

Ninth Edition

Hartmann and Kester's

# Plant Propagation

Principles and Practices



Fred T. Davies, Jr.  
Robert L. Geneve  
Sandra B. Wilson



HARTMANN & KESTER'S  
**PLANT PROPAGATION**  
PRINCIPLES AND PRACTICES

NINTH EDITION

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**Cover Design:** Studio Montage  
**Cover Photo:** Robert L. Geneve  
**Printer/Binder:** LSC Communications  
**Cover Printer:** Lehigh-Phoenix  
**Text Font:** ITC Garamond Std 11/13

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**Library of Congress Cataloging-in-Publication Data available upon request**

# Dedications

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The ninth edition of *Plant Propagation* is dedicated to Dr. Hudson T. Hartmann and Dr. Dale E. Kester, Emeritus Professors of the University of California, Davis. Hudson passed away on March 2, 1994, just as plans for the sixth edition were getting underway. Dale passed away on November 21, 2003, prior to the eighth edition.

Both are remembered as dedicated, hard-working, and passionate scientists and educators whose research paved the way of propagation discoveries in horticulture. Dr. Hartmann conceived the writing of this text around 1955 and asked the second author, Dr. Kester, to join him. Following the publication of the first edition in 1959, eight more editions followed with the current ninth edition in 2018.

Hudson was a world-recognized pomologist at UC Davis, whose research in propagation involved early studies on hormones, mist propagation, and other aspects of cutting propagation along with olive research and development. He taught plant propagation from 1945 until his retirement in 1980. Dale was the first PhD graduate

from the University of California, Davis Pomology Department following the war. His dissertation concerned embryo culture of peaches. In 1951, he was offered an Assistant Professor position in the Department of Pomology at UC Davis where his work focused on almond production and breeding. These efforts led to numerous rootstock introductions, as well as the cause for noninfectious bud failure in almond. This was the position he would hold until his retirement 40 years later in 1991.

Together, Hudson and Dale shared a lifelong collaboration through research, teaching, and service. One of their shared accomplishments was their activity with the International Plant Propagation Society (IPPS). They were Fellows of the Western Region, serving in many leadership roles. Hudson served as Western Region Editor from 1960 to 1993 and International Editor from 1970 to 1991. Dale served as President in 1997. Both received the IPPS highest award—the International Award of Honor. They were longtime members of the American Society for

Horticultural Science (ASHS). Hudson was recognized as a Fellow in 1974, as was Dale in 1977. Dale served as the first chair of the ASHS Propagation Working Group.

During their distinguished careers, Hudson and Dale published many scientific papers and popular articles. Hudson was senior author of *Plant Science: Growth, Development, and*

*Utilization of Cultivated Plants*, first edition (1981) and second edition (1988), published by Prentice Hall. They were two of the most internationally recognized horticulturists of their generation.

Hudson and Dale were close personal friends, collaborators, and respected peers, whose guidance and insight are greatly missed by the horticultural community.

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# Preface

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The ninth edition of *Hartmann and Kester's Plant Propagation: Principles and Practices* continues the legacy of expanding and updating the principles and practices associated with plant propagation. We are very excited to welcome Dr. Sandra B. Wilson as a co-author on the ninth edition. She becomes the fifth co-author to work on the textbook of Hudson T. Hartmann and Dale E. Kester, since its initial printing in 1959.

The ninth edition is the second edition to include color figures. The majority of figures have been reconfigured and updated. In addition, this is the first edition that presents a compiled glossary of propagation terms as a separate section following the subject matter chapters. The co-authors hope that these changes will enhance student learning.

The ninth edition continues the tradition of presenting paired chapters where the principles underlying the science of propagation alternate with the technical practices and skills utilized for commercial plant propagation. As with previous editions, the amount of material between editions has increased substantially and many aspects of plant science and horticultural production systems have been integrated into each relevant chapter. In some cases, it was beyond the scope of this textbook to provide a definitive discussion of some in-depth concepts. Therefore, we have substantially updated the references to help the reader delve deeper into these subjects, depending on their interests and research needs.

As in previous editions, the book is organized into five basic parts. The initial three chapters are introductory chapters meant to support general aspects of propagation, including a historical perspective, basic plant biology concepts, and the environmental control of facilities associated with propagation and nursery practices. Part two provides a discussion of seed propagation from the initial aspects of seed development through seed production, dormancy, and germination. Part three covers important aspects of vegetative propagation. This reorganized section begins with a basic discussion of clonal selection followed by the major chapters describing vegetative propagation by cuttings and grafting. It concludes with chapters covering layering and propagation by specialized structures, including bulbs and tuberous roots. The fourth part of the textbook is a discussion of propagation utilizing tissue culture techniques. This section has been reorganized to reflect the importance of micropropagation in horticultural crop production. The final section includes separate chapters on specific propagation techniques for fruits and nuts, woody perennial nursery crops, and annual and herbaceous perennial crops for the greenhouse and nursery. These final chapters have been updated, new species added and a significant number of references have been compiled to support propagation practices.

There has been a substantial increase in the number of figures used to support the text for the ninth edition. Most of these images have been taken by the co-authors while visiting commercial producers and research labs throughout the world. This was only possible because of

the generosity of companies and individuals associated with those organizations who graciously provided us access to their facilities. Additional images were taken while using the library resources of the Lloyd Library in Cincinnati, and the special collections at the Missouri Botanical Garden and the University of Kentucky. We would also like to express our appreciation to those colleagues who have generously supplied images to enhance this and previous editions.

Mention of any products or techniques in the textbook is for information purposes only and not intended as an endorsement; neither is criticism implied for products not mentioned. Always follow instructions on product labels, and be aware that regulations may change or vary by country, state, and region. Any propagation techniques and references listed are to serve as a guide. In any commercial propagation system, it is important to conduct small trials before implementing propagation techniques on a large scale. Propagators should develop their own procedures and chemical treatments that work best for their particular propagation systems.

In preparing the ninth edition of this book, we have depended upon the assistance of authorities in the various fields of propagation and related subjects. We would like to thank them for their critical evaluation and suggestions. We also thank our spouses, Maritza Davies, Pat Geneve, and Chris Wilson, as well as our other family members for their support, encouragement, and patience during the writing and production of the ninth edition of this book.

The authors and publisher would like to thank the following reviewers for their time, constructive criticism, and suggestions: Kimberly Moore (University of Florida), Hector Perez (University of Florida), Brad Rowe (Michigan State University), Lekha Sreedhar (Johnson County Community College), and Hazel Wetzstein (Purdue University). The authors additionally thank Thomas Colquhoun, Kornelia Fillmer, Brian Jackson, Mike Kane, Cheiri Kubota, Hoang Nguyen, Bart Schutzman, Adrienne Smith, and Wagner Vendrame for their expertise and assistance on various aspects of the book.

Finally, we acknowledge the skill and professionalism of Pearson and associated editors and designers who made this production possible, including Pamela Chirls, Jennifer Sargunar, Rinki Kaur, Faraz Sharique Ali, Johanna Burke, Lara Dimmick, Andrew Gilfillan, Holly Shufeldt, Rajiv Sharma, Shipra Kulshrestha, Jessica Chernyak, and Bert VanderMark.

## New To This Edition

- A world standard of Plant Propagation – most complete guide to principles & practices of propagation.
- Completely reorganized, revised and updated – with latest innovations & advances in propagation.
- Hardcover edition with over 650 updated color images and illustrations.
- A new comprehensive glossary of over 500 terms important to propagation.
- Web support from the Pearson Resource Center includes instructor PowerPoints for each chapter and a test bank for students.
- There are over 3,500 references cited throughout the book including updated references supporting propagation techniques for a wide range of plant species.

## Download Instructor Resources from the Instructor Resource Center

To access supplementary materials online, instructors need to request an instructor access code. Go to [www.pearsonhighered.com/irc](http://www.pearsonhighered.com/irc) to register for an instructor access code. Within 48 hours of registering, you will receive a confirming e-mail including an instructor access code. Once you have received your code, locate your text in the online catalog and click the Instructor Resources button on the left side of the catalog product page. Select a supplement, and a login page will appear. Once you have logged in, you can access instructor material for all Pearson textbooks. If you have any difficulties accessing the site or downloading a supplement, please contact Customer Service <https://www.pearson.com/us/higher-education.html>.

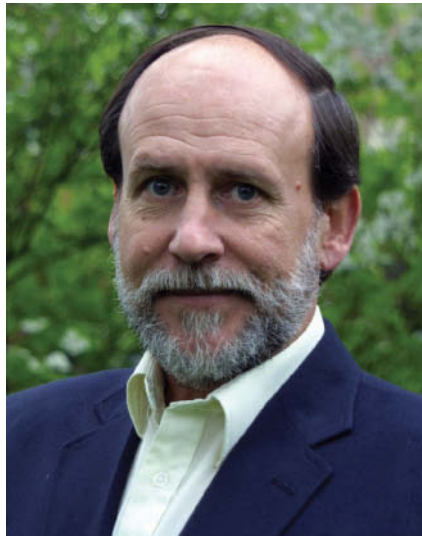
# About the Authors

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**Fred T. Davies, Jr.**, is a Regents Professor Emeritus of Horticultural Sciences and Senior Borlaug Fellow in Horticulture at Texas A&M University. Early in his career, he got hooked on the biology of cutting propagation, presenting propagation research as a graduate student at his first International Plant Propagators' Society (IPPS) meeting in 1975. He is a Past President of the IPPS-SR and the American Society for Horticultural Science (ASHS) (2011). He is IPPS-SR Editor, an IPPS Fellow, ASHS Fellow, Meadows Awardee, and received the IPPS International Award

of Honor (2015). Davies has worked internationally at research institutes and taught at universities as a Guggenheim Fellow (1999), and Senior Fulbright Fellow to Mexico (1993), Peru (2000), and Indonesia (2012). In 2014, he was a Jefferson Science Fellow/Senior Science Advisor at USAID—U.S. Agency for International Development—helping with the Feed-the-Future program. He continues to work internationally in food security and in promoting entrepreneurial and career opportunities in horticulture.



**Robert L. Geneve** is a Professor in the Department of Horticulture at the University of Kentucky. He teaches courses in plant propagation, seed biology, and plant identification. He has co-authored over 100 scientific and technical articles in seed biology, cutting propagation, and tissue culture. He is also the co-editor of the book *Biotechnology of Ornamental Plants* and author of *A Book of Blue Flowers*. He is a Past President for the International Plant Propagators' Society, Eastern Region, and a past Delegate on the International Board of Directors. He has served as the Editor for the

international horticulture journal, *Scientia Horticulturae*, from 2001 to 2008 and is currently on the editorial boards of the *Propagation of Ornamental Plants* and the *Journal of Seed Technology*. He is the recipient of the University of Kentucky George E. Mitchell Jr. Award for Outstanding Faculty Service to Graduate Students (2006), and is a Fellow of the American Society for Horticultural Science (2005), as well as a Fellow (2003) and Award of Merit recipient (2014) for the International Plant Propagators' Society, Eastern Region.



**Sandra B. Wilson** is a Professor in the Department of Environmental Horticulture at the University of Florida. She teaches courses in plant propagation, native landscaping, and annual and perennial gardening. She has co-authored over 150 scientific and technical articles in plant propagation, container production, and landscape use, as well as innovative practices in teaching. She has served as Associate Editor for the *Journal of Native Plants* (2013–2015). She is the recipient of the

University of Florida Undergraduate Teacher of the Year Award (2006) the American Society for Horticultural Science Outstanding Undergraduate Educator Award (2009), and the College of Agricultural and Life Sciences Roche Professorship (2011). She has been recognized with the North American Colleges and Teaching of Agriculture Fellow Award (NACTA) (2005) and the American Society for Horticultural Science Fellow Award (2015). Wilson served as ASHS Vice President for Education (2013–2015) and a Board Member of the International Plant Propagators Society, Southern Region (2013–2015).



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# part one

## General Aspects of Propagation

CHAPTER 1 How Plant Propagation Evolved in Human Society

CHAPTER 2 Biology of Plant Propagation

CHAPTER 3 The Propagation Environment

This book about **plant propagation** describes not only procedures originating thousands of years ago, but also the application of recent scientific advances. Plant propagation can be described as *the purposeful act of reproducing plants*. It has been practiced for perhaps the past 10,000 years, and its beginning probably marks the start of civilization. The traditional concept of a propagator is a skilled technician who loves plants and who acquired the art from traditional skills learned by experience, or whose knowledge was handed down from one generation to another. Today, propagation may be carried out by an array of general and specialized industries that produce plants to feed the world; to provide fiber, building materials, and pharmaceuticals; and to enhance the world's beauty.

# 1

## How Plant Propagation Evolved in Human Society

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### learning objectives

1. Describe the evolution of plant propagation during human history.
2. Describe aspects of modern plant propagation activities.

*“Man has become so utterly dependent on the plants he grows for food that, in a sense, the plants have ‘domesticated him.’ A fully domesticated plant cannot survive without the aid of man, but only a minute fraction of the human population could survive without cultivated plants.”*

From J. R. Harlan, *Crops and Man*, 2nd edition.  
Madison, WI: Amer. Soc. of Agron. 1992.

### INTRODUCTION

The propagation of plants is a fundamental occupation of humankind. Its discovery began what we now refer to as civilization and initiated human dominion over the Earth. **Agriculture** began some 10,000 years ago when ancient peoples, who lived by hunting and gathering, began to cultivate plants and domesticate animals. These activities led to stable communities where people began to select and propagate the kinds of plants that provided a greater and more convenient food supply, as well as other products for themselves and their animals (14, 25, 46, 50). Once this process began, humans could remain at the same site for long periods of time, thus creating centers of activity that eventually would become cities and countries.

**Agriculture** is the deliberate cultivation of crops and animals for use by humans and involves five fundamental activities:

1. **Plant selection**—selecting and (or) developing specific kinds of plants.
2. **Plant propagation**—multiplying plants and preserving their unique qualities.
3. **Crop production**—growing plants under more controlled conditions for maximum yield.
4. **Crop handling and storage**—preserving crop products for long-term usage and transport to other areas.
5. **Food technology**—transforming and preserving crop products for food or other uses (e.g., making bread, pressing oil, preparing wine, and dehydration).

### STAGES OF AGRICULTURAL DEVELOPMENT

The pivotal role of plant propagation in the evolution of human society can be seen in terms of particular stages of agricultural development.

## Hunting and Gathering

Most of the millions of years of human existence as hunters and gatherers were related to the presence of specific food resources, including seeds, fruits, roots, and tubers, as well as animals that fed on plants. The distribution and characteristics of plant species were determined by the environment, that is, both the physical world (climate, soil, topography) and the biological interactions of plant, animal, and human populations (14, 25). Humans and their ancestral species have existed for millions of years, spreading from their presumed place of origin in western Africa into Asia, Europe, and, eventually, into North and South America. Food supplies were abundant in the native vegetation, although quite variable in different parts of the world. Apparently, early humans were quite effective in searching out those that were useful, as well as in developing processes to utilize and preserve them.

What motivated humans to begin to propagate and grow specific kinds of plants near their homes has been the subject of much scientific debate (14, 25, 50). It is clear that the development of agriculture forever changed the relationship between humans and their surrounding environment. This event occurred in separate areas of the world, more or less simultaneously within a relatively short period of a few thousand years nearly 10,000 years ago. These areas included the Near East fertile crescent of Southwest Asia and Northeast Africa, extending from the valley of the Euphrates and Tigris Rivers along the coasts of Syria, Turkey, and Israel to the Nile Valley of Egypt; China, including a northern and a tropical southern area; and Central and South America, including areas in Mexico, and the coastal lowlands and highlands of Peru (25, 33, 38).

The key activity bringing about this change must have been the deliberate selection, propagation, and cultivation of specific plant types that were particularly useful to humans. As a result, a larger and more stable population could be supported, which evolved into cities and countries. Human organization changed from subsistence existence, where everyone participated in the production of food and other items, to a division of labor between agricultural and non-agricultural segments of the population, and even to specialization within the agricultural segment.

In this context, the plant propagator, who possessed specific knowledge and skills, assumed a key role.

## Domestication

**Domestication** is the process of selecting specific kinds of wild plants and adapting them to human use (53). Early civilization developed with relatively fewer domesticated plant species, determined by both their usefulness in the primitive economy and the ease with which they could be propagated. The lists differed in the separate areas of the world where human societies evolved (25, 39, 40, 49). In the Near East, the earliest domesticated food crops included wheat, barley, peas, and lentil. In the Far East, millet appears to be the first domesticated crop, followed by rice. In Central and South America, the first food crops domesticated were apparently squash and avocado, followed by such important modern-day food crops as corn, bean, pepper, tomato, and potato. Many of the early food crops were seed plants (cereals, such as wheat, barley, and rice), which provided carbohydrates, and legumes (beans, peas), which provided protein. These seed-propagated plants could be subjected to genetic selection in consecutive propagation cycles for such agricultural characteristics as high yield, “non-shattering” seed clusters (35), large seed size, and reduced seed dormancy (23, 42, 55). These species were maintained more or less “fixed” because of their genetic tolerance to inbreeding (see Chapter 5). Highly desirable single plants of certain species, such as grape, fig, olive, pomegranate, potato, yam, banana, and pineapple (34, 56), could be selected directly from wild populations and “fixed” through vegetative propagation (see Chapters 2 and 10). Domestication of fruit plants (41), such as apple, pear, peach, apricot, citrus, and others, occurred with the discovery of grafting methods (see Chapters 13, 14, and 15). By the time of recorded history (or that which can be reconstructed), most of the basic methods of propagation (seed, cuttings, grafting, layering, and division) had been discovered. During domestication, crop plants had evolved beyond anything that existed in nature and generally require human intervention to maintain their selected characteristics.

The establishment of specific crops and cropping systems resulted in some side effects

that have continued to create agricultural problems (25). As the fields used to grow plants near human sites were disturbed and became depleted, certain aggressive plant species also were spontaneously established in these sites. These so-called weedy species have become a part of the agricultural system and more or less evolved along with cultivated plants (12).

## ORGANIZATION OF HUMAN SOCIETIES

### Ancient (7000 BC)

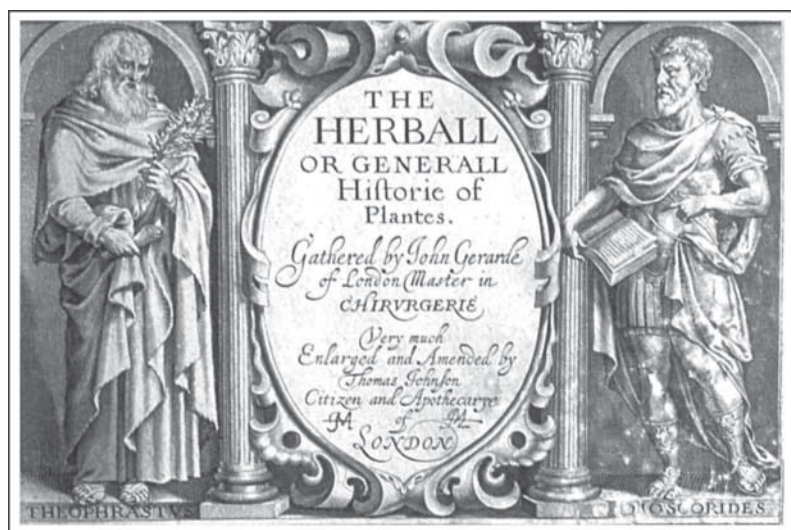
The initial phases of domestication probably involved plant selection, plant propagation, and plant production. With an increase in food supply, a larger population could be supported and division of labor began to occur. Classes of individuals may have included laborers, manufacturers, artisans, government bureaucrats associated with irrigation systems, religious groups, and soldiers, as well as farmers and herdsman. Historical records of early civilizations in Egypt and the Middle East (as well as archaeological investigations) have shown that the agricultural sector was well organized to produce food (cereals, vegetables, fruits, dates), fiber (flax, cotton), and other items for the non-agricultural components of society (30, 34). Early Chinese writings indicate the knowledge of grafting, layering, and other techniques, although rice and millet were the principal food sources. In the Americas, seed-propagated crops (maize, beans, cucurbits, squash), as well as vegetatively propagated crops (potato, cassava, sweet potato, pineapple), were developed and grown (16).

### Greek and Roman (500 BC to AD 1000)

Early writings described the agricultural world in detail with accounts of propagation techniques much as we know them today. Control of land and agricultural surplus was the key to power and wealth (49). Small and large farms existed. Olive oil and wine were exported, and grains were imported. Vegetables were grown near the home as were many fruits (fig, apple, pear, cherry, plum) (29). Not only were food plants essential, but Romans developed ornamental gardening to a high level (25).

Some of the earliest references to plant propagation come from Theophrastus, a Greek philosopher (circa 300 BC) and disciple of Aristotle (**Fig. 1-1**). He described many aspects of plant propagation, including seeds, cuttings, layering, and grafting in his two books, *De historia plantarum* and *De Causis Plantarum* (51, 52). An example from the translation of *De Causis Plantarum* (51) illustrates his understanding of propagation “while all the trees which *are propagated by some kind of slip seem to be alike in their fruits to the original tree, those raised from the fruit . . . are nearly all inferior, while some quite lose the character of their kin, as vine, apple, fig, pomegranate, pear.*”

Additional information on propagation can be seen in surviving works from Romans Pliny the Elder and Columella (circa 1 AD) (15, 43). For example, Pliny recommends that cabbage seeds be soaked in the juice of houseleek before being sown so that they will be “immune to all kinds of insects” (43), and Columella describes taking leafless, mallet stem cuttings in grape (15).



**Figure 1-1**

Theophrastus (300 BC) was an important influence on Renaissance agriculture, as indicated by his being depicted and commemorated on the front page of John Gerard's influential herbal, published in 1597 (24). His image is in the left panel opposite his Greek counterpart Dioscorides (AD 1), renowned as an authority for the medicinal use of plants.



## Medieval Period (AD 750 to 1500)

Society was organized around large estates, manor houses, and castles with landlords providing protection. Large areas of forest were kept as game preserves. Equally important were the monasteries that acted as independent agricultural and industrial organizations and preserved a great deal of the written and unwritten knowledge (**Fig. 1–2**). In both kinds of institutions, a separation developed among those involved in the production of cereals, fibers, and forages grown extensively in large fields (agronomy); vegetables, fruits, herbs, and flowers grown in “kitchen gardens” and orchards near the home (horticulture); and woody plants grown for lumber, fuel, and game preserves (forestry) (29, 30).

The end of the medieval period and the beginning of modern Europe brought a shift from a subsistence existence to a market economy and the emergence of land ownership (50). In Western Europe, both large landowners and owners of smaller individual plots emerged. In Eastern Europe, the shift was toward large wealthy estates with the populace being largely serfs.

Through these periods, the specific skills and knowledge of the plant propagator were possessed by specific individuals. These skills, considered “trade secrets,” were passed from father to son or to specific individuals. Often this knowledge was accompanied by superstition and, sometimes, attained religious significance.



**Figure 1–2**

The monastic garden was an enclosed area of medicinal and edible plants. The Cloisters in New York has several representative enclosed period gardens.

## EXPLORATION, SCIENCE, AND LEARNING

### Plant Exchanges

The **plant exchange** from the area of origin to other countries of the world has been one of the major aspects of human development (33). Not only did the range of plants available for food, medicine, industrial uses, and gardening expand, but plant propagation methods to reproduce them were required. Early movement of useful plants often followed military expansion into different countries when the invading soldier brought plants from his home country into a new land. Conversely, returning soldiers introduced to their homelands new plants they found while on a military campaign. There are numerous examples of this type of exchange taking place during the Roman conquests of northern Europe. Similarly, Islamic expansion in the ninth century introduced citrus and rice to southern Europe, along with new concepts of cultivation and the use of irrigation. The voyages of Columbus opened the world to exploration and the interchange of plant materials from continent to continent (16). Such food staples like potatoes, tomatoes, beans, corn, squash, and peppers all became available to Europe in the 16th and 17th centuries after voyages to the new world.

In addition to edible food crops, new and exotic plants were being sought out for introduction. Centers of learning in which scientific investigations began on all aspects of the biological and physical world were established in many countries. Linnaeus established the binomial system of nomenclature, and botanists began to catalog the plants of the world. Exploration trips were initiated where the primary mission was plant introduction, such as the voyages of Captain Cook in 1768, which included the plant explorers Sir Joseph Banks and Francis Masson who brought large numbers of exotic plants to England for the Royal Botanic Garden, established at Kew, outside of London (38, 44, 45). Nathaniel Ward, a London physician and amateur horticulturist, invented the **Wardian case** early in the 1800s to help preserve plant material on these long expeditions (54) (**Fig. 1–3**).

Plant-collecting trips continued throughout the world: from Europe (David Douglas, Joseph D. Hooker, Robert Fortune, George Forrest,





**Figure 1-3**

The Wardian case was invented by N. B. Ward in the early 19th century to use when transporting plants over long ocean voyages.

Frank Kingdon-Ward) and from the United States (David Fairchild, Frank Meyer, Joseph Rock, Charles Sargent, Ernest Wilson) (17, 21, 38, 44). Significant ornamental species that are mainstays of modern gardens were collected: from the Orient (rhododendron, primula, lily, rose, chrysanthemum), Middle East (tulips, many bulb crops), and North America (evergreen and deciduous trees and shrubs). “Orangeries” and glasshouses (greenhouses) were expanded to grow the exotic species being

collected from India, Africa, and South and Central America (27).

### Scientific and Horticultural Literature

The first important written works on agriculture, plant medicinal uses, and propagation that shaped Western society came from the early Greek, Roman, and Arab writers between 300 BC and AD 2. Although many works were undoubtedly lost, many survive today because they were preserved in Arab libraries and passed on through medieval monasteries. Following the invention of the printing press in 1436, there was resurgence in the production of books called **herbals** (**Fig. 1-4**) describing and illustrating plants with medicinal properties. Much of the information came from older first century Greek literature, especially **Dioscorides**. These early works were written in Latin, but eventually works began to appear in local languages, making plant information available to a wider audience (3).

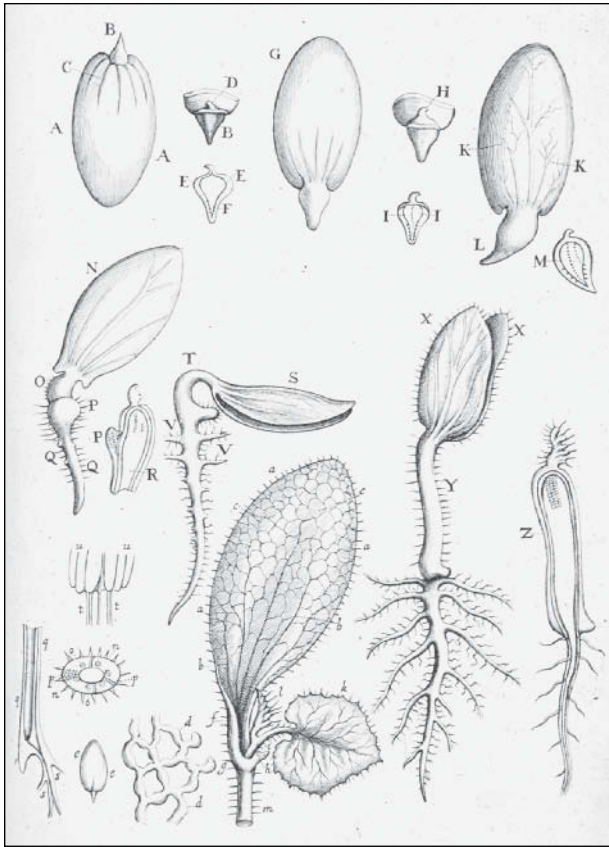
The Renaissance heralded the appearance of scientific enquiry that relied heavily on meticulous observation of plant morphology and behavior. This is wonderfully shown in the illustrations from **Marcello Malpighi** (37) on plant anatomy in 1675 (**Fig. 1-5**).

In the late 1800s, the concepts of natural selection and genetics made a big impact on



**Figure 1-4**

Herbals were produced soon after the invention of the printing press to describe the utility of local and introduced plants. Plants such as this pea in Matthioli’s herbal (*Commentarii*, 1564) were depicted from woodcuts on blocks.

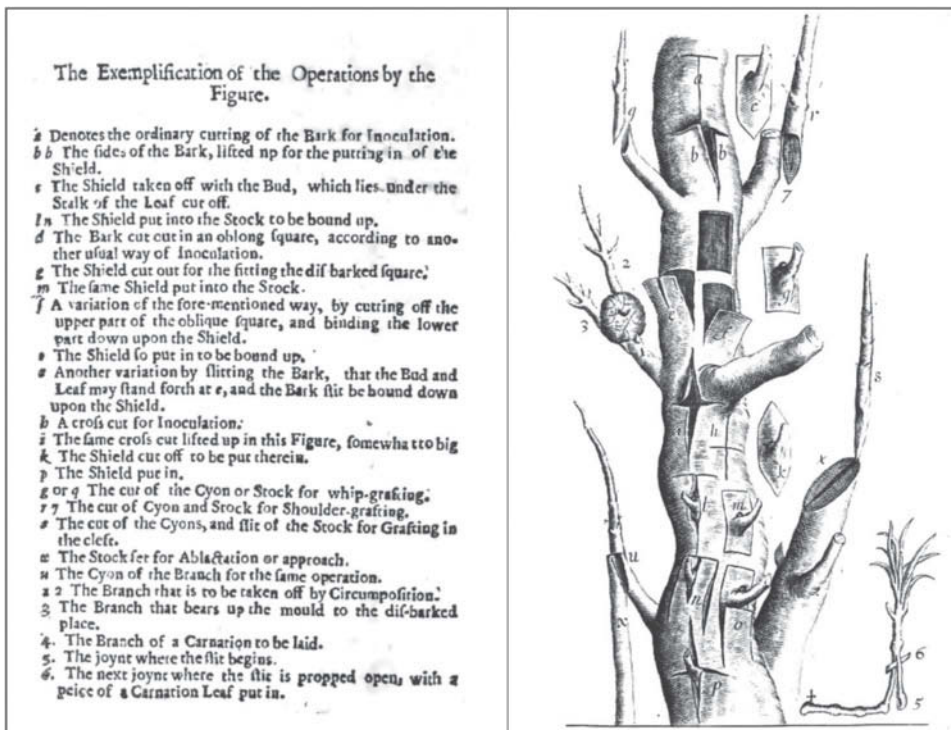


**Figure 1-5**

With the Renaissance, there was a resurgence in scientific inquiry. Malpighi was a keen observer of plants as seen in his depiction of this germinating cucumber in his wonderfully illustrated *Anatome Plantarum*, 1675.

scientific advancement. **Charles Darwin** and his *Origin of Species* (19) as well as its important contemporary *The Variation of Animals and Plants under Domestication* (18) introduced the concept of evolution and set the stage for the genetic discoveries following the rediscovery of Mendel's papers in 1900. The subsequent explosion in knowledge and application provided the framework on which present-day plant propagation is based, as did the increase in knowledge of plant growth, anatomy, physiology, and other basics of biological science (31).

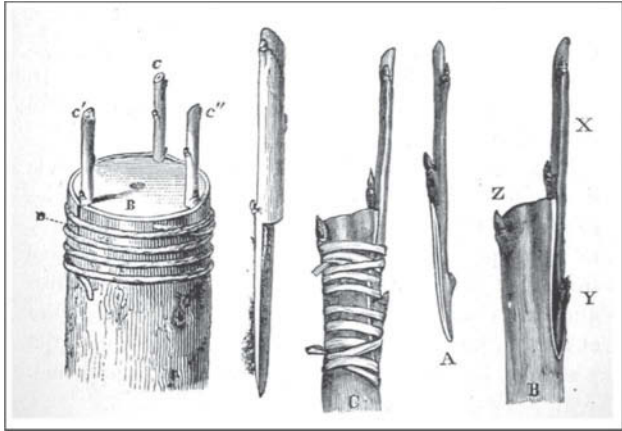
Books and articles on gardening and propagation began to appear (20). The first book on nurseries, *Seminarium*, was written by Charles Estienne in 1530. Robert Sharrock (48) authored a book that included various aspects of propagation and an iconic figure illustrating an incredible number of grafting and budding techniques (**Fig. 1-6**). Georg Andreas Agricola (2) produced a treatise in 1716 that artfully describes many types of grafts and layers. Later, Charles Baltet, a practical nurseryman, published a famous book, *The Art of Grafting and Budding*, in 1821, describing 180 methods of grafting (13) (**Figs. 1-7 and 1-8**). A book by Andrew J. Fuller—*Propagation of Plants*—was published in 1887 (22).



**Figure 1-6**

Grafting illustration from Robert Sharrock's 1660 book (48). Many propagation techniques are readily identifiable. (a-c) shows T-budding; (d, g, m) is a patch bud; (s, x) is a cleft graft; (u) is an approach graft; (1, 2, 3) illustrates an air layer; and (5, 6) is not as well recognized but is called "tonguing the layer" and was a common method for rooting carnation stems.



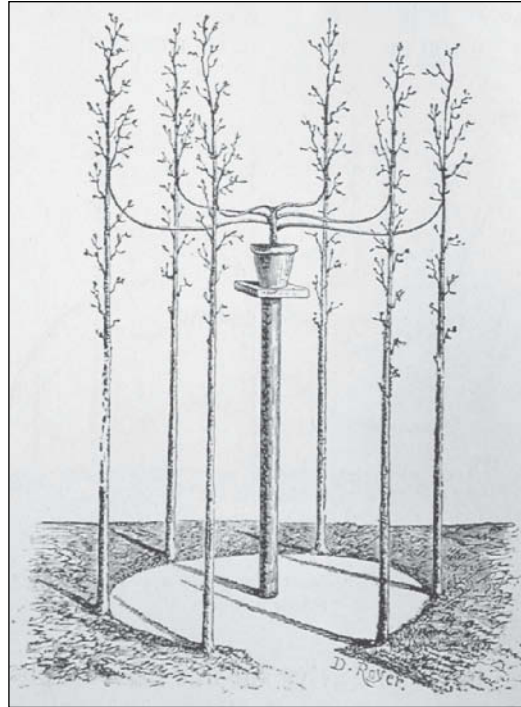


**Figure 1-7**

Bark grafting as illustrated in *The Art of Grafting and Budding* (1910) by Baltet.

### The Morrill Act

The passage of the **Morrill Act** by the United States Congress in 1862 was a landmark event that established land-grant colleges and fostered the scientific investigation of agriculture and mechanical arts. Departments of agronomy, horticulture, pomology, and related fields were established, which became centers of scientific investigation, teaching, and extension. **Liberty Hyde Bailey** (47), a product of this system, published his first edition of *The Nursery Book* (4), later revised as the *Nursery Manual* in 1920 (6), which cataloged what was known about plant propagation and the production of plants in the nursery (**Fig. 1-9**). His *Cyclopedia of American Horticulture* (5) in 1900–1902, *Standard Cyclopedia of Horticulture* (6) in 1914–1917, *Hortus* (8) in

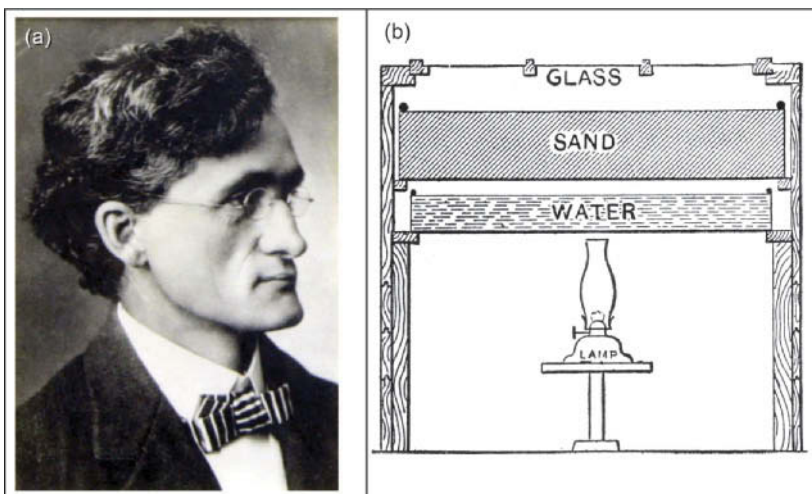


**Figure 1-8**

Approach grafting was a more important propagation technique before the introduction of mist propagation (13).

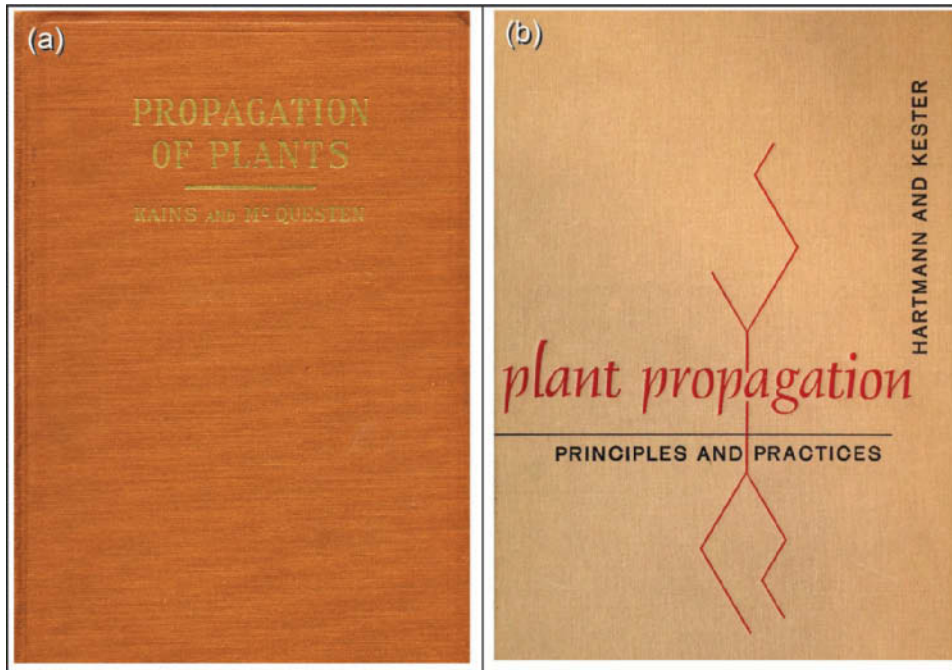
1930, *Hortus Second* (9) in 1941, and *Manual of Cultivated Plants* (10) in 1940 and 1949 described the known plants in cultivation. Today, *Hortus Third* (11) is still regarded as one of the encyclopedic works on plant nomenclature and a classic in the field of horticulture.

M. G. Kains of Pennsylvania State College and, later, Columbia University in New York published *Plant Propagation* (31), later revised by



**Figure 1-9**

(a) Liberty Hyde Bailey is considered the Father of American Horticulture (47). (b) He provides an interesting version of bottom heat for germination and cutting propagation in *The Nursery Book* (4), one of his 63 published books on horticulture.



**Figure 1-10**

Early books for students and nursery professionals include (a) *Propagation of Plants* by Kains and McQuesten (1938) and (b) the first edition of *Plant Propagation: Principles and Practices* by Hartmann and Kester (1959).

Kains and McQuesten (32), which remained a standard text for many years (**Fig. 1-10**). Several other books related to plant propagation were also written during this period including titles by Adriance and Brison (1), Duruz (21), Hottes (28), and Mahlstedt and Haber (36). The first edition of *Plant Propagation: Principles and Practices* (26) written by Hudson Hartmann and Dale Kester from the University of California at Davis was published in 1959 and has continued through nine editions.

## THE DEVELOPMENT OF NURSERIES

The concept of the nursery, where plants are propagated to be transplanted to their permanent site either as part of the agricultural unit or to be sold to others, has likely been a part of agriculture since its beginning. Nevertheless, the development of commercial nurseries is probably something that has developed largely within the recent era. Most agronomic crops (wheat, corn, etc.) and many vegetables were grown by seed. A portion of the seed was retained each year to supply the seed for the next cycle. In regions with cold winters, starting vegetables and flowers in protected structures (cold frames, hotbeds) and later transplanting them to the open was an

important part of production, because doing so extended the length of the growing season.

A number of important nurseries existed in France during the 16th and 17th centuries and, eventually, throughout Europe (20). Ghent, Belgium, had a gardener's guild as early as 1366. The first glasshouse (greenhouse) was built in 1598. The **Vilmorin** family established a seed and nursery business in 1815, which was maintained through seven generations.

Early plant breeding was often combined with a nursery, as exemplified by **Victor Lemoine** (1850) who specialized in tuberous begonias, lilies, gladiolus, and other garden flowers. Nickolas Hardenpont and Jean Baptiste van Mons specialized in fruits, particularly pears. The **Veitch** family started a major nursery in England in 1832. Thomas Andrew Knight, a famous hybridizer of fruits, established the Royal Horticultural Society in 1804.

Early colonists brought seeds, scion, and plants to the United States from Europe, and Spanish priests brought material to the West Coast. **John Bartram** is credited with providing a major impetus with his botanical garden in Philadelphia in 1728. The first nursery, however, was credited to **William Prince and Son** in 1730 on Long Island (**Fig. 1-11**). These were followed by the expansion of nurseries throughout the eastern United States during the 19th century.