and cover for animals, and play a key role in wetland water purification.

Exciting areas of plant research are also covered starting with **seed germination**, which is a very complex process even though it does not appear to be very complicated to the naked eye. Just considering how a tiny seed can rapidly turn into a large tree or how seeds know which way is up and which way is down reveals the complexity. The process of **photosynthesis** is another fascinating area of research, and a better knowledge of how this process works will enable us to provide more food for a hungry world.

Plants are able to move in response to environmental cues—such as light (**phototropism**), touch (**thigmotropism**), and gravity (**gravitropism**)—to protect themselves and increase their efficiency. Plants also respond to environmental cues by dropping their leaves through a process called **abscission,** which protects them against winter injury. After shedding its leaves, the plant can temporarily suspend visible signs of plant growth by a process called **dormancy**, which is another exciting area of research. Currently, researchers are trying to unlock the mystery of dormancy so that humans suffering from serious disease might be put into a dormant state pending a future cure. The regulation of **senescence**, or aging, in plants is currently being studied in hopes that if we can understand how to delay aging in plants, this information might be applied to methods for delaying aging in humans.

The process of **flowering** is another rapidly advancing area of research for a variety of reasons. One of the major economic reasons is the consumer demand for flowering plants at specific times of the year, for example, poinsettias for Christmas. By better understanding the flowering process, it will be easier for growers to have crops come in on specific dates. **Fruit growth and development** is studied to produce an adequate supply of high-quality fruits for human consumption. **Plant growth regulator** research receives a considerable amount of attention from scientists throughout the world for a variety of purposes, including reducing plant height and controlling weeds. The production of important plant chemicals for **pharmaceuticals**, fragrances, and a variety of other purposes is a highly competitive area of research because of the potential to make large sums of money. The production of **genetically modified organisms** is also a highly competitive and highly controversial area of plant research because of the general public's ethical concerns and legal battles with patenting. Many of the topics discussed in this chapter will be discussed in more detail later in the book.


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Figure 1-1 This tree has grown regardless of adverse conditions, illustrating that plants are amazingly adaptable.

WHY ARE PLANTS SO IMPORTANT?

For many years, plants have been thought of as immobile creatures because they do not make any obvious movements. Plants are able to adapt to a variety of surroundings because they continually monitor their environmental surroundings and respond rapidly to the wide variety of conditions they are subjected to (Figure 1-1). One way to determine intelligence is by measuring the ability to move in response to a given situation. A growing shoot has been shown to use near-infrared light to determine the closeness of other plants and consequently alter its direction of growth. Also documented is the fact that the stilt palm can, by differential growth of its prop roots, move away from plants that will compete with it. From the other angle, the parasitic weed dodder touches another plant to determine whether it can be exploited. After the dodder plant determines that the plant is susceptible, it engulfs the host and uses all of the host plant's resources. These few examples demonstrate that plants are intelligent. Trewavas (2002) states that traditional definitions of intelligence use movement as a criterion, but the adaptive behaviors shown by individual plants indicate that they are intelligent.

This section summarizes and briefly explains the numerous reasons plants are so important. Plants are important as a **food source**; for true vegetarians, plants are their only source of food. As a food source, plants provide all the essentials to sustain animal life. In addition to being important sources of vitamins, minerals, and fiber, fruits and vegetables when eaten can reduce certain cancer rates and heart disease, respectively, as the American Cancer Society and the American Heart Association report (Figure 1-2). Fruit pectins trap dietary cholesterol, keeping the cholesterol from depositing in the linings of blood vessels and thereby preventing heart attacks. Fruits and vegetables also contain antioxidants that neutralize free radicals involved in aging and some forms of cancer. Plants also provide people a way to establish shelter; lumber from trees is used to build a variety of structures, which protect humans, animals, machinery, and so on from the sometimes harsh external environment. Many special articles of clothing such as dress shirts, pants, and other clothing are made from cotton (Figure 1-3), which is derived from plants.

Figure 1-2 Produce is important in our daily diet.

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Plants are also responsible for **purifying the air** because they remove the carbon dioxide we create and add the oxygen we need, thereby maintaining a balance in the atmosphere. In fact, a large group of people in a small room creates high levels of carbon dioxide that may cause tiredness. Global warming, which is caused by higher levels of carbon dioxide in Earth's atmosphere, has caused concern among today's scientists. This is a controversial topic because the elevated levels of carbon dioxide are thought to be caused by indiscriminately replacing green spaces with buildings, clear cutting forests without proper restoration, and a variety of other factors. Scientists and politicians are now getting together to determine the best way to overcome the problem of global warming before it worsens. Plants are also grown in an orbiting spacecraft as excellent food sources for astronauts and as air purifiers.

Some plants, such as the common household spider plant, remove pollutants and carbon dioxide from the air in homes and other enclosed spaces (Figure 1-4).

Plants also provide **aesthetic beauty**, such as roses for Valentine's Day and colorful fall leaves (Figure 1-5). You have probably seen futuristic movies where everything is asphalt, and the important green spaces and aesthetic beauty of plants are nonexistent.

Scientific literature also points to plants as significant factors in **stress reduction** in humans. These studies have shown that people working in an environment that included a variety of different plants

Figure 1-3 Cotton bolls harvested from the parent plant.

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Figure 1-4 The spider plant, a commonly grown houseplant, is known to remove pollutants from the air.

were happier and more productive. In addition to being placed in the immediate workspace, plants in areas where people congregate for breaks, lunch, or other purposes also helped people to cope with the dark days commonly found during winter months and throughout the year. Prior to these scientific studies, many viewed the concept that plants have a profound effect on worker behavior as mythical and without merit. However, with more recent findings, the production and use of indoor plants has become a multimillion-dollar industry.

Plants are also an important source of pharmaceuticals. For example, acetylsalicylic acid (**aspirin**) comes from willow trees, taxol from the yew plant (Figure 1-6), and aloe from the aloe plant. There is a variety of other examples that can be given (DiCosmo & Misawa, 1996). Products from plants can serve as **fuel** or as fuel additives, such as ethanol in gasoline.

Plants play an important part in preventing **erosion**, thereby preserving precious topsoil. Today, the availability of high-quality topsoil is limited, and considerable research is underway on ways to prevent erosion. Without topsoil, farmland used to grow crops would be reduced, thereby reducing the food supply. In Pennsylvania, crown vetch along roadways is commonly used to prevent soil erosion (Figure 1-7). Plants provide **habitat** and cover for animals in the wild, protecting them from predators. Plants are an integral part of **wetland** purification of water. Although wetlands were once destroyed as a result of agricultural and urban development, today the federal government protects them. Plants are also used in artificial wetlands to purify wastewater from greenhouses (Figure 1-8). These are only some of the important uses of plants, and you can probably think of many more.


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Figure 1-5 Leaves changing colors in the fall (top) and a beautiful yellow rose (bottom) show the aesthetic beauty of plants.

IMPORTANT PROCESSES IN PLANTS

In this section, a variety of selected examples of important processes in plants will be briefly covered; these examples will be discussed in more detail later in the book.

Seed Germination

Seed germination or propagation by seeds is the major method of reproduction in nature and the most widely used method in agriculture because of its high efficiency and ease. A seed has all the genetic information to make a whole plant. A **seed** is defined as a ripened ovule, which consists of an embryo, stored food reserves, and a seed coat or covering (Figure 1-9). When placed in the soil, the seed's special sensors enable it to determine which way is up and which way is down (Figure 1-10). Much research is underway to understand this process so that plants can be grown in outer space without disoriented growth.

Certain criteria must be met for germination to occur:

- The seed must be **viable**, which means the embryo is alive and capable of germination.
- The proper environmental conditions must be available, such as water, proper temperature, oxygen, and, in some cases, light.
- Primary dormancy must be overcome. Dormancy acts as a safety mechanism that protects the seed from adverse environmental conditions.

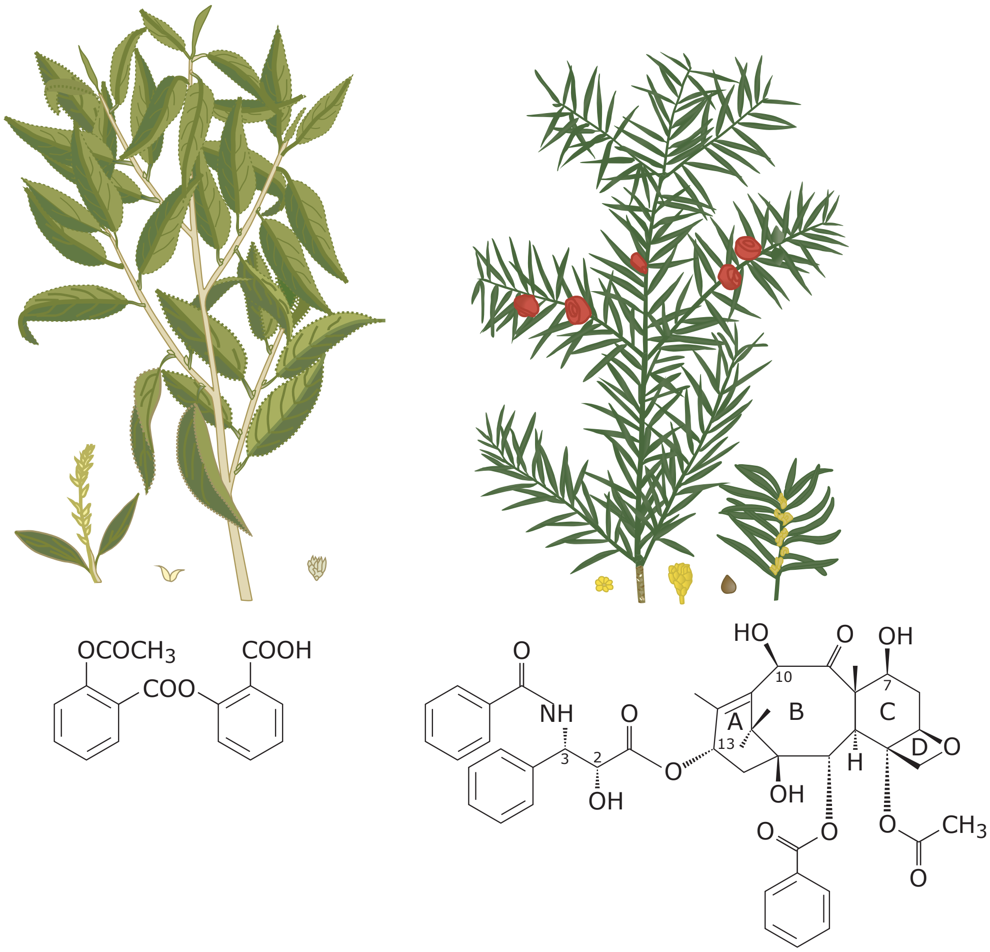

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Figure 1-6 The structure of acetylsalicylic acid (aspirin) derived from willow trees is shown on the left, and taxol, an important antitumor compound derived from the yew plant, is shown on the right.

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Figure 1-7 Crown vetch is used along a roadside to prevent erosion.

Courtesy of Dr. Robert Berghage, Department of Horticulture, The Pennsylvania State University.

Figure 1-8 This man-made wetland purification system operates in a greenhouse.

After the criteria for seed germination have been satisfied, the seed goes through three stages of seed germination prior to any visible changes in the seed. These stages include:

1. imbibition or uptake of water.
2. formation of enzyme systems.
3. breakdown or metabolism of storage products for energy and as building blocks.

Plant hormones are responsible for inhibiting or promoting seed germination. Gibberellins (GA) typically stimulate germination, whereas abscisic acid (ABA) inhibits seed germination (Arteca, 1996).

While the first three stages are in motion, there are no visible changes in the seed. The first visible sign of seed germination is the emergence of the radicle followed by seedling growth. After the radicle has emerged, the seedling begins to grow and acts as a subterranium organism with no pigmentation exhibiting exaggerated growth until it reaches the soil surface. How does the seed know that it is close enough to the soil surface to germinate and survive? For example, pesty weed seeds do not germinate until they know they are close to the soil surface and that their chances of survival are very good. In addition to gravity sensors, seeds also have light sensors to perceive light so that when they perceive a certain wavelength of light, germination occurs.

Photosynthesis

Photosynthesis refers to a series of chemical reactions in which carbon dioxide and water in the presence of light are converted into carbohydrate (sugar) and oxygen (Figure 1-11). Essential to

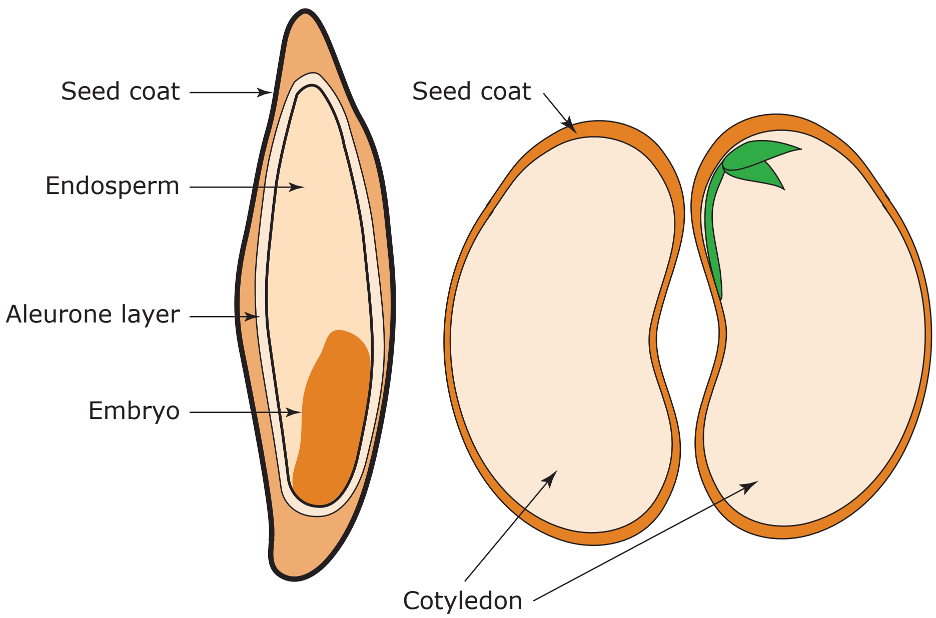

Figure 1-9 The key parts of a seed.

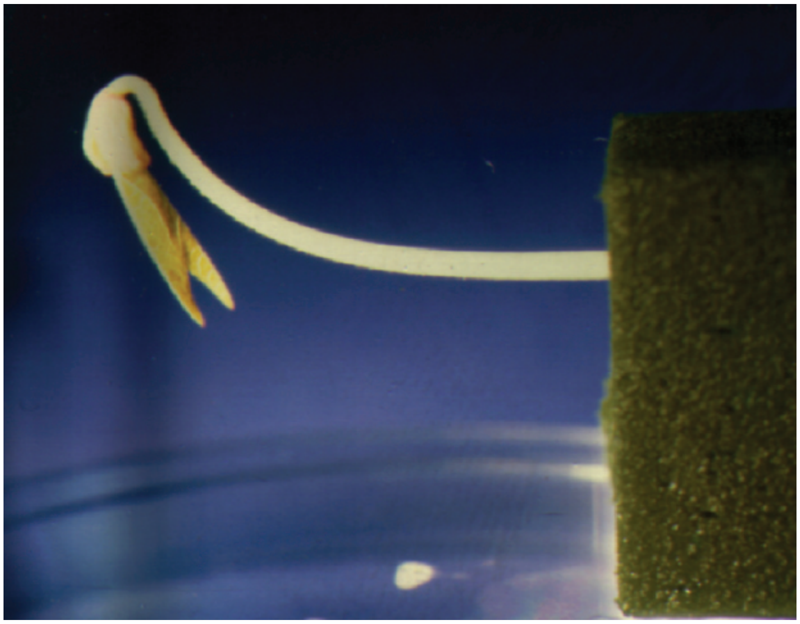

Figure 1-10 This etiolated mungbean seedling bends upward against the force of gravity.

the photosynthetic process is light and chlorophyll, which is a green pigment contained in the chloroplast of plant cells. The purpose of most plant-related research is to explore ways to manipulate growth and increase productivity of plants (Arteca, 1996; Devlin & Witham, 1983). The regulation of photosynthesis and the movement of photosynthetic products from their site of synthesis in the leaf (source) to their sites of accumulation (sink) have a profound effect on the size of the plant and are currently an exciting area of research.

For life as we know it to exist, photosynthesis is essential; however, surprisingly very little research was done in this area until the eighteenth century. One of the main reasons for this lack of research is that the early Greeks believed the plant received its food directly from the Earth, which contained plant and animal debris. They specified that the roots of plants took up everything necessary for plant growth. Early researchers found that adding more plant and animal materials to the soil increased the size of the plant, thereby supporting the Greek theory, which remained uncontested until much later.

Joanne Baptista Van Helmont in the early 1600s performed a simple yet elegant experiment with willow seedlings. This experiment involved carefully weighing a willow seedling, the tub, and the soil it was planted in, and then growing the plant for five years. At the beginning of the experiment, the seedling weighed 2 kg, and by the end of the five-year period, it had increased to 75 kg. Van Helmont also measured the weight of the soil, which had only lost a few grams in dry weight. Based on these facts, he concluded that water, not soil, was responsible for the growth of the plant. The few grams of soil that were lost were nutrients, which were essential to growth, and water did not contribute appreciably to the overall mass of the willow plant; rather, the process of photosynthesis was responsible for the size increase.

In 1699, John Woodward reevaluated the work of Van Helmont and found that plants required more than water for growth. He worked with mint plants grown on water from different sources, which included rainwater, river water, and Hyde Park drainage water. From this study, Woodward came to the following conclusion:

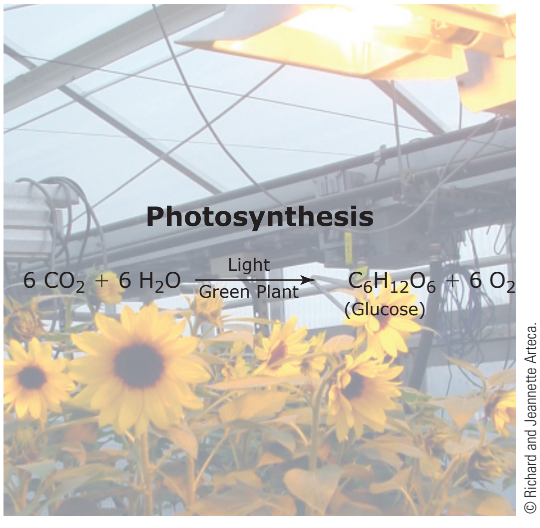

Figure 1-11 A simple chemical equation for photosynthesis.

> Vegetables are not formed of water but of a certain peculiar terrestrial matter. It has been shown that there is considerable quantity of this matter contained in rain, spring, and river water; that the greatest part of the fluid mass that ascends up into plants does not settle there but passes through their pores and exhales up into the atmosphere; that a great part of the terrestrial matter, mixed with water, passes up into the plant along with it and that the plant is more or less augmented in proportion as the water contains a greater or less quantity of that matter; from all of which we may reasonably infer, that earth, and not water, is the matter that constitutes vegetables. (Quotation taken from W. Loomis, 1960)

In 1772, Jason Priestly studied the gas exchange that accompanies the process of photosynthesis. His experiment involved placing a mouse in a bell jar with a burning candle. He concluded that the mouse could not live in the air contaminated by the burning candle. However, he did note that if a sprig of mint were placed in the chamber with the burning candle, the air would be purified and the mouse would survive under these conditions. Priestly also observed that the mint plants could survive in the contaminated air caused by the burning candle. Based on his scientific findings, Priestly concluded that:

> [P]lants, instead of affecting the air in the same manner with animal respiration, reverse the effects of breathing and tend to keep the atmosphere sweet and wholesome when it has become noxious in consequence of animals either living and breathing or dying and putrefying in it. (Quotation taken from W. Loomis, 1960)

In 1779, Jan Ingenhousz reported that plants could only purify the air in the light. In addition, he stated that only the green parts of the plant produced the purifying agent (oxygen); however, nongreen tissues contaminated the air. Ingenhousz was the first to recognize that chlorophyll and light participated in the photosynthetic process.

In 1842, Julius Robert von Mayer established the law of the conservation of energy. He stated that the energy used by plants came from the sun and that this energy was converted to chemical energy by the process of photosynthesis. In 1905, Frederick Frost Blackman demonstrated that photosynthesis consisted of both a photochemical (light) and biochemical (dark) reaction. In 1937, Robert Hill reported that isolated chloroplasts in the presence of light, water, and a hydrogen acceptor resulted in the evolution of oxygen in the absence of carbon dioxide. The significance of these experiments was that they provided evidence that the evolution of oxygen was a result of photochemical reactions. Today we know that oxygen from photosynthesis comes from water and not from carbon dioxide.

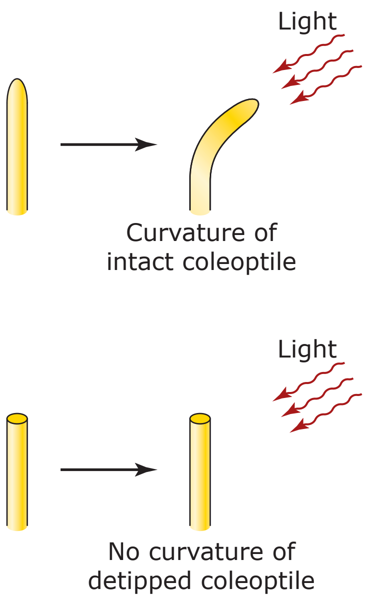

Figure 1-12 Experiments conducted by Darwin demonstrated the phototrophic response in plants. These experiments showed that the phototropic stimulus was found in the tip of the coleoptile.

Phototropism

Phototropism is the movement of the plant in response to directional fluxes or gradients in light. Although Darwin is better known for his theory of evolution, he is considered responsible for initiating modern plant hormone research. In *The Power of Movement in Plants* (Darwin, 1880), he described phototropism and gravitropism for the first time. Darwin used coleoptiles to study phototropism. Coleoptiles are specialized leaves in the form of a hollow cylinder that enclose the epicotyl and are attached to the first node in grasses. The coleoptile protects the growing tip of the grass seedling until the more rapidly growing leaf emerges above the ground. In simple yet elegant experiments, Darwin showed that when coleoptiles were exposed to unidirectional light, there was bending toward the source. If the coleoptile tip was removed, phototropic curvature did not occur, which suggested that the phototropic stimulus is in the tip (Figure 1-12). Today we know that the tip contains auxin, which is responsible for phototropic bending in plants, and that plants bend toward higher light levels to maximize growth and, in some cases, to survive. The Cholodny-Went theory describes how the process of phototropism occurs. This theory states that when higher concentrations of the plant hormone auxin are on the shaded side than on the light side, the shaded side experiences accelerated growth, which causes bending toward the light.

Thigmotropism

Thigmotropism is the movement of a plant in response to touch; examples include the Venus flytrap, sensitive plant, tendrils from the pea, and many others. The inability of plants to move from an adverse external environment has led to the evolution of adaptive mechanisms, which permit them to respond to environmental changes to survive. Plants are exposed to mechanical forces (touch) through wind, vibrations, rain, friction (plant parts rubbing against one another), and others.

Touch stimulation has positive effects, such as:

- shorter and sturdier plants that can withstand certain types of stress (such as wind).
- plants that are more resistant to drought stress, pathogen attack, and more.

Touch stimulation also has negative effects in that it:

- causes an inhibition of leaf expansion.
- decreases photosynthesis.
- promotes leaf yellowing.
- delays flowering, which reduces overall growth and subsequent crop yields (see Figure 1-13).

A number of researchers are studying touch-induced gene expression. They have shown that when a plant is touched for as little as 30 seconds, genes are turned on as rapidly as 5 minutes (Figure 1-14). Research in this area is an attempt to better understand the effects of touch on plant growth. The eventual goal of touch research is genetically engineering plants to reduce plant height, thereby overcoming the need to use chemicals for height reduction, which is a common practice today.

Figure 1-13 The Arabidopsis plant on the left received no touch treatment, and the one on the right received a 30-second touch treatment daily for four weeks. Picture was taken when the plants were six weeks old.

Gravitropism

Gravitropism is the movement of a plant in response to gravity. Research in this area began with Darwin in 1880, and many research groups today are still pursuing it. Studying plant growth and development in response to gravity is important for many reasons, including

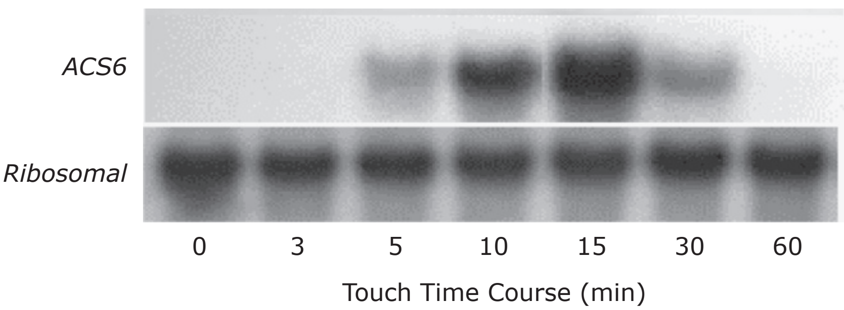

Figure 1-14 Time course of touch-induced ACC synthase (*ACS6*) gene expression. ACC synthase is a gene encoding for an important regulatory enzyme in the ethylene biosynthetic pathway. Three-week-old, light-grown Arabidopsis plants receiving no touch served as a control, and others were touch-stimulated for 30 seconds. At designated time intervals, samples were taken and placed immediately in liquid N_2. Ten micrograms of total RNA was probed with *ACS6*, and a pea ribosomal probe was used as a control to show that equal amounts of RNA were loaded on the gel.