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# Botany for Gardeners

THIRD EDITION | Brian Capon



**The most useful and accessible  
introduction to the science of plants**

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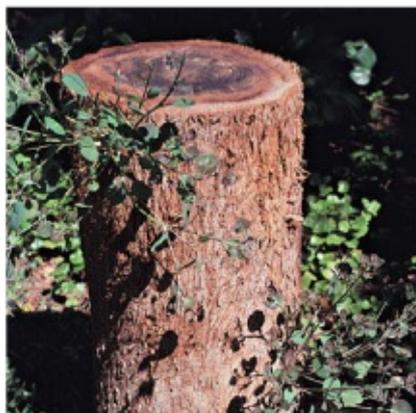
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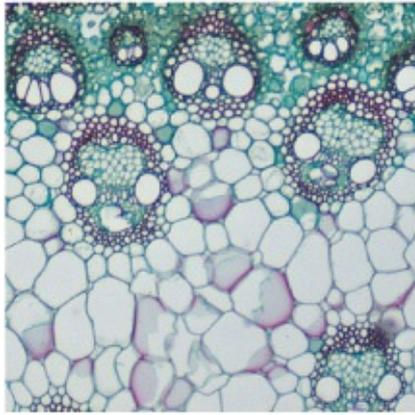
—*Academic Library Book Review*

“This is a reference that should be on the desk of everyone interested in plants.

—*Pappus*



# **BOTANY FOR GARDENERS**



*Third Edition*

**WRITTEN AND ILLUSTRATED BY  
BRIAN CAPON**

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My father's garden. Victoria, British Columbia, Canada

## PREFACE

*With our feet firmly planted* in the twenty-first century, we live in a world greatly changed from that in the middle of the 1980s when I started to plan the first edition of this book. New words have become commonplace in our vocabulary: Internet, global warming, cell phone, and digital camera. And a blackberry is no longer just a luscious fruit. Keeping up with changing technology is becoming more challenging with each passing year. To a person of my generation, at least, finding a place where things are not so hectic, where time seems to take a more leisurely pace, is even more important than it was a quarter of a century ago. That place is my garden.

In my plants I find a connection with the past—happy memories of the days when I planted them—and satisfaction knowing that some will be there for years to come as a legacy, perhaps beyond my lifetime. While tending to their needs, I find comfort in their unchanging, placid ways, unbothered by the fever of human activity. And when working on them with trowels and garden clippers, rather than react as would an attacked animal, the plants miraculously grow even better, rewarding me with more perfect selves. A relationship of this kind is hard to find in any other part of our daily lives.

All gardeners can probably trace their love affair with plants to an earlier experience in their lives. Mine was growing up in a home where my father maintained a spectacular flower garden with beds of perennials arranged in the traditional English style and blooming periods overlapping throughout the summer to create an ever-changing kaleidoscope of color. From this I directed my education and career to studying and teaching botany. When the time came to retire, I looked for a way to continue spreading the good word about plants to a new audience, the readers of a botany book specifically written for gardeners and others who have not had my own privileged scientific background but, nevertheless, are hungry to learn more intimate details about plants other than the practical aspects of growing them.

Among the courses I taught, one of the most satisfying was a general botany for the

non-science majors, students who “had to” take a science course as part of their prescribed curriculum. Most anticipated a tedious litany of dull facts, but by the end of the course so many came to me excited that learning about plants had been a revelation, awakening their awareness of the world around them. It was there that *Botany for Gardeners* was born in 1990.

Botany is a dynamic science, with new information about plants constantly being added by research scientists. Most of the latest discoveries are above the comprehension of gardeners and others without a scientific background, for example, studies of key proteins or other substances and their involvement in complex biochemical systems that regulate growth. But all modern research has, as its foundation, the basic, core principles of plant science that are outlined in laypeople’s language in this book. Equipped with this information, you will be ready to expand your knowledge of plants (and it can be limitless), delve at great depth into any of the many subdivisions of botany, and, perhaps, make discoveries of your own.

For this third edition, new concepts not covered in previous editions are introduced in three short essays related to the topic of plants as human food sources. The dimensions of the text have also been expanded with interesting facts about plants presented in sidebars, and several new photographs have been added, including startling extreme close-up images as seen with scanning electron microscopes.

We hope this twentieth anniversary edition of a gardener’s favorite, in its newly designed form, will give you new insights into the lives of some of the most wonderful living things that share this planet with us.

BRIAN CAPON, 2010

## INTRODUCTION

*Earth has been called the green planet*, a world clothed in a mantle of vegetation that sustains all other forms of life on this tiny spot in the universe. From simple beginnings, plants evolved first among Earth's living things and thereby established a fundamental principle of nature: Plants, in one form or another, can exist forever without animals, but animals cannot exist without plants.

Plants purify the air by exchanging the oxygen we breathe with carbon dioxide, which is poisonous in too high a concentration. Plants convert the energy of sunlight into foods that sustain all animals and, from the soil, draw minerals such as nitrogen, potassium, calcium, and iron that are essential for our well-being. For creatures large and small, plants provide shade from the sun, refuge from predators, and protection from the ever-changing elements. Since the first cells came into being millions of years ago, plants have been the connecting links in an unbroken chain of life. It is they that have made the biosphere, the part of Earth's crust where life exists, a place that humans can comfortably inhabit. The range of uses we make of plants is as broad as our ingenuity permits. We have exploited them for fibers to make cloth, drugs to cure a multitude of ailments, and wood to construct houses, furniture, and ships. From them we have extracted raw materials to manufacture innumerable goods, including paper. Without that latter commodity, our detailed history would not have been recorded and so remembered, nor could knowledge have been so easily disseminated. And culture, the possession of which makes humans out of animals, would never have developed beyond the basic skills and habits of primitive peoples had we not had paper on which to write music, poetry, and prose.

Some of us look at plants as a source of livelihood, while others find them intriguing subjects for scientific study. But most enjoy plants for the sheer delight of having them in their everyday surroundings, to savor the varied colors, textures, tastes, and aromas that they alone can offer. Few gardeners share the botanist's knowledge of plant biochemistry, anatomy, physiology, and intricate reproductive systems, yet all have experienced the extraordinary satisfaction derived from growing flowers, fruits, vegetables, and trees.

When we work with plants, questions about them inevitably come to mind. What takes place inside a seed after we have set it in the ground? How does water travel from soil to treetops? What makes a plant become bushy with repeated pruning? What controls seasonal flowering patterns? How do plants grow, and why is light necessary to make growth happen? Over the centuries, botanists have worked to find answers to these and other questions. Slowly, plants have revealed some of their secrets.

Botany is a useful and rewarding study from which, unfortunately, many laypersons are frightened away by the technical jargon that constitutes the language of the science. The reader will encounter scientific words in the following pages. Some are part of the common parlance of gardeners. For want of suitable nontechnical equivalents, others cannot be avoided when writing such a book. Each technical word, whether common or obscure, is explained in the text and glossary, and occasional reference is made to the Greek and Latin roots from which these words have been

derived. In addition, the numerous illustrations give added meaning to the botanical vocabulary and ideas developed.

Some of the photographic subjects are not the customary things that gardeners look for in plants, but they are plants or parts of them seen in close-up, sometimes through a microscope. A majority of the plant specimens that have been photographed were selected from those available in my own and neighbors' gardens, local parks, and botanical gardens in southern California. But the broad principles of botany each photograph exemplifies are equally applicable to plants in almost any part of the world.

There are close to 400,000 recognizably different kinds of plants, or *species*, in the world today. So diverse are their forms that to write an all-inclusive definition of the word *plant* is not at all easy. One-third of all plants do not have roots, stems, and leaves as we know these parts in the examples most familiar to us. About 150,000 plant species never produce flowers, and almost that same number do not grow from seeds, but rather from dust-like particles called *spores*. The vast majority of plants manufacture their own food supplies by a process called *photosynthesis*. Mushrooms, molds, and other fungi rely on foods created by green plants for their sustenance (as do animals) and, for that reason, have now been reassigned from the plant kingdom to the fungal kingdom. Most plants spend a lifetime anchored in one place, yet a few simple, one-celled plantlike organisms are capable of swimming to different locations in the waters they inhabit. It is this kind of diversity and amazing variety of shapes, colors, and lifestyles that continually excite our interest in these organisms called plants.

As we delve into the science of botany, we shall largely be concerned with the two groups of plants with which we, as gardeners, most often work. One, known as the flowering plants, or angiosperms, is the largest group in the plant kingdom and consists of about 250,000 species. The name *angiosperm* refers to the fact that seeds from these plants are formed inside containers that we call fruits (Greek: *angeion*, "vessel"; *sperma*, "seed"). The flowering plants most often decorate our homes and landscapes, supply almost all of the vegetable matter in our diets, and are the source of the world's hardwoods. They are the most sophisticated of plant forms and are best adapted to survive in a wide range of climates and places.

Second are gymnosperms, plants that produce seeds in the open spaces of cones—between the flaplike parts that make up a pine cone, for example. The Greek words *gymnos*, "naked," and *sperma*, "seed" describe this form of development. On the evolutionary scale, gymnosperms are more primitive than angiosperms but are of considerable economic importance as well as interest to landscapers for their compact forms and richly colored, needle-shaped, or scalelike leaves. Softwoods such as pine and fir are not only used to make paper, lumber, and plywood, but are the source of utilitarian products such as pitch, turpentine, and rosin. The gymnosperms include all the conifers: cedar, redwood, juniper, cypress, fir, pine, and the largest living things on earth, the giant sequoias. Members of this group include many ornamental shrubs, such as varieties of *Chamaecyparis* (false cypress) and *Thuja occidentalis* (American arborvitae); the beautiful maidenhair tree, *Ginkgo biloba*, a broad-leaved species; and, the least typical of gymnosperms, the cycads.

For comparative purposes, passing mention is made of ferns, mosses, and other

primitive plants, but it is to the flowering plants and gymnosperms that we direct our attention because it is they that give us the most revealing picture of how marvelous plants are.

## PART I Growth



***A person, a plant, a pebble, this book page***—four objects no one has trouble putting into simple categories of living and nonliving. But what makes the difference? Why can we be so sure that the potted geranium is living and a piece of the same plant that was pressed and dried last year is unquestionably dead? From all appearances, a seed also seems dead. What happens when, upon reawakening, it becomes charged with life during germination, and what mysterious entity leaves a plant when it dies? Few people believe in the departed souls of plants. Philosophers may endlessly ponder such questions, but trying to find answers strictly based on observation and repeatable experiment is the essence of scientific inquiry.

In the broad sense, a living plant has the ability to make seeds or spores from which other plants of the same species can be grown. In other words, a living plant can reproduce. A dead one has lost that capacity. Then again, if one has the opportunity to look at any part of a plant through a microscope, it becomes obvious that plants are composed of countless numbers of cells, which are invisible to the naked eye. This gives another clue to the nature of living things. It may be argued that cells are still in a leaf when it is dead and dried. But when the leaf was a part of a living plant, its cells were actively engaged in a complicated chain of chemical reactions, grouped together under the term *metabolism*. We can be quite sure that, as long as a cell or a whole creature is alive, it is going to display some sort of metabolic activity. When their chemistry irreversibly stops, cells die.

Perhaps the most obvious difference between a rock and a rose is that the rock does not grow. In fact, it progressively becomes smaller as its surface erodes. Plants and animals, on the other hand, begin life as single, fertilized eggs and become larger as they mature. In the case of animals, including ourselves, a *determinate growth* pattern dictates a prefixed, maximum size that the body may reach. This pattern is implicit in and established by *genes*, cellular instructions inherited from parents, and is more or less related to the number of cells that the body is programmed to produce. Strenuous exercise may enlarge cells, but relatively few new cells are added. Full growth potential is realized if an animal receives adequate nutrition and its muscles are exercised, especially during the formative years.

For the most part, plants have no definite size toward which they grow. That is, they display *indeterminate growth* or, at least, their stems and roots do. When left untouched and growing in an unrestricted volume of soil, a plant's roots will never reach an established size, nor will its branches in the freedom of an open-air space. Limits of plant growth are proportional to the availability of light, water, minerals, and oxygen. Life span is genetically determined—one year for annuals, two for biennials, and indefinitely for perennials.

Compare the indeterminate growth pattern of roots and stems with the pattern found in leaves, flowers, fruits, and seeds. The latter are characteristically ephemeral and determinate in growth. Their maximum possible sizes are rarely displayed in nature but can be realized under a skillful gardener's control of the plant's environment. With plenty of fertilizer, careful watering schedules, optimum illumination, and thinning—removal of parts that may compete for available nutrients—a plant can be pushed to the limits of leaf, flower, and fruit growth. All regular visitors to county fairs know what prize-winning blossoms and fruits look like. They are giants compared with normal specimens but never reach super-giant status.

Animals grow and spend their lives in a variety of places. Mobility enables them to choose habitats that are most favorable for existence under changing conditions at different times of the year. A plant is anchored in one place throughout its life. Half of its body, its *root system*, is buried in the dark, damp, and somewhat stuffy recesses of the soil. Despite being surrounded by a legion of potentially destructive grubs and soil microorganisms, such as fungi and bacteria, from which the roots cannot escape and their passage through the soil manipulated by encounters with immovable rocks, roots are wonderfully adapted to this strange, hidden environment.

In contrast, *shoot systems*, consisting of stems and leaves, occupy a sunlit, airy, but frequently tempestuous world. Growth impediments are different from those belowground and may range from insects and larger animals with voracious appetites, out to survive at the plant's expense, to the drying effect of wind and sun or even damage from fire.

Roots and shoots are frequently thought of as different entities growing in opposite directions. To a plant they are parts of the whole body that must be as well coordinated as are torso and legs during the course of growth and the varied activities humans undertake. Root growth and shoot growth are harmonized events, one complementing the other, with energy reserves and raw materials for body building equally allocated to the two halves. And when daily or seasonal environmental changes affect one part, the other must respond in sympathy. The fact that plants do respond to their environment, albeit in more subtle ways than animals, could be listed as another characteristic of their being living organisms. Fulfillment of the fundamental qualities of living things—*reproduction, cellular metabolism, growth, and response to the environment*—can only be achieved by such precisely controlled interactions between roots, stems, leaves, and flowers.

The science of botany is divided into various disciplines, each having its specialists, subject limitations, and technical vocabulary. Among them, *cytology* (Greek: *kytos*, “container”) is the detailed study of cells. Study of the form and structure of plants is the work of morphologists (Greek: *morphe*, “form”). By virtue of their practical

relationships with plants, gardeners are more familiar with *morphology* than with cytology.

This section deals with plant cells, their structure and role in growth processes, followed by a look at the growth of representative flowering plants from germinated seeds to maturity. For convenience, growth and the external forms of roots, stems, and leaves are treated separately. This is not to imply that all parts of a plant do not develop simultaneously. The reader is invited into the realm of cells to better understand what goes on inside roots, stems, and leaves when they grow.

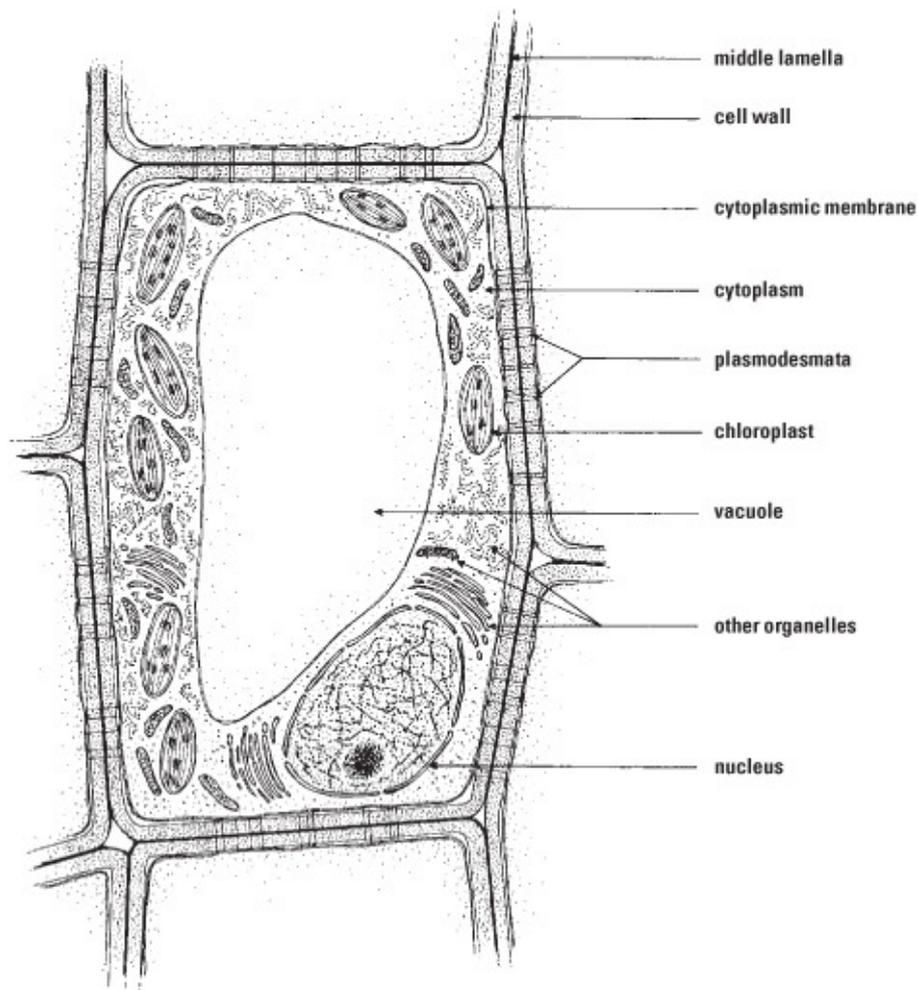
## 1 CELLS AND SEEDS Basics and Beginnings

### CELLS

Robert Hooke, an English physicist, was understandably excited when, in 1665, he wrote about having used a crude microscope to look at a slice of cork. He probably thought he'd simply confirm the prevailing idea that plants are composed of some sort of amorphous material, like clay shaped by the Creator's hands. But contrary to such expectations, Hooke was the first person to find that plants are actually constructed of tiny units, which he named *cells*. His choice of word more likely reflected his acquaintance with Latin (*cella*, "a small room") than with the interior of a jailhouse.

What subsequently became known as the cell theory—that all living things are composed of one or more cells—was as revolutionary to scientific thought as was, in our own time, the discovery of DNA (deoxyribonucleic acid), the chemical substance controlling biological inheritance. As scientists delve deeper into cells, the revelation of what life really is, at microscopic and finer levels, continues to offer surprises.

To get an idea of what a typical plant cell is like and what it can do, think of a large factory capable of manufacturing thousands of different and elaborate products from simple raw materials: water, air, and soil. The factory uses sunlight rather than electricity or oil as an energy source. It is designed to exert considerable autonomous control over what goes on within its boundaries and, whenever increased productivity is called for, it simply builds an exact copy of its entire physical structure within a day or two. Now, mentally squeeze the factory into a box, each side approximately 1/2000 of an inch (0.05 mm). That is a cell.



Details of a plant cell

The living part of a cell, the *protoplasm*, consists of two parts: a *nucleus*, which is the center of inheritance and cellular control, and the *cytoplasm*, a soft, jellylike material (a colloid) in which most of the cell's metabolism takes place. The cytoplasm is enclosed within a sac called the *cytoplasmic membrane*. This, like other membranes in a cell, is composed of protein and fatty substances and has the ability to control the passage of water, foods, and selected minerals across the boundary that it defines.

Suspended in the semi-liquid cytoplasm are numerous small bodies, or *organelles*, that specialize in the cell's separate functions. Some organelles are the same in both plant and animal cells, hinting at ancient ancestral ties. *Chloroplasts* are organelles unique to plants, and they are the place where photosynthesis takes place, where light energy is used to manufacture foods. The green pigment *chlorophyll*, essential for the process, is located within the chloroplasts, as its name indicates (Greek: *chloros*, "green"; *plastos*, "body"; *phyll*, "leaf"). Obviously, chloroplasts are not found in most roots or other parts of a plant that are not green. The color of a leaf is actually the combined appearance of millions of chloroplasts discernible only with the aid of a microscope.

Other organelles include *mitochondria* that extract energy from foods by the process of *cellular respiration* and those that specialize in protein production, the *ribosomes*. The functions of some organelles, visible only with powerful electron

microscopes, are still not fully understood.

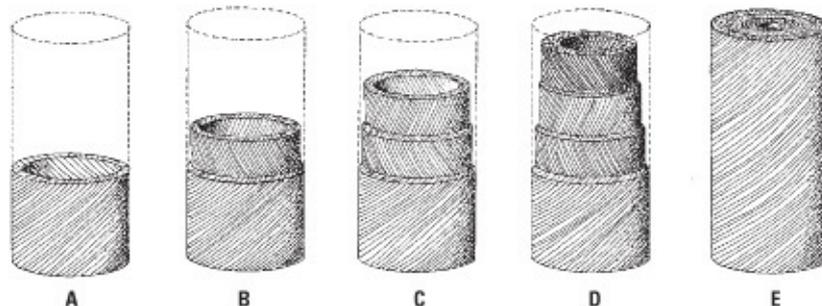
The nucleus of a cell is its control center from which instructions for the cell's operation, maintenance, and reproduction emanate. It is comparable to the main office in the imaginary industrial plant. Inherited *chromosomes*, bearing genes that are composed of the DNA mentioned earlier, are located in the nucleus. These are the blueprints for making more cells.

A *vacuole* occupies a large part of the volume of most plant cells. Although the word *vacuole* means "empty space," it is a membrane-bound inner sac containing much of a cell's stored water and serves as a repository for excess mineral nutrients as well as toxic waste products from the cell's metabolism.

Each cell is designed to function most of the time as an independent unit. Yet their metabolism and other activities are enhanced when groups of cells act in concert by the exchange of foods and other materials by way of interconnecting stands of cytoplasm, called *plasmodesmata* (Greek: *desmos*, "chain").

## CELL WALLS

The protoplasm of each cell is surrounded by a rigid *cell wall* that protects the living contents. Between adjacent cell walls the substance *pectin* forms a thin layer, a *middle lamella* (a sheet), which binds the cells together. This same substance, when commercially extracted from plants and sold in supermarkets, is used to thicken jams and fruit jellies.



Schematic diagram illustrating how cell walls thicken. (A) A primary cell wall of cellulose microfibrils. (B–E) A secondary wall is formed from additional cellulose layers, sequentially placed inside the others. Lignin is also formed and inserted with each cellulose layer. The protoplasm progressively shrinks and eventually dies.

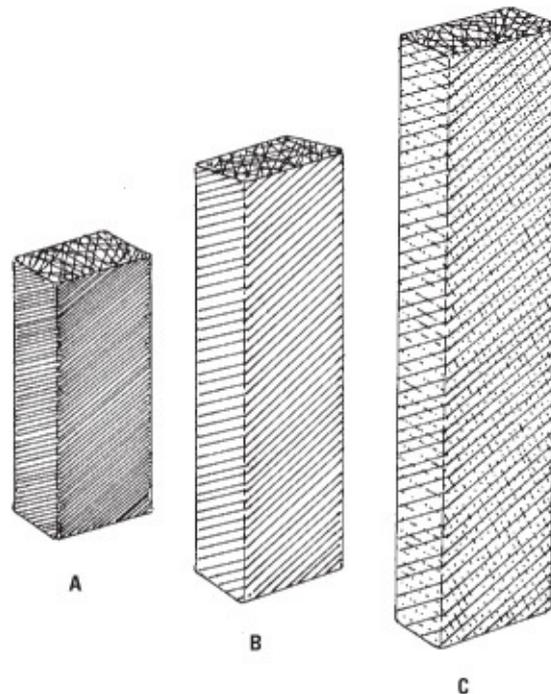
Collectively, cell walls give structural support to a plant, the degree of rigidity of any part being proportional to the relative thickness of its constituent cells' walls. The lightweight, delicate structure of a leaf, for example, indicates that it is composed of thin-walled cells, whereas in woody stems supporting heavy loads, cells with extra-thick walls are developed.

When a cell is first formed, its wall is thin and largely composed of the substance *cellulose*. This is called the cell's *primary wall*. With increased age, the wall may thicken by addition of more cellulose and by the introduction of *lignin*, a hardening substance. Hardwoods like oak and ash are made up of cells with heavily lignified walls. All of these extra layers constitute the cell's *secondary wall*. Cellulose is laid down in microscopic threads called *microfibrils*; lignin forms deposits on the cellulose surface. Each new layer of wall material, produced by the living cytoplasm, is set in place inside the previously formed layer.

Obviously, as walls thicken, the space occupied by the living contents decreases and the ability of water and oxygen to reach the cytoplasm is diminished. It is literally an act of suicide that kills the protoplasm and ends wall thickening. Even so, the remaining hollow cell walls continue their supportive roles throughout the life of the plant. Most people are surprised to learn that, in a living tree, as much as 98 percent of its trunk and branches are composed of dead cells, including those that conduct water.

### **WALL STRUCTURE AND CELL GROWTH**

Most cells in a plant, especially those in roots and stems, grow in a specific direction, dictated by the way in which cellulose microfibrils are arranged in the walls. If one thinks of a cell as a slightly elongated box, placed in an upright position, the four sides are formed from microfibrils placed parallel to one another and coiled around the box. Microfibrils in the top and bottom have a very different, crisscross pattern.



How cellulose microfibrils determine the direction of cell growth. (A) The side walls of a young cell have microfibrils arranged in parallel formation. (B) The cell elongates when microfibrils in the side walls spread apart from internal pressures within the cell; the crisscross pattern of end-wall microfibrils prevents the cell from growing in width. (C) Having reached its maximum length, secondary wall thickening prevents further growth in the cell's length.

When a cell enlarges, its walls temporarily soften. At the same time, cytoplasmic swelling takes place as a result of water uptake. Bonds between side-wall microfibrils are loosened and the cellulose threads are spread apart by the internal pressure. Because the microfibrils in end walls are interwoven, similar stretching is not possible. That is why cells principally grow in length, paralleling the general direction of vertical growth of stems and roots. (Thickening of these plant parts results from a different growth process that shall be discussed later.) Once a cell reaches a predetermined maximum length, the addition of secondary wall thickening prevents further enlargements.