Preface

It is not essential that a concept should be perfectly clear. It is not essential that you should be able to distinguish a chair from a stool that closely resembles a chair. As a matter of fact, there is always a fuzziness about a concept, and one of the main differences between ordinary life and science is that scientific concepts are less fuzzy. But they are fuzzy nevertheless. It is only in mathematics that we find clear-cut concepts, and it is probably this inhuman characteristic that makes the subject repellent to many people.—J. L. Synge, *Talking About Relativity*

This book has two interweaving themes—one that emphasizes plant biology and another that emphasizes physics. For this reason, we have called it *Plant Physics*. The basic thesis of our book is simple: plants cannot be fully understood without examining how physical forces and processes influence their growth, development, reproduction, and evolution.

The history of science has shown that botanists can learn much from collaborations with physicists, mathematicians, and engineers. While writing the 1682 edition of his *The Anatomie of Plantes*, Nehemiah Grew (1641–1712) sought the advice of the engineer-inventor and author of *Micrographia* Robert Hooke (1655–1703) to explain how cells expand and why some tissues are stiff and strong while others are not. The philosopher and engineer Herbert Spencer (1820–1903) first proposed that "internal mechanical stress itself" caused the formation of "strong bonds" in plant cell walls, whereas the Barba-Kick law, which helped Gustave Eiffel (1832–1923) to construct his tower, was essential to the work of Alfred G. Greenhill (1847–1927), who sought to define mathematically the physical limits to the height of a tree. And without the elegant dimensionless equation developed in 1885 by the engineer and mathematician Osborne Reynolds (1842–1912), which permits modeling of the complex behavior of fluid flow around different-sized objects, the field of bio-fluid mechanics would be impossibly "fuzzy" (Vogel 1981).

Physical scientists can also learn much from studying plants. In 1638, Galileo Galilei (1564–1642) used the hollow stalks of grass to illustrate the idea that peripheral rather than centrally located construction materials provide most of the resistance to bending forces. He also developed the concept of geometric self-similarity, which presaged J. S. Huxley's (1887–1975) study of allometry and biological scaling principles (Huxley 1932) by comparing the mechanics of small and large oak trees. Leonardo da Vinci's (1452–1519) interest in fluid mechanics was inspired by observing the cross-sectional areas of tree trunks and noting that they roughly equal the sum of the cross-sectional areas of branches above any point. Likewise, his drawings illustrating the concept of a parachute and an autogyroscopic propeller are alleged to be based on his study of the dandelion's pappus and the maple tree's samara (Richter 1970). Over two hundred years later, in a book published after his death, Duhamel du Monceau (1700–1782) compared the skeletons of animals with the wood in trees (du Monceau 1785). In 1811, T. A. Knight (1759–1838) studied the effects of mechanical perturbation on the growth and morphology of trees. And in 1868, Julius von Sachs (1832–1897) wrote about the role of turgor (the hydrostatic pressure exerted on cell walls by their living protoplasts) in stiffening plant tissues and organs—a concept based on his observations of balloons.

This book explores these and many other insights that emerge when plants are studied with the aid of physics, mathematics, engineering, and chemistry. Much of this exploration dwells on the discipline known as solid mechanics because this has been the focus of much botanical research. However, *Plant Physics* is not a book about plant solid mechanics. It treats a wider range of phenomena that traditionally fall under the purview of physics, including fluid mechanics, electrophysiology, and optics. It also outlines the physics of physiological processes such as photosynthesis, phloem loading, and stomatal opening and closing. These and other aspects of plant biology demand attention and are treated to the best of our abilities in this book.

By its nature, any attempt to understand plant physics requires a considerable familiarity with mathematics, quantitative analyses, and computational methods. Our experience as teachers has shown that these occupations are best presented first using words and analogies and only later with formulas and mathematical derivations. Therefore, the majority of mathematical derivations and quantitative examples are placed in "boxes" to improve the flow of the text and the communication of concepts. A list of the most frequently used mathematical symbols (and their definitions and units) is provided at the beginning of the book. Less frequently used symbols are defined when they are used in the text to avoid confusion when reading individual chapters out of sequence.

This book is organized so as to present basic concepts first and, when appropriate, to deal with them in greater detail in subsequent chapters as new material is presented and explained. For this reason, we advise readers unfamiliar with the topics treated in this book to read the text linearly, from the beginning to the end. For those readers who are already familiar with some or all of the material presented in this book, we have subdivided each chapter into numbered sections that are cross-referenced throughout the book so that a topic treated in different chapters can be traced as it is developed further. Equations in the text and in the boxes are treated similarly. In this way, topics such as photosynthesis, the cell wall, and the mechanics of wood, which are dealt with at different levels of complexity, can be followed throughout the book as new details or concepts are introduced. As an additional aid, a glossary is provided at the end of the book to assist those who may be unfamiliar with some of the more technical terms used in botany, engineering, chemistry, or physics.

The first chapter covers such fundamental topics as the importance of plant life, the relationship between organic form and function, plant reproduction and development, the importance of multicellularity, and the developmental basis of the basic plant body plans—topics that establish a conceptual framework for much of the material presented in the following chapters. The second chapter offers a general outline of how fundamental physical principles and processes affect plant growth and ecology. Its purpose is to introduce the reader to environmental phytophysics. Many of the concepts introduced in these first two chapters are elaborated in chapters 3–7, wherein we present the physical and chemical principles required to understand plant water relations, solid and fluid mechanics, electrophysiology, and optics in relation to plant form, function, and ecology. Chapter 8 attempts to synthesize this information by emphasizing how different plant materials and processes are juxtaposed to function as a single organic entity. The last two chapters describe and discuss many of the experimental tools and modeling approaches that have been used to discover new things about plant physics. It is our hope that this organization allows *Plant Physics* to be used in the classroom as well as by professional scientists who find our perspectives on particular topics useful.

In terms of citations and the literature, even a casual inspection of the many currently available textbooks shows that there are many philosophies and practices concerning references. However, based on our teaching experiences, we believe that references are optimally placed at the end of individual chapters, rather than compiled into a single bibliography, which can be cumbersome and difficult to use. Additionally, we believe that references should be limited to those that are accessible by means of ISBN numbers. In this way, a reader can find the more extensive literature, both old and new, that is typically widely scattered in a variety of journals. Clearly, it would be pretentious to claim an extensive knowledge of this literature. Fortunately, bibliographies are far less necessary than in the past. Electronic tools to search for even the older literature using keywords have become extremely efficient and generally accessible.

We hope this book inspires future generations of students to study plant physics. Scientists have learned a great deal about how physical principles and processes influence plant growth, behavior, and evolution. However, there is still very much more to learn. It is to those future generations that we dedicate this book.

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